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WORKING GROUP INTEGRATED CONTROL IN CEREALS "APHID ECOLOGY"

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<u>Contents</u>	<u>Pages</u>
Introduction	1
List of Participants	3
C.A. DEDRYVER: Premiers résultats concernant le rôle de trois espèces d'Entomophthora dans le limita- tion des populations de pucerons des céréales dans l'Ouest de la France	5
G. LATTEUR et J. DESTAIN: Etudes de l'action des champignons et des hyménoptères parasites inféo- des aux populations de Sitobion avenae (F.) et de Metopolophium dirhodum (Walk.) dans le champ experimental de Milmort en 1978 et 1979	II
J.P. LATGE et D.F. PERRY: The utilization of an Ento- mophthora obscura resting spore preparation in biological control experiments against cereal aphids	19
B. PAPIEROK et J.P. LATGE: Considérations sur le pouvoir pathogène de Entomophthora obscura Hall et Dunn à l'ègard des pucerons des céréales	27
G. DEAN, A.M. DEWAR, W. POWELL and N. WILDING: Integrated control of cereal aphids	30
E. BODE: Aphids in winter wheat: Abundance and limi- ting factors from 1976 to 1979	49
S.C. HAND: Overwintering of cereal aphids	59
C.T. WILLIAMS: Low temperature mortality of cereal aphids	63
TH. BASEDOW: Studies on the ecology and control of the cereal aphids (Hom., Aphididae) in Northern Germany	67
K.D. SUNDERLAND, D.L.STACEY and C.A. EDWARDS: The role of polyphagous predators in limiting the increase of cereal aphids in winter wheat	85
N. CARTER and R. RABBINGE: Simulation models of the population development of Sitobion avenae	93
R. RABBINGE, G.W. ANKERSMIT, N. CARTER and W.P.MANTEL: Epidemics and damage effects of cereal aphids in the Netherlands	99
J. REITZEL and J. JAKOBSEN: The occurrence of and damage caused by aphids in cereal crops in Den- mark	107

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Following the foundation at Kiel-Kitzeberg on 3rd of April 1974 the Working Group 'Integrated Control in Cereals' was divided into subgroup in order to facilitate a co-operation in special directions. In addition to the sub-group 'Cereal Aphid Ecology', about the work of which is reported in this Bulletin on occasion of the last meeting in December 1979, three other sub-groups were founded:

'Host Plant Resistance to Cereal Aphids', Convenor Th. Basedow (Federal Republic of Germany)

'Crop Loss', Convenor K.S. George (United Kingdom) and G. Latteur (Belgium)

'Soil Fauna and Cereal Pests', Convenor R. Bardner (United Kingdom)

The members of these sub-group are meeting as a rule once in two years in order to discuss experiences and further co-operation.

The sub-group 'Cereal Aphid Ecology' was founded at Gembloux on 11.12.75 with the predominant aim to develop a prognosis based on ecological connections. Dr. H. Suter (Switzerland) was suggested and elected as Convenor. He invited to the second meeting on 1. and 2.12.77 at Zürich. Unfortunately it was not possible for Dr. Suter to continue the leadership of the group longer than 1978, because he was employed in another country. Therefore, a third meeting was scheduled by the undersigned for 14. and 15.11.79 in Colmar (France). On the second day of this meeting Dr. Dedryver (France) was elected as new Convenor.

It was pleasant to learn, that the sub-group came already to a joint publication about the activities at the third meeting. It is however, regrettable that Dr. Suter, who spent quite a time and enthusiasm for the construction of the group, could not compile the first visible success. I would like to thank him again for his excellent work.

The papers published here are to show which subjects are included within the sub-group and which future developments are to be taken into consideration. In this respect it was conspicuous, that the success of the working group had its Origin less in the similar directed methods of the same project at various stations, but more on the mutual influence and the promotion of the works, which is possible during the meetings. This progress and the performance of the meetings and the publication of this Bulletin was only possible by financial support by IOBC/WPRS. The committee may by thanked again for the help at this occasion.

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2

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PREMIERS RESULTATS CONCERNANT LE ROLE DE TROIS ESPECES D'Entomophthora DANS LA LIMITATION DES POPULATIONS DE PUCERONS DES CEREALES DANS L'OUEST DE LA FRANCE

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RESUME

Trois espèces d'*Entomophthora* sont fréquemment rencontrées sur les pucerons des céréales dans l'Ouest de la France : *E. aphidis*, *E. obscura* et *E. planchoniana*. *E. aphidis* est le principal agent pathogène de ces pucerons du fait de sa présence au sein des populations pendant une longue période dans l'année et de sa particulière aptitude à provoquer des épizooties. *E. obscura* a cependant un rôle non négligeable, essentiellement dans la limitation des populations de *Sitobion avenae* lorsque celles-ci se trouvent sur les feuilles des céréales à pailles. *E. planchoniana* ne se développe en général que tardivement dans les colonies résiduelles.

INTRODUCTION

L'importance des Entomophthora en tant qu'agents régulateurs des populations de pucerons des céréales a été mise en évidence dans différentes régions d'Europe (DEAN et WILDING, 1971, 1973 ; LATTEUR, 1973 ; DEDRYVER, 1978). Dans l'intention de rationaliser à l'avenir la lutte microbiologique contre ces pucerons par une meilleure connaissance des potentialités de leurs divers agents pathogènes, nous avons, de 1975 à 1978, cherché à estimer l'impact naturel des différentes espèces d'Entomophthora sur les pucerons des céréales dans l'Ouest de la France. Les principaux résultats obtenus sont résumés ici et seront prochainement détaillés dans une approche quantitative du phénomène (DEDRYVER et PAGES, en prép.).

La répartition des différents *Entomophthora* dans le temps, selon le niveau de la végétation et selon l'espèce de puceron (*Metopolophium dirhodum* et *S. avenae* essentiellement), a été estimée en considérant uniquement comme mycosés les pucerons morts de mycose au moment des prélèvements.

I - REPARTITION DES Entomophthora AU COURS DE L'ANNEE

Dans l'Ouest de la France les pucerons des céréales sont principalement anholocycliques et diverses graminées cultivées (repousses de céréales, céréales à pailles, maïs) hébergent successivement des populations parthénogénétiques de janvier à décembre, exception faite des années à hiver particulièrement rigoureux. Le tableau 1 indique le nombre de semaines de présence des trois principales espèces d'*Entomophthora* sur les pucerons des céréales au cours de 4 années : *E. aphidis* se manifeste pendant une grande partie de la période de présence des pucerons sur graminées, même lorsque ceux-ci sont en faible nombre, c'est par exemple le cas en hiver sur repousses.

E. obscura n'est généralement pas ou très peu présent en hiver. Au printemps il apparaît plus tard que *E. aphidis*. Sa disparition en novembre ou décembre, selon les années, est précédée par une abondante formation de spores durables.

E. planchoniana apparaît en général fin mai ou début juin pour disparaître de la fin juin à la fin juillet, en même temps que les derniers pucerons abandonnent les céréales à pailles. Certaines années cette espèce a un deuxième pic d'activité en automne, sur les *Rhopalosiphum padi*, très nombreux sur mais à cette époque.

:::::::::::::::::::::::::::::::::::::::		1975 ======	: 1976 :	1977	1978 : ======
:	E. aphidis	14	20	33	27 :
-	E. obscura	12	17	11	12 :
;	E. planchoniana	. 11	. 6	12	16 :
:	N	: 28	: 43	43	43;

<u>TABLEAU 1</u> - Nombre de semaines de présence de 3 Entomophthora sur les pucerons des céréales, de 1975 à 1978. (N = nombre total de semaines d'observation).

II - ACTION LIMITATIVE DES DIFFERENTES ESPECES

Les tableaux 2, 3 et 4 indiquent que *E. aphidis* est pratiquement toujours le pathogène qui a le rôle le plus important dans la limitation des populations de pucerons des céréales. Dans la plupart des cas (11 prélèvements sur 15, répartis sur 3 années), 75 % ou plus des pucerons mycosés le sont par *E. aphidis*, quelle que soit l'espèce de puceron ou sa position sur la plante. En particulier *E. aphidis* est, d'une part, la seule espèce qui limite les populations en début de saison (fin mai - début juin), d'autre part, le principal agent des épizooties lorsque celles-ci ont lieu (21-28 juin 1977).

				•						
	====	Nombre total de pucerons		Nombre de morts de mycose	: : <i>E</i> . : =	¶ aphidis =======	: : : :	% obscura	* * * *	% E.plancho- niana
: 1	30 mai	591	:	20	:	95	:	5	:	0
:	8 juin	464	:	23	:	87	:	8,7	:	4,3 ;
:	15 juin	456	:	20	:	90	:	5	:	5
÷	22 juin :	324	·	23	:	78,3	:	8,7	;	13 :
÷	29 juin	416	:	55	:	56,4	:	0	t	43,6 :
÷.			:		:		:		٩.	- /
;	:	:	1		1		:		1	:

TABLEAU 2 - 1975

:	1		:	:		:		;		;
÷	1 juin j	14 930	74	:	85,1	:	14,9	:	0	;
1	8 juin ;	21 691	61	:	47,5	:	52,5	:	0	:
÷	15 juin j	34 711	1 089	:	56,6	÷	42,4	:	1	;
;	21 juin :	22 613	- : 3 567	:	82,8	-	16	:	1,2	;
;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;;	28 juin :	13 943	6 213	:	92,3	:	7,1	:	0,6	:
;	:		:	:		:		:		:

TABLEAU 3 - 1977

: :		:	;		:	:	:
30 mai	9 137	660	:	97	2,9	0,1	:
. 7 juin :	5 591	592	:	91,4	; 7,8	. 0,8	:
14 juin	3 147	514	:	90,3	5,4	4,3	:
: 21 juin :	1 652	92	:	80,4	; 16,3	· : 3,3	:
28 juin -	763	73	:	46,6	31,5	21,9	:
: :			1		:	1	:

TABLEAU 4 - 1978

<u>TABLEAUX 2, 3 et 4</u> - Evolution au cours du temps des pourcentages de pucerons tués par *E. aphidis, E. obscura* et *E. planchoniana*, par rapport au total des pucerons morts de mycose en 1975, 1977 et 1978. Les périodes mentionnées sont celles où les populations de pucerons toutes espèces confondues sont maximales sur le blé.

E. obscura n'infecte que rarement plus de 30 % des cadavres récoltés, et généralement beaucoup moins (1975, 1978). Son impact est maximal en 1977, dans de fortes populations, alors que le pourcentage de pucerons mycosés par toutes espèces confondues est faible. Lorsque le processus épizootique se déclenche, *E. obscura* n'y participe que pour une faible part.

E. planchoniana n'infecte guère plus que 5 % du total des cadavres mycosés, sauf en fin d'évolution des colonies. Au cours des périodes mentionnées (tabl. 2, 3 et 4) son action sur l'évolution des populations de pucerons est très faible. Cependant lorsque les pucerons se maintiennent sur les céréales jusqu'en juillet, ce qui est assez rare dans l'Ouest de la France (DEDRYVER, 1978), *E. planchoniana* peut constituer jusqu'à 30 % du total des mycoses (DEDRY VER et PAGES, en prép.).

Il a été établi qu'au niveau du feuillage du blé, M. dirhodum était presque uniquement mycosé par E. aphidis (entre 78 % et 97 % des cas de mycose) alors que chez S. avenae, E. obscura infecte entre 13 et 51 % du total des mycosés récoltés. Au niveau des feuilles, l'action de E. obscura paraît donc plus importante chez S. avenae que chez M. dirhodum mais, globalement, E. aphidis est le pathogène principal des deux espèces de pucerons.

Chez S. avenae, l'impact de E. obscura est plus grand chez les pucerons qui se trouvent sur le feuillage que chez ceux qui se trouvent sur épi, alors que E. planchoniana a la même action aux deux niveaux de végétation. Comme dans le cas précédent, <u>E</u>. <u>aphidis est le pathogène principal quelle que soit la position de</u> <u>S. avenae sur la plante.</u>

CONCLUSION

Nos résultats confirment ce que l'on savait déjà sur l'excellente pathogénie de E. aphidis sur les pucerons dans l'Ouest de la France. Cette espèce, très peu spécifique au sein du groupe des aphides, est très répandue dans la nature et projette beaucoup de conidies, ce qui lui permet de s'installer rapidement dans les populations dès que les circonstances climatiques sont favorables. Enfin, contrairement à d'autres Entomophthora, son cycle annuel n'est pas rompu par la formation de spores durables, ce qui en fait un pathogène bien adapté aux conditions de l'Ouest de la France où les pucerons sont anholocycliques : il y a toute l'année coincidence hôte-pathogène et présence constante dans les populations de pucerons d'un inoculum immédiatement infectieux. Bien que globalement moins efficace que E. aphicis, E. obscura contribue presque toujours à la limitation des populations printanières et estivales des pucerons des céréales, sa moins grande pathogénie devrait pouvoir être compensée par le renforcement de l'inoculum naturel à l'aide de pulvérisations de spores durables de cette espèce obtenues en culture liquide (LATGE et al., 1978) dont il a déjà été montré qu'elles pouvaient provoquer des mycoses chez R. padi en serre (DEDRYVER et al., 1979).

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ETUDE DE L'ACTION DES CHAMPIGNONS ET DES HYMENOPTERES PARASITES INFEODES AUX POPULATIONS DE <u>SITOBION AVENAE</u> (F.) ET DE <u>METOPOLOPHIUM</u> <u>DIRHODUM</u> (WALK.) DANS LE CHAMP EXPERIMENTAL DE MILMORT EN 1978 ET 1979.

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1. METHODE

Les observations ont été réalisées dans 6 parcelles (en 1978) et 4 parcelles (en 1979) de 2,50 ares (5 m x 50 m) faisant chacune partie d'un bloc de 8 parcelles consacrées à des recherches sur l'influence des pucerons sur le rendement du froment d'hiver. Les parcelles dans lesquelles se sont déroulées les observations étaient en fait le témoin de chacun des blocs. En 1978, ces parcelles n'ont reçu aucun traitement insecticide ni fongicide; en 1979, elles ont reçu un traitement antifongique.

La densité moyenne de pucerons vivants par talle a été déterminée en effectuant des comptages <u>in situ</u> sur un nombre de talles compris entre 100 et 25 par parcelle. En même temps, étaient recensés, sur ces talles, les pucerons morts de mycose ou tués par Hyménoptères, ainsi que les larves de coccinelles, chrysopes et syrphides.

D'autre part, pendant la période de forte infestation aphidienne, des échantillons de pucerons vivants ont été prélevés à des intervalles réguliers au moyen d'un filet, par secouage des épis et des feuilles. Ramenés en laboratoire, les pucerons des 3ème et 4ème stades larvaires, ainsi que les adultes, étaient prélevés afin d'être mis en élevage sur de jeunes plantules de froment pendant 4 jours à 20°C et 70 % d'humidité relative.

Tous les jours, matin et soir, les pucerons mycosés étaient prélevés et mis sur eau pour induire la sporulation du champignon et l'identifier par l'observation des conidies recueillies sur une lame. Les quatre jours écoulés, les momies de pucerons parasités par Hyménoptères étaient détachées des feuilles et placées individuellement dans des petits tubes en verre afin de recueillir le parasite. D'autre part, les aphides adultes encore vivants étaient placés dans de l'alcool afin d'être disséqués plus tard et compléter ainsi l'observation relative

4/VII 10/VTT 14/VII 20/VIII 30/V 12/VI 19/VI 26/VI S. avenae épi 0 0,1 0,2 0,3 0,4 0,1 0 0,2 feuille 0,04 0,1 0,1 0,1 0 0,1 0 0,05 0.25 0 M. dirhodum 0,5 0,4 0.3 0.6 0.8 1,0 0,6 Total 0,3 0,5 0.9 0.8 1,2 1.4 0 Pucerons 18 % 19 % 8 % 6 7 4 % 3 72 12 % _ parasités Pucerons 0,3 % 4 % 07 3 % 1 7 1 7 2 73 mycosés

Tableau 1 - Evolution des populations de pucerons en 1978

 Pucerons vivants en nombre absolu par talle
 Pucerons parasités et mycosés au champ (en pourcentage par rapport à la somme du nombre de pucerons vivants et morts.

 Tableau 2
 Pourcentage de pucerons (S. avenae et M. dirhodum) parasités et mycosés, recueillis au laboratoire pendant 4 jours d'élevage à 20°C (échantillon de 100-125 pucerons par date)

	12 / VI	19 <u>/ V</u> 1	26/V1	4/VII	10/VII
Pucerons parasités °	22 %	38 %	35 %	10 %	8 %
Pucerons mycosés	3 🕱	8 %	9 %	2.2 %	25 %

° Y compris les pucerons parasités trouvés par dissection après les 4 jours d'élevage.

au parasitisme.

2. RESULTATS ET COMMENTAIRES

2.1. Année 1978

Présents en nombre relativement élevé au début des observations, les pucerons ne se sont guère multipliés par la suite (tableau 1). La densité maximum observée par talle fut de 0,4 <u>S. avenae</u> et de 1,0 <u>M</u>. <u>dirhodum</u>. Fin mai, début juin, le pourcentage de pucerons tués par Hyménoptères observés au champ était élevé. Par la suite, du fait des intempéries, particulièrement abondantes en 1978, de nombreuses momies de pucerons parasités furent détachées des talles et échappèrent au comptage, ce qui explique la diminution du parasitisme observé

Tableau 3 - Evolution des populations de pucerons en 1979

- Pucerons vivants en nombre absolu par talle

- Pucerons parasités et mycosés au champ (en pourcentage par rapport à la somme du nombre de pucerons vivants et morts)

	8/VI	20/VI	27/VI	3/VII	6/VII	10/VII	16/VII	20/VII	24/VII	27/11	30/VII
S. avenae											
épi	0	0	0,16	1,3	2,1	3,7	6,2	6,5	2,0	1,9	0,7
feuille	0	0,03	0,06	0,1	0,3	0,1	0,1	0,1	0,1	0	0
R. padi											
épi	0	0,02	0,1	0	0,3	0,1	٥,3	0,9	0,9	0,1	0,2
feuille	0	0,01	0,3	0,3	0,6	1,2	1,6	1,1	0,9	0,2	0,1
M. dirhodum	0,2	1,5	6,0	12,5	13,4	15,2	18,2	8,8	3,1	1,0	() , 2
Total	0,2	1,6	6,6	14,2	16,7	20,3	26,4	17,4	7,0	3,2	1,2
Pucerons parasités	0 %	0,2 %	0,6 %	0,4 %	0,6 %	0,8 %	0,6 %	1;5 %	1,6 %		
Pucerons mycosés	0 %	0 %	0,2 %	0,6 %	0,4 %	1,2 7	11,5 %	35,8 %	51,1 %		

12

Tableau 4 - Pourcentage de pucerons momifiés et mycosés, recueillis au laboratoire pendant 4 jours d'élevage à 20°C (échantillons de 4 x 120 pucerons par date de prélèvement et par espèce).

	27/VI	3/VII	6/VII	10/VII	16/VII	20/VII
M. dirhodum parasités mycosés	4 % 2 %	2 % 4 %	2 % 11 %	1 % 34 %	1 % 71 %	0% 62%
S. avenae parasités mycosés				 	5 % 26 %	2 🕺 27 %

<u>Tableau 5</u> - Nombre absolu de pucerons tués au laboratoire par les différentes espèces d'Entomophthora.

		M. d:	irhodum			
	27/VI	3/VII	6/VII	10/VII	16/VII	20/VII
E. aphidis	8	12	45	131	191	172
E. obscura	2	4	6	17	22	22
E. planchoniana	1	0	3	2	13	4
	I	<u>S. a</u>	venae sur	épis	I	
E. aphidis					26	20
						00

obscura 45
inchoniana 13

Tableau 6 - Evolution de la structure des populations d'aphides

	Date	Stade et forme				
		3 + 4 ap	3 + 4 ai.	Apt.	Ai.	100 % =
M. dirhodum	27/VI 20/VII	24 % 21 %	41 % 58 %	25 % 5 %	10 % 16 %	429 274
S. avenae	3/VII 20/VII	51 % 14 %	33 % 79 %	16 % 5 %	0 %2	206 215

in situ alors que celui relevé au laboratoire à partir des pucerons vivants mis en élevage (tableau 2) est nettement plus élevé et atteint 38 % le 19 juin. Il diminua assez rapidement en juillet du fait de l'action des hyperparasites toujours très actifs en fin de période.

Pour la même raison que celle qui vient d'être évoquée pour les Hyménoptères, les relevés au champ des pucerons mycosés sont peu représentatifs. Les résultats obtenus au laboratoire montrent une progression relativement lente de l'action des <u>Entomophthora</u> qui n'évolua pas en épizootie.

Parmi les parasites éclos des momies mises en élevage, c'est l'espèce <u>Aphidius frumentarius Latteur</u> qui domine, suivie par <u>Aphidius pici-</u> <u>pes Nees, Praon volucre Haliday</u> et <u>Aphidius ervi Haliday</u>.

En ce qui concerne les prédateurs, les coccinelles adultes furent très rares. Seuls, quelques spécimens de <u>Coccinella septempunctata</u> ont été repérés fin mai. Le 4 juillet, nous avons trouvé 1 larve de Coccinellide et le 10 juillet, quelques oeufs et 1 pupe. Aucune larve de syrphe ni de chrysope n'a été observée.

Plusieurs facteurs peuvent être incriminés pour expliquer le développement très faible des populations aphidiennes en 1978 :

- le climat relativement froid et pluvieux en juin et juillet, accompagné de plusieurs tempêtes;
- 2) l'action des parasites qui fut particulièrement importante;
- le développement des <u>Entomophthora</u> qui, malgré la faible densité aphidienne, a atteint jusqu'à 25 % des pucerons élevés en laboratoire.

2.2. Année 1979

Tout d'abord, il faut rappeler que l'hiver 1978-1979 fut particulièrement froid et il est vraisemblable que les populations de <u>S. avenae</u>, qui chez nous hivernent sur les graminées, principalement sous la forme de larves et d'adultes, ont été plus décimées que celles de <u>M. dirhodum</u> qui passent l'hiver sous forme d'oeufs sur les rosacées.

Cela explique (tableau 3) que les <u>S. avenae</u> n'ont pas été repérés avant la deuxième quinzaine de juin. De ce fait, leurs populations n'eurent guère la possibilité de se dévelopPer avant que la céréale arrive au début de sa maturité, stade peu favorable à la multiplication des pucerons. Au contraire, dès le début juin, les <u>M.</u> dirhodum étaient bien représentés et leurs populations ont atteint à la mi-juillet leur densité maximum, soit 18 individus par talle, avant de régresser. Quant à l'infestation par Rhopalosiphum padi, elle a été très faible.

Le 8 juin, aucun puceron tué par Hyménoptère n'avait été repéré. L'activité de ces derniers se manifesta par la suite, mais resta très faible pendant toute la durée du développement des aphides (tableaux 3 et 4).

La raréfaction des <u>S. avenae</u> durant l'hiver peut expliquer celle des parasites car, en hiver doux, ceux-ci continuent à se reproduire aux dépens des colonies de <u>S. avenae</u> qui constituent ainsi une excellente réserve de parasites prêts à se multiplier activement dès le printemps.

Parmi les parasites recueillis, <u>Praon volucre</u> vient en tête, suivi par A. frumentarius, A. ervi et A. picipes.

Absentes au début des observations en champ, les <u>Entomophthora</u> se multiplièrent ensuite pour atteindre au maximum de leur développement quelques 70 % des <u>M. dirhodum</u> ramenés au laboratoire et 27 % des <u>S. avenae</u> (tableau 4). Cette différence peut s'expliquer, tout au moins en partie, par le fait que ces derniers, qui colonisent quasi exclusivement l'épi, se trouvent dans un milieu où l'humidité relative de l'air est en moyenne moins élevée que celle qui règne au niveau du feuillage occupé par les M. dirhodum.

On voit (tableau 5) que l'importance relative des espèces d'<u>Ento-</u> mophthora est différente selon que celles-ci se sont développées sur les <u>M. dirhodum ou sur les S. avenae.</u>

Toutefois, l'épizootie à Entomophth*ora* s'est déclenchée trop tardivement pour juguler la pullulation des populations de <u>M. dirhodum</u> avant que celles-ci n'atteignent des densités importantes.

Signalons aussi que, contrairement aux années précédentes, aucune coccinelle de l'espèce <u>C. septempunctata</u> n'a été observée. Seuls quelques spécimens de <u>C. quatuordecimpunctata</u>, lesquels sont habituellement nettement plus rares que l'espèce précédente, ont été recensés.

En ce qui concerne les syrphes, la première larve fut trouvée le 27 juin et la densité maximum observée fut d'une larve pour 406 pucerons, le 10 juillet, ce qui, en céréales, constitue un rapport relativement important.

Iб

Enfin, en ce qui concerne l'évolution de la structure des populations, on voit (tableau 6) qu'entre le début de l'infestation et son apogée, la proportion de larves à ptéroptèques augmente beaucoup moins parmi les populations de M. dirhodum que parmi celles de <u>S. avenae</u>.

De même, le pourcentage d'adultes ailés restés sur la céréale permet d'observer que l'émigration a été plus importante au sein des colonies de <u>S. avenae</u> que parmi celles de <u>M. dirhodum</u>, ce qui a dû favoriser la multiplication de ces dernières.

REMARQUE

Ces résultats constituent un résumé des observations qui ont été recueillies au sujet de la dynamique des pucerons des céréales en 1978 et 1979. Afin d'être pleinement discutés et exploités, en vue notamment d'élaborer un système de prognose relatif à l'évolution des populations aphidiennes, ils devront être inclus dans l'ensemble des données accumulées dans ce domaine depuis 1971.



THE UTILIZATION OF AN <u>ENTOMOPHTHORA OBSCURA</u> RESTING SPORE PREPARATION IN BIOLOGICAL CONTROL EXPERIMENTS AGAINST CEREAL APHIDS

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Abstract

Of those Entomophthorales species studied, <u>Entomophthora</u> obscura has been chosen for use in biological control against cereal aphids due to its high pathogenicity and its convenient resting spore production and germination. The known characteristics of 5 other resting spore producing Entomophthorales are also reviewed. Industrial production of <u>E. obscura</u> resting spores, their subsequent germination, conservation and formulation is being investigated. The application of resting spores in cereal fields will be effected using 3 types of treatments based on seasonal changes and the life cycle of <u>E. obscura</u>.

Introduction

Entomophthorales species are the only microbial pathogens known to reduce aphid populations in temperate zones. Their biological control use has long been discussed (MacLeod, 1963, Gustafsson, 1971, Remaudière, 1972, Latgé et al., 1978 c); recent research has focused on the influence of these fungi in controlling cereal aphid populations (Dean et Wilding, 1971, 1973, Latteur, 1973, Dedryver, unpublished).

The following paper concerns the choice of species and the types of treatment best suited for the first application of an Entomophthoraceous species against cereal aphids in natural conditions.

I. Choice of the fungal propagule

Two types of spores may be produced in the Entomophthorales: conidia, the infective units propagating the disease and resting spores, the overwintering, conservation stage of the fungus.

In laboratory conditions conidia are short-lived, although it is thought that conservation may occur in the soil (Latteur, 1977). Mass conidia production is difficult at this time because of their projection after being produced on solid medium. Liquid culture of conidia has been unsuccessful. In contrast, resting spores, either azygospores or zygospores depending on the species, are resistant to adverse conditions, allowing the conservation of the fungus from year to year, furnishing the inoculum for spring infections. Furthermore, mass production in liquid culture of resting spores has been achieved for several species. Using these criteria, resting spores are thought to have the greatest chance for success in biological control applications (MacLeod, 1963, Gustafsson, 1971, Remaudière, 1972, Latgé et al., 1978 c).

II. Species choice

Research in temperate zones in Europe and America has allowed the isolation of Entomophthorales species of interest in biological control against aphids. Of the resting spore producing species found infecting aphids, 6 species have been selected for biological control consideration utilizing the following characteristics: pathogenicity, ease of cultivation, seasonal requirements, resting spore production in liquid culture and resting spore germination (Table 1).

SPECIES	PATHOGENICITY	IABORATORY CULTURE	SEASONAL REQUIREMENTS	RESTING SPORE PRODUCTION IN LIQUID CULTURE	RESTING SPORE GERMINATION
C. OSMODES	LOW	+	WINTER	+	+
C. THROMBOIDES (=E. VIRULENTA)	VERY LOW	+	ALL YEAR	+	+
<u>E. FRESENII</u>	VERY SPECIFIC	-	SUMMER	-	+
E. PLANCHONIANA	нісн	-	ALL YEAR	-	-
E. SPHAEROSPERMA	нісн	+	AUTUMN SPRINC:	_	-
E. OBSCURA	нісн	+	AUTUMN SPRING	+	+

C. = CONIDIOBOLUS E. = ENTOMOPHTHORA

Table 1 : Characteristics of 6 aphid infecting Entomophthorales species forming resting spores.

20

<u>Conidiobolus thromboides (= E. virulenta)</u>, was lowest in pathogenicity (Remaudière et al., 1976 a), therefore its use in biocontrol against aphids was not chosen. However, because this species produces resting spores readily in liquid culture and these spores germinate easily, it was used as a model for futher culture studies of the other species (Latgé, 1977, Latgé et al., 1977).

<u>C. osmodes</u> produces resting spores (Latgé et al., 1978 b); the strains isolated in Europe demonstrated a cold temperature requirement limiting the range of its use (Remaudière et al., 1976).

<u>E. fresenii</u>, found predominantly infecting the black <u>Aphis</u> group is frequently encountered in nature (Remaudière et al., 1976 b); in vivo produced resting spores are capable of germination (Bitton et al., 1979). However, <u>in vitro</u> culture has not been obtained (Gustafsson, 1965).

E. planchoniana is very common, but culture has not been obtained in vitro. Resting spores found in nature are rare and have not been seen to germinate.

E. sphaerosperma, although highly pathogenic in laboratory conditions (Torres, unpublished) is rarely found infecting aphids in nature. Liquid culture production of resting spores has not been developped and in vivo produced resting spores have not germinated.

E. obscura is highly pathogenic for several aphid species (Papierok et Wilding, 1979). Mass resting spore production in liquid culture has been developped (Latgé et al., 1978 b); germination levels exceed 80 % for resting spores stored for 3 months in soil at low temperatures (Latgé et al., 1978 a). This species will be the preferred choice for biological control experiments foreseen for 1979-1980, in temperate zones throughout Europe.

III. Inoculum production

The different steps of E. obscura spore preparation are represented in Fig. 1. In fermentor, E. obscura develops unicellular multinucleate hyphal bodies (stage SO) in a homogenous mass. Nutrient exhaustion induces resting spore formation. Young resting spores (= prespore, stage S1) are characterized by a thin wall and a dense protoplasm containing many oil globules. Resting spores mature in 4 to 5 days at constant culture conditions; mature spores (stage S2) are characterized by a single oil globule and a thick wall. Spore production attains 3 x 10⁶ sp/ml medium on media containing vegetable oil and yeast extract (Latgé, 1980, Latgé et al., 1978 b), Spores produced in the fermentor are uncapable of germination without a "vernalization" period of 3 months at 4 to 7°C in humid conditions. "Vernalized" spores (stage S3), morphologically similar to spores coming out of the fermentor (S2), begin to germinate when placed in water at 14° in 2 to 7 days; maximum germination reaches 80 % 8 to 10 days later. At the beginning of germination the oil globule and



Fig. 1 : Schematic representation of <u>Entomophthora obscura</u> laboratory cycle.

thick spore wall are digested (stage G1). A germ tube then protrudes (stage G2) eventually producing a conidia at the extremity. This conidia may subsequently infect an aphid (Perry and Latgé, 1980).

IV. Industrial development

Mass resting spore production on industrial media containing corn steep liquor and Ambrex or unrefined corn oil (SPM) has exceeded 10^6 sp/ml.

The addition of adjuvants to the resting spores to improve the insecticidal qualities of a spore formulation is being investigated. Some of these adjuvants may serve as substrates for spore "vernalization". Current conservation experiments show that the spores may be conserved for over 8 months. Many currently employed fungicides such as sulfur, methylthiophanate, triforin, oxycarboxin, have little or no effect on spore germination.

These preliminary results indicate the feasability of the industrial production and agricultural utilization of <u>E. obscura</u> resting spores in biological control against aphids in temperate zones.

V. Field application

Traditional theory for the use of fungal pathogens (Fig. 2) in biological control advocates the introduction of the pathogen, early



Fig. 2 · Theoretical use of fungal pathogens in nature (from latgé et al., 1978 c).

in the season, when the pest population densiries are low, to prohibit the lise in population and the accompagnying economic damage.

The i ro-environmental conditions encountered in these first trials in cereal crops will have an effect on the success of such ireatments. As cerea. Fields are not commonly irrigated, natural humidity, an important fact rior E. obscura development, will play a great role (Latgé et al., 1978 c). The quantity of the fungal inoculum applied will also be a factor in the success of these first treatments, as such, a large inoculum will be applied in order to maximize the initial chances of success. Utilizing the general theory for the application of fungal pathogens in biological control and the special characteristics concerning the life cycle of E. obscura, 3 types of treatments have been designed for implementation in 1979-1980 (Table 2):

APPLICATION TIME	LATE AUTUMN	EARLY SPRING	LATE SPRING
TYPE OF SPORE	NON VERNALIZED	VERNALIZED	VERNALIZED
APPLIED	SPORE	SPORE	GERMINATING SPORE
A PHID	NO A PHIDS	APHIDS	HEAVY
POPULATION	PRESENT	FIRST APPEARING	APHID INFESTATION

Table 2 : Types of treatments developed utilizing Entomophthora obscura against cereal aphids. 1. "Non-vernalized" spores will be applied at the end of autumn, synchronizing the laboratory produced spores with the natural "vernalization" cycle that occurs at winter temperatures. Germination in the spring time would provide the necessary infective inoculum at the beginning of aphid infestation.

2. Laboratory "vernalized" spores will be introduced into low aphid populations in the spring. Germination would occur along side insect population growth.

3. Laboratory "vernalized" spores that have been incubated in water (stage Gl without germ tubes protruding) will be applied to heavily infested wheat to simulate a "chemical insecticide" treatment. Pre-germination would allow for rapid infection and insect mortality.

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CONSIDERATIONS SUR LE POUVOIR PATHOGENE DE <u>ENTOMOPHTHORA</u> OBSCURA HALL ET DUNN A L'EGARD DES PUCERONS DES CEREALES

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RESUME

La comparaison de la virulence des souches de <u>Entomophthora</u> obscura à l'égard de <u>Sitobion avenae</u> a été rendue possible grâce à la mise au point d'une méthode permettant de déterminer leurs CL 50. Au sein de <u>E. obscura</u> on distingue ainsi des souches non-virulentes, des souches peu virulentes et des souches fortement virulentes.

Les auteurs discutent la valeur de la CL 50 comme unique caractère permettent de juger de l'activité d'une souche. Ils introduisent la notion de "pouvoir multiplicateur" de l'inoculum. Les souches qui devraient se révéler les plus actives en lutte biologique sont celles caractérisées à la fois par une CL 50 faible, un pouvoir multiplicateur élevé et un cycle d'infection de courte durée.

Entomophthora obscura Hall et Dunn est avec <u>E. aphidis</u> Hoffman et <u>E. planchoniana</u> Cornu l'une des trois Entomophthorales régulièrement actives dans les peuplements de Pucerons des Céréales. La rapidité de sa croissance, associée à la propriété de certaines de ses souches de former facilement des spores de résistance en culture distinguent <u>E.</u> <u>obscura</u> des deux autres espèces. <u>E. planchoniana</u> ne peut être en effet cultivé sur milieu artificiel; par ailleurs <u>E. aphidis</u> ne produit jamais de spores durables en culture.

Une méthode de lutte biologique contre les Pucerons au moyen des spores de résistance de <u>Entomophthora</u> ne peut donc être actuellement développée qu'avec <u>E. obscura</u>. Un procédé de production des spores de résistance de cette espèce transposable à l'échelle industrielle a été mis au point (Latgé et al., 1978). Les facteurs assurant la levée de la dormance de ces spores ont été définis (Latgé et al., 1978). On peut donc ainsi disposer actuellement d'un inoculum directement actif en quantité très importante.

Parallèlement aux recherches physiologiques entreprises sur la croissance et la sporulation de <u>E. obscura</u>, l'étude de son pouvoir pathogène à l'égard de <u>Sitobion avenae</u> F. a été abordée au laboratoire.

La méthode d'estimation comparative de la virulence des souches de <u>E. obscura</u> utilisée présentement est celle mise au point précédemment sur Acyrthosiphon pisum Harr. (Papierok et Wilding, 1979).

Dans ces conditions, certaines souches de <u>E. obscura</u> se révèlent totalement non-virulentes, même lorsque les pucerons sont exposés à de très fortes concentrations de conidies. D'autres souches peu virulentes, ne conduisent jamais à des taux de mycose supérieurs à 50 %. En revanche, pour un certain nombre de souches, dès que la concentration en conidies est suffisante, la totalité des pucerons exposés meurent infectés par le champignon.

Au sein de ces souches fortement virulentes, on distingue deux groupes A et B définis par Remaudière et al. (1979): à l'opposé des souches B, les souches du type A forment des cystides sur les cadavres, leur culture sur milieu jaune d'oeuf coagulé ou milieu de Sabouraud enrichi de jaune d'oeuf (80/20) est fortement plissée et leur aptitude à former des spores durables est très grande.

La concentration létale 50 (exprimée en nombre de conidies par mm²) est de l'ordre de 16 pour les souches A et de l'ordre de 8 pour les souches B qui apparaissent ainsi environ deux fois plus virulentes que les premières. L'étude du comportement pathogène de <u>E. obscura vis-à-vis</u> de <u>S. avenae</u> montre en outre que, d'une part, la durée d'incubation de <u>la maladie à 18° + 1°C est d'un</u> jour plus longue pour les souches B que pour celles de type A et, d'autre part, le nombre total des conidies émises par un cadavre lors de la sporulation est significativement plus grand pour les souches de type B que pour celles de type A (Papierok et Wilding, 1980).

Le cycle d'infection par une souche de type B se traduit donc par un "pouvoir multiplicateur" plus élevé de l'inoculum. Les souches de type B deux fois plus virulentes que celles de type A possèdent aussi théoriquement une meilleure "aptitude parasitaire" que les souches de type A. Toutefois leur plus grande capacité d'expansion dans les populations aphidiennes est tempérée par une durée d'incubation plus longue de la maladie.

Dans un premier temps, le choix d'une souche de <u>E. obscura</u> utilisable en lutte biologique est fondé sur les critères de virulence (exprimée en termes de CL 50) et de facilité de sporulation <u>in vitro</u>. Dans un deuxième temps, l'étude précise du comportement pathogène des souches retenues permettra de déterminer la ou les souches caractérisées à la fois par un fort pouvoir multiplicateur de l'inoculum, une courte durée d'incubation de la maladie et de faibles exigences écologiques. Seules ces souches seront parfaitement adaptées à la stratégie développée pour l'emploi des <u>Entomophthora</u> dans la lutte contre les Pucerons (Remaudière, 1971; Latgé et al., 1978): apport d'inoculum visant à installer précocement la maladie dans les peuplements aphidiens, de manière à maintenir ceux-ci en-dessous du seuil économiquement dommageable.

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INTEGRATED CONTROL OF CEREAL APHIDS

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1979 has been called 'The year of the greenfly' by the national press, and indeed the swarms of aphids that plagued eastern and southeastern England this summer gave rise to some alarmist headlines. Many farmers were worried by the possible damage that these aphids, mainly <u>Metopolophium dirhodum</u>, were doing to their crops, and as will be seen in this paper, they probably had every right to be so.

This paper is an explanation of the events that led up to the development of these 'plague' populations on a wheat crop at Rothamsted. It is largely an account of the results of a co-operative experiment originally designed to compare methods of biological and chemical control of cereal aphids and other pests, with a view to developing an integrated approach to the control of all components of the insect pest complex in cereals. However, since neither biological nor chemical agents prevented aphid populations reaching extremely high levels in 1979, results which help to explain these failures have been extracted from other comparable experiments at Rothamsted.

The main experiment. The integrated control experiment (ICE) was carried out in a crop of Flanders winter wheat sown on the 19 October 1978 (Fig. 1), and consisted of three replicates of four treatments. All plots were treated with appropriate weedkillers and adequate nitrogen, and the experimental treatments were as follows (Fig. 2):-

- - Nil
- A Aphicide: Aphox (50% pirimicarb) at 280g/ha at growth stage 60 (Zadoks et al., 1974)
- B Biological: release of Entomophthora-infected aphids
- M Multichemical: aldicarb granules to control soil pests and nematodes, metaldehyde pellets for slugs; omethoate for stemborers, and pirimicarb for aphids applied as in treatment A

The incidence of pests other than aphids was monitored throughout the growing season, but none developed significant populations and have therefore been ignored here.

Sampling was facilitated by the provision of tramlines (Fig. 2) which also allowed successive applications of chemical and other treatments without damaging the crop. A central harvest area for yield determination was left undisturbed by sampling operations.

Aphid population development. Initial aphid immigration is often so low that it is impossible to find aphids by searching in the crop. Aphids

were, therefore, sampled in two ways:- (i) using a modified insect vacuum sampler (Thornhill, 1978) to detect early immigrants and to monitor the subsequent build up of the population while still at low densities (ii) counting the numbers of aphids and natural enemies on 10 shoots at each of four sites per plot. Vacuum samples of $\frac{1}{2}m^2$ were taken weekly from each plot from late May to mid July and in situ counts made weekly, from mid-June to mid-August when the numbers present were large enough to make the effort worthwhile. In both methods, the aphids were identified to species and classified as apterae, alatae, 4th instar apterae and alatae and 1-3rd instar numphs.

A comparison between the two methods showed there to be considerable differences in the sampling efficiency of the vacuum sampler between the various morphs, ranging from about 10% for the very young instars to 100%+ for alates (Table 1). Therefore, where appropriate, correction factors have been applied to the results.

on 21	.7. 78.				ATHCEL WHE	10	
		Nos. apl	hids/100	tillers			
Instar	I	II	III	IV apt	IV alate	Apt	Alate
Plant counts	181	243	93	29	23	22	7
Suction sampler	17	25	32	20	18	8	8
% efficiency	9	10	34	70	76	36	115

Table 1. The efficiency of a suction sampler in sampling <u>Metopolophium</u> dirhodum in a field of winter wheat on 21.7.78.

Immigration. The first cereal aphid, a Metopolophium dirhodum, was caught in the Rothamsted Tower 12.2 m suction trap on 20 May. This trap is situated 0.8 km from the integrated control experiment in which 1 alate <u>M. dirhodum</u> per m^2 ($1m^2 = 514$ shoots) was found using the vacuum sampler two days later (Fig. 3). The value of the suction trap for indicating the arrival of immigrants was thus well demonstrated.

Of the other cereal aphid species, no <u>Sitobion</u> avenae were caught in the trap until the end of June and their absence was reflected in the crop. A few <u>S. fragariae</u> and <u>Rhopalosiphum</u> padi were recorded in both trap catches and vacuum samples in early June but their populations did not increase substantially thereafter, possibly because <u>S. fragariae</u> is predominantly a grass feeding aphid, while <u>R. padi</u> prefers seedling cereal plants.

<u>M. dirhodum</u> therefore constituted the major aphid pest of winter wheat in 1979, and is the species to which most of the following results refer.

It is important to determine the environmental conditions that allowed M. dirhodum to build up to \cdot enormous proportions when the initial colonisation had been so low.

Laboratory measurements of generation time have shown that apterous <u>M. dirhodum</u> require about 150 day degrees above 0°C to develop from birth to maturity (7-8 days at 20°C). Between the initial immigration of aphids on 20 May and the attainment of peak populations at the end of July, the aphids could have passed through 7-8 generations, and reach very large numbers in the absence of significant mortality.

During this period crop development was retarded by about two weeks compared with most previous years, due to the very cold winter and wet spring. The aphids were therefore provided with nutritious food for longer than usual. Rapid multiplication was further encouraged by 2-3 weeks of optimal warm, dry weather from early July.

<u>The spread of infestation</u>. The even distribution of <u>M. dirhodum</u> across the whole experiment was probably enhanced by the production of alates which migrated from and re-entered the crop during June and early July. These alates were recorded in small numbers by the 12.2 m suction trap, but many more were caught in another trap set at 1.5 m (Fig. 3), suggesting that the alates were only flying locally and not indulging in long distance migration.

Alates are usually produced during the summer because of overcrowding and/or poor nutrition, but neither of these factors appeared to be operating in June of 1979. Alates were first produced in the crop when the population was below 1/shoot (Fig. 4) and the plants were in a very healthy condition, only just beginning to produce ears (Zadoks 50-57). This suggests that very low densities induce the appearance of alates in this species, or that alates are sometimes continually produced by apterous parents, irrespective of environmental conditions.

Emigration would normally be regarded as a mortality factor (Hughes, 1972) but in 1979 the re-entry of alates into the crop seemed to be a major factor in producing economically damaging populations.

The effect of insecticides. Current advice in England and Wales given by Ministry of Agriculture entomological advisers for aphid control in cereals is to spray with a persistent systemic insecticide when populations reach 5 per ear at the beginning of anthesis (Zadoks 61) (George, 1974). Although populations of <u>M. dirhodum</u> had only reached 55/100 shoots at this time, all of which were on the leaves, a spray of pirimicarb was nevertheless applied in the integrated control experiment. Populations on the treated plots declined to 6/100 shoots (98% reduction) 2 days after treatment whereas on untreated plots they had quadrupled (Fig. 5). No significant differences in subsequent aphid numbers were found between the nil (-) and biological (B) plots, or between the aphicide only (A) and multichemical (M) plots. Results from these pairs of treatments were therefore amalgamated to give six replicates of both unsprayed and sprayed plots.

The insecticidal action of pirimicarb apparently persisted for only about 5 days, since the sprayed plots rapidly became reinfested due to immigration of alates and possible apterae from surrounding unsprayed areas. By the middle of July the aphid populations in both treated and untreated plots were similar and achieved maximum numbers (35/shoot) in the following week. Thereafter <u>M. dirhodum</u> rapidly became fewer and there were none in the ripening crop by the second week of August. Subsequent analysis of crop yields showed no significant difference between the sprayed (7.3 tonnes/ha) and unsprayed plots (7.1 tonnes/ha).

A nearby wheat experiment received two pirimicarb sprays on some plots - the first at the beginning of anthesis, as in the integrated control experiment, and the second in mid-July at the medium milk stage (Zadoks 75) when the numbers of aphids on untreated and treated plots were 75 and 25 respectively.

The effect of the first spray was similar to that obtained from the integrated control experiment (Fig. 5). There was an immediate decrease in the numbers of <u>M. dirhodum</u> followed by a rapid reinfestation so that populations in both treated and untreated plots were converging by mid-July. However, a week after the second application the populations in the treated plots had decreased by about 80% whereas those in the untreated plots had further increased. Thereafter the numbers of aphids rapidly decreased in both treated and untreated plots.

The presence of the large numbers of aphids on the leaves during the milky ripe stage significantly reduced yields by 12½% from 10.3 t/ha in the twice-treated plots to 9.1 t/ha in the untreated plots. Yield losses caused by aphids (usually <u>S. avenae</u>) have previously been thought to be a result of feeding damage to the ears during flowering and earfilling. However, in 1979 the yield loss occurred almost exclusively through damage to the leaves and in particular the flag leaf. Although 1979 must be regarded as an exceptional year, future advice on the control of cereal aphids must take into account the effect on yield of extremely high numbers of aphids of whatever species, whether on the leaves or the ears, at later growth stages than flowering.

Natural enemy populations

(a) <u>Aphid specific predators.</u> In 1979, weekly surveys found few aphid specific predators, especially coccinellidae. Of the coccinellids, adults of <u>Propylea 14-punctata</u> were most common both in the crop and in the Rothamsted Tower 12.2 m suction trap (Table 2). There were more syrphid larvae than coccinellids in the crop during July and of the five species reared, <u>Syrphus vitripennis</u> and <u>Platycheirus clypeatus</u> had not been recorded before from cereals in England (Table 3). As in previous years, larvae of <u>Episyrphus balteatus</u> were the most common species in winter wheat although there were only two adults in the 12.2 m suction trap compared with 130 <u>Metasyrphus corollae</u>, a species not associated with cereals in England.

It must be concluded, therefore, that unlike 1976, when there were many <u>Coccinella 7-punctata</u>, aphid specific predators were ineffective in limiting the size of the aphid populations on cereals in 1979. Three factors may have contributed to this: (1) aphids were few in 1978 limiting the multiplication of predators, (2) 1978-79 winter was severe and probably reduced overwinter predator survival, and (3) food was scarce in the spring and early summer of 1979 limiting the production of the first predator generation. In particular there were very few aphids on the young nettle beds, <u>Urtica dioica</u>, in April and May, a factor which has been shown to strongly influence subsequent numbers of predators, especially coccinellids.
Table 2.	Aphid	Specific	Predators	_	Coccinellidae/Chrysopidae
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	Total Number (June-August)			
	Random samples in winter wheat	12.2 m Suction trap		
Adalia 2-punctata L.	0	6		
Coccinella 7-punctata L.	1	4		
Coccinella 10-punctata (L.)	0	2		
Coccinella 11-punctata L.	0	2		
*Halyzia 16-punctata L.	0	0		
Propylea 14-punctata L.	10	16		
*Thea 22-punctata (L.)	D	0		
Chrysopa carnea Steph.	2	514		

* Recorded previously (Dean, 1974)

Table 3. Aphid Specific Predators - Syrphidae

Total Number (June-August)		
Random samples in winter wheat	12.2 m Suction trap	
51	2	
0	130	
0	2	
13	0	
0	2	
9	0	
27	2	
13	0	
0	0	
	Total Number (J Random samples in winter wheat 51 0 0 13 0 9 27 13 0	

(1) Not reared from cereals in England

(2) Recorded previously (Bowden & Dean, 1977)

(b) Entomophthora. Entomophthora spp. have been shown by many authors to be an important cause of mortality in cereal aphids in field populations though usually acting too late to make the use of insecticides unnecessary. It is not known how much the late action of the fungi is attributable to adverse weather conditions or to the initial low densities of fungi or host. In experiments to determine the effect of artificially increasing the density of <u>Entomophthora</u>, it has been shown at Rothamsted that the fungi can be established in <u>Aphis fabae</u> populations in plots of field beans by distributing living aphids that have been infected in the laboratory. Further, except in very dry seasons, such treatment leads to an earlier collapse of the aphid population than in untreated plots.

With this knowledge, an <u>Entomophthora</u> treatment was included in the experiment on the integrated control of cereal pests at Rothamsted in 1979. <u>Sitobion avenae</u> and <u>Metopolophium dirhodum</u> were reared in the laboratory and infected by 2 h exposure to conidia of <u>E. aphidis</u> discharged from infected pea aphids, <u>Acyrthosiphon pisum</u>. After inoculation, approximately 8,000 <u>S. avenae</u> and 4,750 <u>M. dirhodum</u> were distributed systematically in each of the (B) plots on 20 and 21 June. Samples showed that about 70% of the <u>S. avenae</u> distributed and 90% of <u>M. dirhodum</u>/m², or about 1 of each species for every 40 tillers.

To estimate the proportion of aphids that became infected in the field, samples of 50 living aphids were taken weekly from each plot and individuals were reared separately. The numbers killed by <u>Entomophthora</u> within four days of the sampling date were recorded.

The weekly mean aphid population and the mean proportion infected with <u>Entomophthora</u> species from the <u>Entomophthora-treated</u> and untreated control plots are presented in Fig. 6 together with the rainfall for the corresponding period.

The weekly aphid population and the total proportion of aphids infected were similar for untreated and <u>Entomophthora-treated</u> plots. However, the relative importance of <u>E. aphidis</u>, the species that was introduced, and <u>E. planchoniana</u>, which arrived from natural sources, differed strikingly between treated and untreated plots. Following its application, <u>E. aphidis</u> infected a few aphids in the treated plots during early and mid-July, when conditions were very dry, and then infected many aphids at the end of July and beginning of August at the start of a rainy period. In the untreated plots, however, <u>E. aphidis</u> was absent until late July end infected only a small proportion of aphids then and during early August. These aphids were probably infected by <u>E. aphidis</u> that had dispersed from the adjacent treated plots because the fungus was not found on M. dirhodum in other sites at Rothamsted.

E. planchoniana occurred in all plots and was the dominant species throughout the season in the untreated plots. It seemed less affected than E. aphidis by the dry conditions, infecting a steadily increasing proportion of aphids in successive weeks after early July when it first appeared. In mid-July, <u>E. planchoniana</u> was equally abundant in treated and untreated plots. In view of the subsequent increase in mortality caused by <u>E. aphidis</u> in treated plots, it is difficult to understand why

the combined mortality caused by the two fungi was not greater than that caused almost exclusively by <u>E. planchoniana</u> in the untreated plots. One explanation is that all the susceptible individuals were infected by one or other of the fungi; the others remaining uninfected perhaps because the microenvironment they occupied was too dry.

The source of <u>E. planchoniana</u> was not determined. It may have remained in the soil from the previous season but, more probably, it was introduced by immigrant alates. By late June, many alates were being produced in the crop and in neighbouring cereals and grasses as mentioned above. <u>Entomophthora</u> species probably begin to multiply in the spring in perennial vegetation, such as grasses, and <u>E. planchoniana</u> probably came from these to the cereal crop. Further invasion by the fungus may have occurred throughout July in view of the large, prolonged migrations of alate <u>M. dirhodum</u> that occurred then.

The introduction of <u>E. aphidis</u> failed to control the <u>M. dirhodum</u> population in 1979. However, this preliminary experiment provided some interesting information: (i) this fungus can be introduced in cereal aphid populations by the release of infected aphids, (ii) when introduced into 19 x 19 m plots, there was a delay of several weeks before the fungus spread into neighbouring plots which encourages further investigations of such treatments in small plot experiments on cereals, (iii) when the weather became rainy, the fungus spread very rapidly from the small inoculum present in the third week in July. Had there been more rain during July, the fungus in the treated plots might have prevented aphid numbers from increasing then, and (iv) <u>E. planchoniana</u> may well spread more effectively than E. aphidis during dry weather.

(c) <u>Parasites</u>. Parasitoid mummies were recorded during the weekly aphid counts in situ, described above, but the numbers of mummies found were too small to be analysed in terms of the experimental treatments. However, the percentage parasitisation in the untreated and <u>Entomophthora</u>-treated plots was estimated from the samples of live <u>M</u>. dirhodum which were collected each week and reared in the laboratory as part of the <u>Entomophthora</u> studies. The aphids were reared for 2 weeks to allow mummies to develop. In late June, 25% of the aphids developed into parasitoid mummies, but by mid-July, the level had fallen to below 5%, where it remained for the rest of the season.

All mummies from these samples were kept, and the parasitoids that emerged were identified. The relative proportions of each species are shown in Fig. 7. Toxares deltiger Haliday, a species previously unrecorded from cereal aphids, was the dominant species of primary parasitoid for most of the season. 67% of the mummies formed in these samples were those of I. deltiger. Aphidius uzbekistanicus Luzhetski was the other major primary parasitoid, and this was the only species present at the end of July. Small numbers of Aphidius picipes (Nees), Praon volucre (Haliday) and a hyperparasite, Phaenoglyphis sp. also were obtained by this sampling method. Many species of hyperparasite attack the primary parasitoids after mummy formation, and so cannot be detected by sampling live aphids.

Throughout the season, parasitoid mummies were collected randomly in the experimental area, and these were reared in the laboratory to determine which parasitoids were present (Fig. 8). The absence of <u>I. deltiger</u> from these collections is striking. Eleven <u>I. deltiger</u> mummies, in fact, were collected, but this is too few to appear in the histogram. Similarly, <u>Ephedrus plagiator</u> Nees mummies were too few to be plotted. <u>A. uzbekistanicus</u> was the dominant primary parasitoid, with <u>A. picipes</u> and <u>P. volucrepresent</u> in smaller numbers throughout the season.

In laboratory cultures of <u>I. deltiger</u> on <u>M. dirhodum</u>, parasitised aphids tended to leave the plant before dying. This would explain why the species was so poorly represented in the mummy collections as compared with the samples of living aphids, since all the mummies from the field were from plants. A wide variety of hyperparasites were reared from the mummy collections (Fig. 8), and these greatly outnumbered the primary parasitoids in June and the first half of July. After mid-July, the proportion of hyperparasites declined. The most numerous hyperparasite was Phaenoglyphis sp.

From mid-July onwards, there was a gradual increase in the proportion of mummies which failed to produce parasitoids after collection. A number of unemerged mummies, some of which had been collected as early as the last week in June, were dissected in October, and most of them contained living final stage larvae, presumably in diapause. The environmental stimuli which caused the onset of diapause so early in the season, and in only part of the population, are not known.

Fig. 9 shows the parasitoids caught in the 12.2 m suction trap at Rothamsted this year (after Dr. Margaret Jones). <u>Aphidius</u> spp. greatly outnumbered other genera, particularly in July and August, but there has been insufficient time to identify these to species. <u>I. deltiger</u> first appeared in the trap in July. This corresponds to the time when, from the samples of living aphids, many adults of this species would have been expected to be emerging in the crop. Apart from <u>Aphidius</u> spp., <u>I. deltiger</u> was the most abundant aphid parasitoid caught in the trap in July and August, although very few occurred in the trap catches for 1976 - 1978. Catches before 1976 have not been examined. It will be interesting to see whether or not <u>I. deltiger</u> continues to parasitize cereal aphids in future years.

Summary: Metopolophium dirhodum was the major pest aphid species in cereals in 1979, and reached very large numbers as a result of a combination of factors, namely, a late crop, providing optimal nutrition for longer than normal; warm dry weather, encouraging rapid reproduction; and absence of parasites, predators and disease until very late in the season.

The enormous numbers of aphids had a large effect on yield especially during late stages of crop development. In most years natural enemies combine to reduce the numbers of aphids during this late stage, and their absence in 1979 highlights the importance of their contribution to aphid control, which has been unrecognised previously. The future development of integrated control systems must exploit the potential of these natural enemies to the fullest.

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Fig. 1

Project Layouts in Stackyard (1979)



W/8 Integrated control experiment in winter wheat W/9 Study of parasites and predators of insect pests of wheat W/12 Study of wheat bulb fly and soil predators











Fig. 5 Effect of single and double pirimicarb sprays on populations of M. dirhodum in winter wheat, 1979



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Infection of <u>Metopolophium dirhodum</u> with <u>Entomophthora</u> spp in untreated plots and in plots treated with <u>E. aphidis</u>, compared with aphid population development and rainfall





Fig. 7 Parasites from live samples of M.dirhodum





Aphid parasites caught in a 12 2m suction trap





APHIDS IN WINTER WHEAT: ABUNDANCE AND LIMITING FACTORS FROM 1976 TO 1979

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ABSTRACT

Metopolophium dirhodum (Walker) and Macrosiphum (Sitobion) avenae (F.) are the most important aphids of winter wheat in the Rhine - Main area. Their abundance and the efficacy of their antagonists were investigated from 1976 to 1979 by counting procedures in the fields. M. dirhodum usually is infesting winter wheat in the beginning of May, about a fortnight before M. avenae arrives. Both species reach their population maximum at plant growth stage 65 to 71 (scale of Zadoks et al.) though M. avenae reaches its maximum density about one week later. There is a positive correlation between population development and the number of infested tillers. After a short discussion of the reasons why aphid populations always were far below a preliminary economic threshold of about 35 aphids per tiller at plant growth stage 65 the efficacy of natural antagonists is treated in detail. Whereas Chrysopidae and Coccinellidae only gain importance in certain years, the most reliable predators are the larvae of the hover fly Epistrophe balteata Deg. Parasitoids (mainly Aphidius uzbekistanicus Luzhetzki, A. ervi Haliday, Praon volucre (Haliday)) and fungal pathogens (mainly Entomophthora aphidis Hoffmann, E. planchoniana Cornu, E. obscura Hall and Dunn) may play an important role as antagonists when weather conditions are suitable. It is the cumulative effect of the various antagonists that contributes to the suppression of cereal aphids. Furthermore, it is pointed out that weather cond-itions are favouring or limiting aphid populations directly and can become a basis for a "negative prognosis" in forecasting the population development of cereal aphids.

1 INTRODUCTION

For a long time aphids now and then occurred as pests of cereal crops and feed grasses in some European, African, and American countries (Börner, 1913; Kolbe, 1969; Mühle, 1941). The recent increase of corn-growing areas, the change of tillage methods, and the application of fertilizers and pesticides, especially herbicides and fungicides (Delorme and Fritz, 1978; Hintz and Schulz, 1969; Kolbe, 1969; Latteur, 1977; Potts, 1970; Zimmermann, 1976), greatly favoured outbreaks of aphids which are nowadays important pests of cereal crops both by sucking plant sap and occasionally transmitting viruses (Basedow, 1976; Dedryver et al., 1977; Huth, 1979; Kolbe, 1969; Latteur, 1972). Knowing these facts farmers are afraid of possible yield losses and tend to spray insecticides. To avoid superfluous or preventive plant protection measures one has to establish reasonable economic thresholds and methods to forecast population dynamics of cereal aphids. In this connexion it is essential to evaluate and consider the efficacy of predators, parasitoids, and fungal pathogens.

Since 1976, investigations on population dynamics of cereal aphids and the efficacy of their naturally occurring antagonists are carried out in winter wheat, an important cereal crop in the Rhine - Main area, to get data for the management of those pests. The experimental plots are located near Darmstadt within an isolated agricultural area of about 250 ha mostly surrounded by deciduous forest and at one side by a park-like suburban housing estate. Crop rotation includes winter wheat (cultivar "Pantus"), spring barley, winter barley, and sugar beet. The following report summarizes the results of counting in

the fields from 1976 to 1979 both of living and dead aphids be they parasitized or killed by fungal pathogens. These studies were done in plots not treated with insecticides; tillers were chosen at random.

2 ABUNDANCE OF CEREAL APHIDS

Metopolophium dirhodum (Walker) and Macrosiphum (Sitobion) avenae (F.) are by far the most important aphid species in winter wheat of the Rhine - Main area. Both species may immigrate into the fields in the beginning or middle of May (Fig. 1 b), but usually the first alatae of <u>M. avenae</u> appear about 2 weeks later than those of <u>M. dirhodum (Figs.</u> 1 a, d). As shown in Figs. 1 a - d, <u>M. dirhodum and M. avenae</u> normally reach their maximum population densities at plant growth stages 65 to 71 (scale of Zadoks et al., 1974), though <u>M. avenae</u> reaches its population maximum about 1 week later.

There is a positive correlation between the percentage of tillers infested by an aphid species and its population density as visible in Figs. 1 and 2. The break down of the two pest species is characterized by a quick decrease of numbers of aphids as well as of infested tillers. The final disappearance of cereal aphids is linked with the yellowing of leaves (M. dirhodum) and ears (M. avenae), with M. dirhodum usually being about 1 or 2 weeks earlier. Of course, natural antagonists and climatic conditions are not only limiting factors during population increase, but also contribute to a quick decline of aphids. The data presented in Figs. 1 and 2 disclose that in the Rhine - Main area M. dirhodum always gains more importance than M. avenae, a quite peculiar fact compared to the situation in other German regions and other European countries.

In the fields the counting results of which are presented here for 1976 to 1979, the mean number of aphids per tiller ranged from about 9 to 13 with <u>M. dirhodum</u> and from 1 to 6 with <u>M. avenae</u> at the time of highest population density. Even after adding up the number of all aphids per tiller



Fig. 1: Population development of Metopolophium dirhodum and Macrosiphum (Sitobion) avenae in 1976 (a), 1977 (b), 1978 (c), and 1979 (d).



there were only about 12 in 1976, 19 in 1977, 14 in 1978 and 1979. These numbers are far below the preliminary economic threshold of about 35 aphids per tiller at plant growth stage 65 calculated from studies on aphid caused yield losses (Bode, unpublished). Perhaps this fact is due to the farmer's strict avoidance of spraying insecticides in cereal crops. There is some evidence in this direction for in experimental plots in the same agricultural area the mean number of aphids rapidly decreased subsequent to insecticide treatments, but some weeks later reached densities exceeding those in untreated plots. Therefore, in additional experiments an insecticide was used known to be far more toxic to predators and parasitoids than to aphids. In this case a maximum number of aphids being about 10 times higher than that in check plots was counted (Bode, unpublished).

3 ANTAGONISTS

The above findings do underline the importance of natural antagonists. Experiments in field cages and in the laboratory by many authors provide good quantitative data on the efficacy of enemies. On the other hand, it is rather difficult to ascertain those findings under natural field conditions. Here, numbers of predators and the percentage of parasitized and diseased aphids are usually underestimated in counting procedures. Moreover, the overall efficacy of antagonists can only be assessed in special investigations.

3.1 PREDATURS

From the well known group of predators the Chrysopidae (mainly <u>Chrysopa carnea</u> Steph.) enter winter wheat at first at the end of April or in the beginning of May when aphids are still scarce. The number of eggs is the only reliable measure for <u>Chrysopa</u> density in the field because larvae and pupae, the latter appearing after the middle of June, are almost undetectable. There are two main egg laying periods: the first up to the middle of June, the second starting at the end of June. Both these periods are characterized by relative small numbers of aphids and infested tillers. The ratio of <u>Chrysopa</u> eggs and aphids ranges from about 1 : 10 in the beginning to 1 : 200 later on. During the period of rapid increase of aphid populations, this ratio is even worse with 1 : 500 to 1 : 3, 000. From greenhouse experiments we know that one needs at least 1 C. carnea-larva per 20 aphids for successful control. Considering these data one can only expect a rather slight impact of this predator against cereal aphids. The Coccinellidae (mainly <u>Coccinella septempunctata</u> L. and <u>Propylaea quatuordecimpunctata (L.)</u>) only contributed to the suppression of cereal aphids in winter wheat when during some weeks at the end of June 1976 lots of larvae and later of adults were found. The following year, adult coccinellids came into the fields in the middle of May. From then up to the end of May, they had an average density of about 3 to 5

beetles per m². In the middle of June the ratio eggs : aphids ranged from 1 : 20 to 1 : 40. When the aphids reproduced most quickly (plant growth stages 65 to 71), however, neither adults nor larvae were present. The first larvae hatched in the beginning of July. From then onwards, the ratio larva : aphids was about 1 : 100, increasing towards the final break down of the pests up to 1 : 4. At that time, larvae had not yet pupated and died or, mainly the edge dwelling specimens like in 1976, left for the adjacent sugar beet fields and the banks. Having contributed to the suppression of aphids rather well in 1976 and 1977. coccinellids were of no importance in 1978 and 1979. From all experience it is obvious that the only reliable and important predators over the years are the larvae of the hover fly <u>Epistrophe balteata</u> Deg. Contrary to the other predators they are also feeding during the period when aphids are building up their population maximum. The predator : prey ratio then ranges from 1 : 150 to about 1 : 300. Only during the hot and extremely dry summer of 1976 most of the young syrphid larvae died by hunger and drought and therefore were uneffective.

3.2 PARASITOIDS, FUNGAL PATHOGENS

Parasitoids are favoured in years with adequate weather conditions: weather must not be too hot or too cool, not too dry or too wet, or too stormy. All this happened in 1977 (Fig. 3 b). Then 8 % of <u>M. avenae</u>, but only 1 % of <u>M. dirhodum</u> were parasitized during the plant growth stages 65 to 71. <u>Aphidius uzbekistanicus</u> Luzhetzki, <u>A. ervi</u> Haliday, and <u>Praon volucre</u> (Haliday) were the most abundant parasitoids in the course of the 4 years investigations, followed by <u>Aphidius picipes</u> (Nees) and <u>Ephedrus plagiator</u> (Nees). Bearing in mind the above mentioned underestimation of antagonists in counting procedures, parasitoids may have a considerable influence during favourable years preferring the ear dwelling species <u>M. avenae</u>.

In years with long lasting periods of more than 90 % r.h. or many rainy days, fungal infections become important (Roberts and Campbell, 1977). 1978 (Fig. 3 c) was such a year when at plant growth stage 71 the considerable amount of 10 % of <u>M. dirhodum</u> was killed by <u>Entomophthora</u> species (<u>Entomophthora aphidis</u> Hoffmann, <u>E. planchoniana</u> Cornu, <u>E. obscura Hall</u> and Dunn). Fungi generally prefer this leaf dwelling aphid species the habitat of which is offering suitable climatic conditions.

Summarizing the role of natural antagonists in the area studied it is obvious that there is no key factor, be it a species or a group, which is able to regulate effectively cereal aphid populations. It is rather the cumulative impact of several factors contributing to population suppression.

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Fig. 3: Maximum and minimum temperatures (2 m above ground) and precipitation at Darmstadt in 1976 (a), 1977 (b), 1978 (c), and 1979 (d).

3.3 WEATHER

Besides biotic control factors attention must be drawn also to the direct antagonistic effect of weather conditions against aphids (Figs. 3 a - d). From my experience, weather is at least as important than all other antagonists. Cold and stormy weather and heavy rainfalls are severely influencing population development of aphids throughout the whole period of their occurrence in cereal crops. Especially when moving to the summer host and during early colonization weather conditions may influence population development. Suitable weather favours the increase of aphid populations thus necessitating regular surveys. Bad weather may retard infestation so that a threatening population increase is only possible after the plant growth stage 71 as it happened in 1979. Of course, bad weather may also impair population development after a fairly good initial infestation as in 1978. In the area of Darmstadt, all these events became especial-

ly effective with <u>M. avenae</u>. Though also being influenced by climatic conditions, <u>M. dirhodum</u> obviously does not suffer to the same extent as <u>M. avenae</u>.

In my opinion, weather is an important if not the most important factor we have to consider in a prognosis of population development of cereal aphids. It can become the basis for a "negative prognosis". For example, unfavourable weather at a given plant growth stage (e.g. 59 or 61) lasting for several days may influence population development in such a way that the economic threshold will not be achieved, and this the more so as the natural antagonists add to the limiting effect of weather.

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OVERWINTERING OF CEREAL APHIDS

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The aim of this work is to obtain more information about how and where the major cereal aphid species survive the winter.

Anholocyclic overwintering

Regular samples were taken after the cereal harvest in late summer until the following summer from fields of ryegrass and cereals (including maize) on two mixed arable-livestock farms in Hampshire, England. Samples were also taken from non-crop Gramineae in hedgerows and from grass weeds and volunteer cereals in other crops. During the 1977/78 and 1978/79 winters most samples were taken with the Dietrick vacuum insect net. In both 1978 and 1979 maize plants were examined in the field; counts were made of the numbers of the different cereal aphid species and feeding sites were recorded.

The prevalence of cereal aphids in two grass fields is illustrated in Figs. 1 and 2. In the three year old perennial ryegrass (<u>Lolium</u> <u>perenne</u>) field numbers (mainly <u>Rhopalosiphum</u> spp.) declined in late September as a result of emigration and grazing and remained at a relatively low level throughout October and early November (Fig. 1). Numbers then increased in the middle of November to reach a peak of c. $40/m^2$ in mid-December, and then declined in late December and early January. The decline in the population coincided with grazing by sheep (Fig. 1) and no cereal aphids were found in the field after early February.

On the first year perennial ryegrass field (ungrazed) numbers also increased in November and December, to a much higher level (c. $90/m^2$), and remained at a relatively high level until the middle of January (Fig. 2). The rapid decline in numbers in January and February coincided with periods of snow and low temperatures. The effect of this on <u>Rhopalosiphum padi</u> (L.) was more severe than on <u>Sitobion avenae</u> (F.); no <u>R. padi</u> were found in the field after the end of February, whereas <u>S. avenae</u> persisted until the spring.

Populations of <u>S</u>. <u>avenae</u> also persisted throughout the winter on autumn sown cereals, but numbers were usually lower than on ungrazed grass leys. No cereal aphids were found overwintering on hedgerow Gramineae in the 1977/78 winter.

Cereal aphids (mainly <u>R</u>. <u>padi</u>) were found in very high numbers on maize in autumn 1978 and 1979. Populations of c. $500/m^2$ were recorded in September 1978 and c. $400/m^2$ in October 1979 - approximately ten to twenty times the density normally found on grass leys at this time of the year. This host may act as an important bridge between the cereal harvest and the emergence of autumn sown cereals.

Holocyclic overwintering

Although relatively few <u>Metopolophium dirhodum</u> (<u>Walk</u>.) virginoparae appear to survive the winter on Gramineae, sexual morphs and eggs were found on wild rose (<u>Rosa</u> spp.) growing in hedgerows and woodland. Estimates of the density of <u>M</u>. <u>dirhodum</u> on rose have been obtained on a farm scale together with data on distribution, survival and host site preferences (in collaboration with C. Williams, Southampton University). In both 1977/78 and 1978/79 more <u>M. dirhodum</u> were found on rose in tall hedgerows than in short ones. In 1978/79 the most dense populations of <u>M. dirhodum</u> were found on rose growing in woodland.

Eggs of \underline{S} . avenue were found on grassland on one occasion, but no oviparae or fundatrices have been found in vacuum net samples.

The primary host of <u>R</u>. <u>padi</u> (<u>Prunus</u> <u>padus</u>) is not found naturally in the South of England. A large proportion of the <u>R</u>. <u>padi</u> found on Gramineae (including maize) in the autumn are sexual forms.

Both <u>Sitobion fragariae</u> (Walk.) and <u>Rhopalosiphum insertum</u> (Walk.) have been found on their primary hosts, but no quantitative studies have been done on these species.

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LOW TEMPERATURE MORTALITY OF CEREAL APHIDS

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 Winter mortality of Sitobion avenue and Metopolophium dirhodum in the field

The experiment, run between January and March 1979, was designed to provide quantitative data on the relative importance of rain, snow, high winds and sub-zero temperatures as mortality factors acting on <u>S. avenae</u> and <u>M. dirhodum</u> virginoparae overwintering on winter wheat. The aphids were exposed on winter wheat growing in pots in the field. The pots had a narrow, sticky barrier round their rims to exclude predators, and were sunk into the ground in a plot of winter wheat planted in early October. Similar batches of aphids were exposed one after the other and the mortality each experienced was related to the weather conditions during the period of exposure. Each batch was assessed after four days⁴ exposure and again four days later, and was then replaced by a fresh batch. The aphids used were cultured at $20^{\circ} \pm 12^{\circ}$ C and acclimated at 62° C for six days. Only medium-sized nymphs (1.1 - 2.2 mm) were used.

Results

1) Some of the aphids were always missing after exposure; presumably most of these were blown or washed off the plants. The great majority of the dead aphids found were on the plants with their stylets still inserted. It is difficult to see how these could have been killed by wind or rain, and most must have died as a result of low temperatures. This view is borne out by the clear relationship between the proportion of aphids found dead on the plants after a period of exposure and the minimum temperature experienced during that period. (Fig. 1).

- ii) The proportion of <u>M</u>. <u>dirhodum</u> dead or missing was significantly higher than that of <u>S</u>. <u>avenae</u> (P < 0.05) in all three of the four-day periods when the temperature dropped below $-7^{\circ}C$. In the one other period when there was a significant difference between the species more <u>S</u>. <u>avenae</u> than <u>M</u>. <u>dirhodum</u> were missing, but the reason for this difference is obscure as weather conditions were not extreme.
- iii) For both species multiple regression analyses of aphid mortality on parameters for the different weather factors show that when the mortality parameter used is "per cent dead or missing" the only weather parameter with a statistically significant partial regression coefficient (P<0.05) is minimum temperature. The dominant influence of temperature is shown in Fig. 2. When aphids found dead on the plants are excluded from the mortality parameter, temperature is, as expected, no longer significant, but the presence or absence of snow becomes so. Alternative parameters for wind and rain were tested but their partial regression coefficients were never significant.

Conclusions

Neither species succumbed to sub-zero termperatures unless the temperature fell below about -4° C. <u>M. dirhodum</u> was more susceptible to cold than <u>S. avenae</u>, but the difference was relatively small and was only apparent after severe frosts. In this experiment low temperatures and snowfall appear to be the most important weather factors causing

mortality of <u>S</u>. <u>avenae</u> and <u>M</u>. <u>dirhodum</u> virginoparae overwintering on winter wheat with wind and rain being relatively unimportant (at least at the levels experienced during this experiment). Further field work planned for 1979/80 includes experiments to assess the extent to which the effect of cold may have been over-estimated in this experiment due to the limited acclimation of the aphids used.

2. Low temperature mortality in the laboratory

The experiments were carried out to assess the relative coldhardiness of the three main cereal aphid species, <u>S. avenue</u>, <u>M. dirhodum</u> and <u>R. padi</u>, and to investigate some factors which might affect low temperature survival. The aphids used were cultured on winter wheat at $20 \pm 1\frac{1}{2}$ °C and 16 h. day-length. In most experiments they were exposed to sub-zero temperatures after removal from the host plant.

Results and Conclusions

i) When apterous adults were exposed in a cold chamber for 3 hours (Fig. 3) mortality of <u>R</u>. <u>padi</u> was much greater than that of <u>M</u>. <u>dirhodum</u> or <u>S</u>. <u>avenae</u> (P<0.001), but the LT50's of the latter two species do not differ significantly (P>0.6).

- ii) Testing apterous adults of <u>S</u>. <u>avenae</u> together with three different size categories of nymphs showed that small nymphs (1.3 mm) were significantly less cold-hardy than the other size categories (P<0.05).
- iii) Wetting <u>S</u>. <u>avenae</u> nymphs before testing so that they were exposed to sub-zero temperatures with ice crystals on the cuticle (as would occur in the field during a frost) significantly increased mortality over 'dry' controls ($P \le 0.01$).
- iv) <u>S. avenae and M. dirhodum</u> nymphs tested while feeding on summergrown winter wheat seedlings can survive even when the leaves on which they are feeding freeze. (No tests on winter-grown plants have yet been run).

More work is planned to investigate the effect of the host plant, time of exposure and of low temperature pre-treatment on mortality at sub-zero temperatures, and on differences between morphs, instars and clones of the three main cereal aphid species.

FIG. 1: The relationship between the proportion of <u>S.avenae</u> and <u>M.dirhodum</u> found dead on winter wheat seedlings after exposure to winter weather conditions for a 4-day period and the minimum temperature reached during each period.

<u>KEY</u> (FIGS. 1 and 2): $\bigcirc = \underline{S.avenae}$ mortality. $\triangle = \underline{M.dirhodum}$ mortality S \bigcirc and S \triangle = points representing 4-day periods during which snow fell. In FIG. 2 where mortalities of the 2 species differ at the 5% significance level in a particular period, the points concerned are joined by a broken line.



FIG. 2: The relationship between the proportion of <u>S.avenae</u> and <u>M.dirhodum</u> dead or missing after exposure to winter weather conditions for a 4-day period and the minimum temperature reached during each period.



FIG. 3: Mortalities of apterous <u>S.avenae</u>, <u>M.dirhodum</u> and <u>R.padi</u> adults tested for three hours at different sub-zero temperatures.

(Each point represents % mortality in a batch of 50 aphids. The mortalities have been corrected to take account of 'control' mortality. Smoothed curves are fitted by eye.)



STUDIES ON THE ECOLOGY AND CONTROL OF THE CEREAL APHIDS (HOM., APHIDIDAE) IN NORTHERN GERMANY

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I. Introduction

The agricultural importance of the cereal aphids has increased in the past years by reasons to be discussed below, which resulted in a widespread use of insecticides (Vicker-<u>man & Wratten</u> 1979). This makes it desirable, from the environmental point of view, to work out facts which lead the farmers to use insecticides as seldom as possible, just in economically inevitable cases. Some contributions which may help to reach this aim shall be communicated here.

My thanks are due to Miss U. Nottmeier for excellent technical assistance during the investigations, and for preparing the drawings.

II. Study area and methods of investigations

The investigations were run since 1976 in a wheat growing area northeast of Kiel (Federal Republic of Germany). A triangle-shaped area was chosen (fig. 1), which was limited on the northwest side by villages at the coast of the Baltic Sea, on the northeast side by a small river with narrow meadows on both banks. In the south, the triangle was limited by a street, only. The triangle covered an area of about 5 km^2 and was divided into about 70 fields, 4 to 10 ha each. The crops grown in this area were winter wheat, winter barley, winter rape and spring sown oats. Table 1 shows, that from 1976 to 1979 winter wheat and winter barley were equally dominant, while winter rape was covering a smaller percentage of the area, and that the importance of spring oats was declining during the respective years.

For investigations on cereal aphid ecology within the area described above it was regarded as necessary to sample fields of wheat and oats only, since the attack of winter barley is insignificant in Northern Germany (Basedow 1976).

<u>Population counts</u> were done weekly during the time the aphids infested the cereals, i.e., from the beginning of June to the beginning of August. Two samples were taken on each field, one near the edge (10 m into the field in 1976, 15 m in the following years), and one more to the centre of the field (50 m into the field in 1976, 65 m in the other years).

The sample size was 100 tillers, divides into subsamples of 5 tillers each, taken in 5 m distance from each other. Aphids and predators were counted in situ, except in oat fields in July 1976, when <u>Rhopalosiphum padi</u> was too numerous for this procedure. In this case a smaller sample of 50 tillers was cut and frozen at - 20° C. So the aphids could be counted later, according to <u>Strickland</u> (1954). The coccinellids, especially the adults, often were moving on the ground, not on the plants. In that case they were added to those tillers, to which the respective area 'belonged'. In order to make possible the calculation of the abundance of the aphids and their predators as numbers per m², the number of tillers per m² was measured once in July (10 x 0,1 m² per field).

One experiment for damage assessment was performed in 1979 in winter wheat on plots $(5 \times 5 \text{ m})$, with 4 replicates, insecticide sprays applied at 3 different dates. Aphids were counted in situ on 10 x 5 tillers per plot, weekly. Whole plots were harvested with a combined plot-harvester when the straw was dead. Grain was dried to 16 % water content before weighing.

Year	percentage of fields with					
	winter barley	winter wheat	winter rape	spring oats		
1976	32	29	20	20		
1977	29	29	22	20		
19 7 8	31	37	23	10		
1979	38	27	29	6		
ø	32,5	30,5	23,5	14,0		

<u>Table 1</u>: The relative importance of the different crops in the study area, 1976 - 1979


Fig. 1: The area of investigations at Brodersdorf/Laboe (near Kiel) in 1976. Built-up areas are chequered thinly, fields of spring oats are chequered with fat lines. Fields, whose marginal lines are incomplete, were not sampled. The place of the only individuum of <u>Prunus padus</u> L. found within the area in one of the typical hedges of Schleswig-Holstein (marked with an arrow)

III. Contributions to the ecology of Rhopalosiphum padi (L.)

During the study period (1976 bis 1979) <u>Rhopalosiphum padi</u> was of economic importance in 1976, only. This was probably due to the very hot and dry summer (e.g., the air temperature of July at Kiel averaged 18,6°C in 1976, that is 1,7°Cmore than normal). In 1977, <u>R. padi</u> was practically absent from the area, which was possibly a consequence of the very high pressure by predators in 1976 (see IV.). And the summers of both 1978 and 1979 were very cool, which may explain the low levels of infestation by <u>R. padi</u>. Additionally, as mentioned above, the area of spring oats had been declining. So most results concerning <u>R. padi</u> communicated here are basing on observations made in 1976.

1. Host plant preference

It has been reported previously already, that the distribution of the attack by R. padi is rather even in fields of spring oats, while in fields of winter wheat the infestation by R. padi is confined mostly to the edges of the field (Basedow 1976). This could be confirmed in 1976. Additionally the attack by R. padi proved to start prior to wheat fields in oat fields, and **also** to reach a higher level there (table 2; data beyond 28.6.1976 are not given, since several fields were sprayed with insecticides in the beginning of July). So it seems, that R. padi early in June first infests the oat fields and then spreads from these to the edges of winter wheat fields. This may be due to the fact, that migrant alatae of R. padi prefer fields with low plant spacing (A'Brook 1973): in June the crop density of spring sown oats is always lower than of winter wheat. Even in Juli there proved to be a difference: in the average of 1976 to 1978 there were stated 512 fertile tillers per m^2 of oat fields, and 572 fertile tillers per m^2 in fields of winter wheat.

Number of fields	crop	Distance	aphids/100 tillers			
		field edge	21.6.76	28.6.76		
12	spring oats	10 m	565	3.932		
		50 m	655	4.166		
16	winter wheat	10	7	303		
		50 m	3,4	213		

<u>Table 2</u>: The infestation of spring oats and of winter wheat by <u>Rhopalosiphum padi</u>, Brodersdorf-Laboe (Schleswig-Holstein), June 1976

2. Dispersal from the winter host

The oat fields of 1976, marked in fig.1, were unevenly distributed over the area of investigation. When the degree of infestation of the single field by R. padi was compared - each variety regarded separately -, it was conspiceous, that the fields in the marginal zones of the area were least attacked. No winter host (Prunus padus L.) had been found so far, but in 1977 searching was intensified, and one single winter host could be found rather central in the area (fig. 1). Now the aphid density on the oat fields was plotted against the distance from the winter host, and a relationship could be seen: the greater the distance from the winter host, the lower was the infestation level (fig. 2). This relationship was very clear for the susceptible variety 'Leanda', but at least this was true for all varieties, that the fields 300 m distant from the winter host showed the lowest attack. The different susceptibility of the oat varieties will be referred to elsewhere.



Fig. 2: The degree of infestation by <u>Rhopalosiphum padi</u> of fields with different varieties of spring oats, 21.6.1976, in relation to the distance from the winter host plant. Brodersdorf/Laboe, Schleswig-Holstein (Federal Republic of Germany). Figures are given for every point, since the ordinate has logarithmic scale. The data of fig. 2 indicate, that in Northern Germany populations of <u>R. padi</u> undergo a holocyclic overwintering, i.e., that they are indigenous populations. Subsequently, in 1978 and 1979, Fundatrigeniae of <u>R. padi</u> could be found on <u>Prunus</u> padus in early June, as well as Oviparae in August/September. The significance of these results for agricultural practice will be dealt with at the end of this paper.

IV. <u>Some aspects of the population dynamics of Coccinella</u> septempunctata L.

Among the aphidophagous Coccinellids, C. septempunctata is the most common species in Northern Europe (Clayhills & Markkula 1974). The preferred sites of its reproduction in early summer seem to be cereal fields (Heathcote 1978). For the postdiapause ovariole maturation aphids are an essential food (Bonnemaison 1964, Honek 1978). During the present study it could be stated, that aphid density on cereal fields in the end of June was decisive for the success of reproduction of C. septempunctata. Table 3 shows, that the more aphids were available for each individual adult in June, the higher was the reproduction rate. For 1978 two figures are given for population density of Coccinellids and aphids in June, one for mid of June and one for the end of June. In contrast to two previous years, in 1978 the adults of C. septempunctata immigrated hesitatingly into the area. So more aphids per Coccinella adult were available for those arriving first, than for the late majority. The reproduction rate of 1978 was calculated for the maximum population in the end of June.

No figures were obtained in 1979, since in July, 1978, most Coccinellid larvae died from starvation, so that adults were very scarce in 1979.

The dependence of the reproductional success of <u>C. septem-</u> <u>punctata</u> on the number of aphids available during its maturation phase has the effect, that the increase of the population density of <u>C. septempunctata</u> is slower than that of the aphids. This is clearly to be seen from fig. 3 for 1976. This rather late appearance of the very voracious late larval

74

Table 3: Maturation of Coccinella septempunctata adults:

Influence of predator/prey ratio on reproduction rate (fields of spring oats and winter wheat, Bordersdorf/Laboe, Schleswig-Holstein)

Year	<u>Specimes per</u> <u>C. septempunctata</u> (adults)	m ² (June) cereal aphids (3 species)	aphids per ladybird	C. septempunctata maximum of larvae/m ² , July)	<u>C. sept</u> adults (June)	emp :	unctata larvae (July)
1976	0,3	1680	5600	23,5	1		78,3
1977	3,9	560	144	2,9	1	:	0,7
1978	0,6 to 5,7	161 to 852	268 to 149	44,0	1	:	7,7

75



Fig. 3: The increase of population density of cereal aphids and of <u>Coccinella septempunctata</u> on cereal fields, Brodersdorf/Laboe (Schleswig-Holstein), 1976.

stages is thought to have no more economic effect, since damage to the cereal plant will be done already at that time (<u>Dean</u> 1974, <u>Lutze</u> 1977). But aphid populations have been shown to decline by the influence of C. septempunctata (<u>Barbalescu</u> 1977). This will be discussed further below.

V. <u>Studies on the chemical control of cereal aphids in win-</u> ter wheat

There are two facts, which have induced European farmers in extensive wheat growing areas to spray insecticides for the control of cereal aphids early in the season, i.e. in the stage of heading or flowering of wheat:

- It has been published, that a very early control of cereal aphids may result in an high increase of yield (Wetzel et al. 1975, George 1976, Hinz & Daebeler 1976a).
- 2. In most European extensive wheat growing areas it is a common farm practice now since a few years, to spray fungicides at the heading stage against several fungal diseases of wheat. So it is near at hand to add an insecticides to this treatment without having application costs.

These chemical measures, applied to increase yield, are accompanied by an increase of nitrogen supply, in the form of extra nitrogen dressing at heading. It has been shown, that an increased nitrogen supply favours the cereal aphids (<u>Hinz & Daebeler</u> 1976b, <u>Hanisch & Gräpel</u> 1979) and that it postpones the maximum aphid density (<u>Vereijken</u> 1979). It is likely, that the latter effect may change the present strategy of cereal aphid control.

For the control of cereal aphids, German wheat growers up to now mostly have used the broad spectrum insecticide parathion-ethyl, because it is the cheapest one. In 1978 14 unsprayed fields of winter wheat could be compared with 3 fields, that had been sprayed with parathion at flowering. Fig. 4 shows, that a re-colonization of sprayed fields by <u>Macrosiphum avenae</u> (F.) happened within 4 weeks, so that at the stage of milky ripeness sprayed and unsprayed fields were attacked equally.



Fig. 4: The infestation of winter wheat fields, unsprayed and sprayed with Parathion-ethyl at flowering (125 g a.i./ha), by <u>Macrosiphum avenae</u>. Brodersdorf/Laboe (Schleswig-Holstein), 1978.

Now, bearing in mind, that in the stage of milky ripeness of winter wheat

- predators may be important in reducing aphid numbers, and - early sprays of insecticides may have lost their efficiancy, it is important to know, whether the cereal aphids still cause yield losses during milky ripeness, under the modern growing conditions.

Table 4 shows the results of a first experiment on this topic, performed in 1979. Within the study area, at Brodersdorf, a 10 ha field of winter wheat 'Topfit' was chosen. It had received an amount of 255 kg/ha N, the last dressing (78 kg/ha N) at heading, 15.6.1979. The whole field had been sprayed with the following fungicides: 1. Thiophanate-methyl, 350 g a.i./ha (23.5.1979), 2. Triadimefon, 125 g a.i./ha (1.6.1979) and 3. Captafol, 1000 g a.i./ha, plus Halacrinate, 500 g a. i./ha (1.7.1979).

Plots of 5 < 5 m were sprayed with insecticides at different growth stages (table 4). The effect of these sprays on <u>Macro-</u> <u>siphum avenae</u> proved to be good, while control of a late infestation <u>stopelophium dirhodum</u> was poor in the case of the early sprays. Spraying insecticide at full flowering produced the gratest increase of yield (14,3 dt/ha), but surprisingly maying at milky ripeness still seemed to produce two thirds (9,6 dt/ha) of the greatest increase of yield (the difference was not statistically significant). Table 4: The effect of Macrosiphum avenae and of Metopolophium dirhodum on the yield of winter wheat 'Topfit' at different growth stages. Brodersdorf (Schleswig-Holstein), 1979. No other pests of wheat than aphids where observed on the plots.

Treatment	Maximun	of aphids				
	per head (<u>M. avenae</u>)	per flag leaf (<u>M. dirhodum</u>)	yield (dt/ha)*	Increase of yield (dt/ha)	1000 grain weight (g)*	
Untreated	22	17	68,0 a	-	39,5 a	
Oxydemeton-methyl (200 g a.i./ha) at beginning of flowe- ring (27.6.1979)	1	12	80,2 b	+ 12,2	45 , 3 b	
Oxydemeton-methyl (200 g a.i./ha) at full flowering (4.7.1979)	0,2	12	82,3 b	+ 14.3	44,5 Ъс	
Parathion-ethyl (175 g a.i./ha) at milkey ripeness (27.7.1979)	22	17	77,6 ъ	+ 9,6	42,0 c	

* Differences between figures followed by the same letter are not significant at the level of p = 0,05

VI. Discussion

The results obtained may help to reduce the present amount of insecticides sprayed to control the cereal aphids.

1. Rhopalosiphum padi

This species should be looked for in oat fields first. Even if these are heavily infested and it seems necessary to spray them with insecticides (as in 1976 in the area of investigations described), an insecticidal control of <u>R. padi</u> on fields of winter wheat will be necessary on their marginal zones, only.

2. Macrosiphum avenae and Metopolophium dirhodum

In further years it will have to be examined, whether the trends observed in 1979 will replicate, especially whether the damage done to wheat by <u>M. avenae</u> occurs rather lately. In any case, wheat growers should not add an insecticide, if they ware spraying fungicides to winter wheat at the heading stage. At this stage, in most years, it will be impossible to decide, whether it will pay to spray an insecticide. The decision, whether or not to spray, may well be put off until the end of flowering/watery ripeness.

This later decision - without bearing the risk of yield losses - has several advantages. At this time (beginning of July) it will be mostly possible to predict roughly whether a noxious population of aphids will build up (e.g., <u>Rautapää</u> 1976), and whether antagonist populations will be important in controlling the aphids (Lutze 1977). Additionally, as to be seen from table 4, in 1979 an early of Oxydemeton-methyl did not prevent the late infestation by <u>Metopolophium dirhodum</u>. A later spraying is likely to have done it and so to have increased the yield even more.

It is to be added here, that cereal fields should not be sprayed with insecticides, if infestations by aphids are heavy already: this bears the risk of doing damage to bees feeding on honeydew, a fact, which is discussed by <u>Benas</u> (1976).

Summary

VI. TLECHSELS

Studies were run from 1976 to 1979 in a wheat growing area northeast of Kiel (Schleswig-Holstein, Federal Republic of Germany). Fields of winter wheat and of spring oats were sampled weekly in summer within an area of ca. 5 km² at the coast of the Baltic Sea.

The bird-cherry-oat-aphid, <u>Rhopalosiphum padi</u> L., in early June first infested fields of spring oats. Apparently infestation extended from these to the edges of winter wheat fields.

Within the study area, <u>Rhopalosiphum padi</u> undergoes an holocyclic overwintering. Fields of spring oats near to a winter host (<u>Prunus padus</u> L.) proved to be infested more heavily than those being more distant.

The effectiveness of <u>Coccinella septempunctata</u> L. in controlling cereal aphids depended on the numbers of aphid available to each adult during the maturation phase in June. The Coccinellid larvae were effective predators of cereal aphids mostly not prior to the stage of milky ripeness of wheat.

wheat. Fields of winter wheat, sprayed with Parathion-ethyl at flowering, to control <u>Macrosiphum avenae</u> (F.), were soon re-colonized. Also, an early spray of Oxydemeton-methyl though being effective against <u>Macrosiphum avenae</u> longer than Parathion - did not prevent a late infestation by <u>Metopolophium dirhodum</u> (Wlk.)

In 1979, the heaviest damage done by the cereal aphids to wheat occurred during the stage of milky ripeness. The decision, whether or not to control the cereal aphids, should therefore be taken not prior to the end of flowering/watery ripeness of wheat.

For the insecticidal control of Rhopalosiphum padi on wheat, marginal spraying are mostly sufficient.

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THE ROLE OF POLYPHAGOUS PREDATORS IN LIMITING THE INCREASE OF CEREAL APHIDS IN WINTER WHEAT

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INTRODUCTION

Natural enemies of cereal aphids include pathogenic fungi, parasites, and predators. The predators may conveniently be divided into stenophagous or aphid-specific species (Coccinellidae and Syrphidae) and polyphagous species (Carabidae, Staphylinidae, Dermaptera, Avaneae, Acari). Of the latter, the Dermaptera and many of the Carabidae are known to feed on cereal aphids (Sunderland 1975; Vickerman and Sunderland 1975; Potts 1977). This paper describes field experiments designed to measure the effect that polyphagous predators (as a group) can have on populations of cereal aphids in winter wheat. The experiments were done in 1978 and 1979 at North Farm, West Sussex and at Rothamsted. The results for 1978 are reported in detail by Edwards, Sunderland and George (1979).

METHODS

Barriers, pitfall traps and insecticide applications were used to manipulate predator density and the aphid populations associated with each treatment were measured by counts on the plant and by sampling with a vacuum insect net (D. Vac.) in each plot.

In March 1978 three square plots of 100 m^2 were laid out at 15 m from the edge of the field. Around two of these plots a 60 cm high polyethylene barrier was erected; it was supported by wooden posts and inserted into the soil to a depth of 15 cm. Thirty-six plastic beakers (7 cm maximum diameter and 9 cm deep) were buried to soil level within the plots to act as pitfall traps. Predator populations were depleted by capture in these traps. In one of the enclosed plots predator populations were further depleted by contact with an insecticide (2 kg ha⁻¹ fonofos) applied to the soil when the barrier was put up. The third plot was an unenclosed control. Identical sets of plots were established in April and May (giving a total of nine plots).

In 1979 the experiment was repeated but with the addition of an enclosed control (at North Farm and Rothamsted) and a plot surrounded by a horizontal barrier which allowed ingress but not egress of arthropods (at North Farm only). Five plots were established in April and five in May.

Pitfall trap catches were used to assess the abundance of Carabidae in 1978 and of all polyphagous predators in 1979.

RESULTS

The abundance of polyphagous predators varied between treatments and increased in the order (i) fonofos plus barrier plus pitfalls (ii) barrier plus pitfalls (iii) enclosed control (iv) unenclosed control (v) ingress only. This sequence applied to all predator groups with the exception of Dermaptera (Table 1). Thus the techniques used here provided a range of levels of predator abundance with which to relate aphid density.

In 1978 at North Farm there were significant negative correlations between carabid numbers and aphid numbers, a two-fold decrease in aphids being associated with an approximately ten-fold increase in carabids (Fig. 1). A similar, but weaker relationship was obtained at Rothamsted. It should be noted that carabid numbers were positively correlated with total predator numbers (Table 1) and so carabids are not necessarily the only functionally important predators in this relationship. At North Farm there were also positive relationships between aphids and aphid-specific predators (Fig. 2) and between aphids and aphid parasites (Fig. 3). This, together with the virtual absence of the pathogenic fungus, <u>Entomophthora</u> spp., indicated that the differences in aphid density between plots were caused by polyphagous predators rather than by other natural enemies.

In 1978 aphid densities were very low (maximum 800 m^{-2}) and were mainly <u>Sitobion avenae</u> (F.) on the ears whereas in 1979 densities were high (maximum 4700 m^{-2}) and were mainly <u>Metopolophium dirhodum</u> (Wlk.) on the leaves. In 1979 at North Farm there was no significant relationship between aphids and polyphagous predators but at Rothamsted in plots with depleted predator populations aphids were 2-4 times more numerous than in control plots (Fig. 4).

CONCLUSION

The experiment at North Farm in 1978 established that a significant decrease in aphid density resulted from an increase in the abundance of polyphagous predators. In three out of four experiments an inverse relationship between numbers of predators and aphids has been found in spite of differences in the year and geographical location of the experiment and differences in the density and dominant species of aphid. Our results agree well with those of de Clercq (1979) who reported double the numbers of cereal aphids in plots with reduced soil fauna during experiments carried out in winter wheat in Belgium in 1977 and 1978.

These experiments demonstrate the value of polyphagous predators in reducing populations of cereal aphids and future work will be directed towards (i) determining the relative importance of the different groups of polyphagous predators and (ii) finding ways to encourage populations of these beneficial arthropods in cereal crops.

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TABLE 1. Number of polyphagous predators caught in pitfall traps in 1978
(15/3-15/8, mean of three replicates) and in 1979 (26/4-7/8,
mean of two replicates)

	Fonofos & barrier & pitfalls	Barri e r & pitfalls	Enclosed control	Unenclosed control	Ingress only
1978					
Carabidae	465	1384	-	6939	-
1979					
Araneae	235	563	931	1452	1743
Carabidae	55	116	231	416	1065
Staphylinidae	35	60	82	80	115
Coleoptera larvae	4	49	74	102	102
Acari	1	27	31	58	74
Dermaptera	5	15	22	11	6
Total polyphagous predators	335	830	1371	2119	3106



Fig.1. Relationship between number of aphids and number of carabids, North Farm 1978.



Fig.2. Relationship between aphids and aphid-specific predators, North Farm 1978



Fig.3. Relationship between aphids and aphid parasites, North Farm 1978



Fig.4. The aphid populations resulting from four different treatments at Rothamsted, 1979.



SIMULATION MODELS OF THE POPULATION DEVELOPMENT OF SITOBION AVENAE

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Abstract

Two models simulating the population development of <u>Sitobion avenae</u> are described. The output results from the models are compared with field observations from the Netherlands and England over a number of years. The agreement between the models and the field results is not always good but in several years the date and size of the peak density is accurately predicted. This indicates that most of the important processes are included in the model, but certain parts of the system are not fully understood. Sensitivity analysis shows that immigration and wing induction of the aphids on the crop are important processes acting on the population build-up and crash respectively. The models are reliable enough to be used for short term predictions.

Description

Two models simulating the population development of <u>Sitobion avenae</u> exist; one developed in England and written in FORTRAN IV (Carter, 1978; Carter et. al., in prep.), the other in the Netherlands and written in CSMP III (Rabbinge et. al., 1979). The initial inputs for the two models are similar. They include the initial

The initial inputs for the two models are similar. They include the initial number of aphids, determined either from suction trap catches or from field counts respectively, the latitude of the site (this is used in the calculations of daylength), the initial crop development stage (metric scale), the natural enemy data, which is either the number of coccinellids and the percentage parasitism and disease or the number of syrphids respectively, and daily maximum and minimum temperatures.

Both models simulate population growth only on cereals. Temperature and crop development stage are the major driving variables. Temperature is calculated for each step using a sine curve passing through the minimum temperature at sunrise and the maximum temperature at 14.00. The step lengths of the two models are short, one hour for the English model and approximately 15 minutes for the Dutch one. These short steps are dictated by the rapid development of the aphids at optimum temperatures. Immigration into the cereal crops depends on the size of the aerial popu-lation, whose origin is unknown. The settling behaviour of these alate aphids has not been studied but it probably depends on the crop development stage and the aphid density. In the English model it is assumed that the suction trap catches are an accurate representation of the aerial population and can be used to initialise the model. The trap catches are multiplied by two factors: the first can be called the Taylor-Palmer coefficient (Taylor and Palmer, 1972). In the model it is 64, ie. for each aphid caught in the trap 64 settle per million tillers. This assumes a flight duration of two hours, a density-height profile of -1.0 and one and a half million tillers per acre (or ca. four and a half million tillers per hectare). The second factor, the concentration factor, is the increase in the number found in the crop to what is expected from the calculations of Taylor and Palmer. This factor is set at 40 and appears constant from year to year. Development and survival is based on the data from Dean's work using barley



leaf discs (Dean, 1974), although this is supplemented in the Dutch model by measurement on whole plants (Ankersmit, unpubl.). More experimental data on these processes are however needed. Development is dependent solely on temperature while survival depends on temperature and crop development stage (see Watt, 1979). In the Dutch model development is handled in a more complicated way; instead of using the mean values for development it uses an associated standard deviation to mimic dispersion. The data for reproduction come from Dean's work (English model) or from Ankersmit (unpub.) (for the Dutch model). In the English model it depends, not only on temperature but also on crop development stage and this latter factor has now also been incorporated into the Dutch one. Much of the information for this comes from Watt (1979). Crop condition is however not included. Morph determination in the English model occurs at birth and is controlled by a multiple regression equation dependent on crop development stage and aphid density. This equation has been calculated directly from field data and this aspect of the system is in need of further experimentation. A similar approach is used in the Dutch model. After the algoiform nymphs have moulted to the adult stage they emigrate immediately without making any reproductive contribution. The natural energies are treated in a simple way. In the English model actual field observations are used in the model, while in the Dutch one predation by syrphids is calculated using a simple functional response curve. The numerical response of the syrphids is handled in a simplified way too, assuming an aphid density dependent reproduction rate. The role of natural enemies in controlling aphid population growth is still a controversial subject and will remain so until detailed quantitative experiments are carried out. Crop development is carried out by integration of development rate over time dependent on temperature. Output from both models is daily (although this can easily be changed to give more or less frequent output) providing information on the number of aphids (morphs and instars), the number of natural enemies or the num-ber of aphids killed, and crop development stage. These results can be compared directly with field results to validate the models or can be used to provide information which is not measureable in the field. Obviously this latter process can only be used if the model has been shown to be reliable and accurate.

Validation

The simplest way to validate a model is to compare output with <u>independent</u> field observations. This has been done with the two cereal aphid models. Both were compared with the results from field observations in England (1977 and 1978) and the Netherlands (1979). The Dutch model is also compared with Dutch field results from 1975 and 1976 and the English model with English field results from 1976.

As the English model uses suction trap catches to initialise it this section of the model has to be validated in detail. This was done by comparing the alate numbers in the model with those in the field (U.K. 1977). The fit is reasonable, with the model predicting the correct number of alates early in the season. Later in the season many of the alates are produced on the crop, thus the model will underestimate this level. This is only important if these alates remain and make a major contribution to reproduction. Both models underestimate the field results from the Netherlands (1979) by an order of magnitude (fig. 1a). Problems were encountered with the crop development sub-model in both models as the crop ripened much quicker than in the field. The sub-model has been changed in the English version but not in the Dutch one at present. This is reflected in the early decline in the Dutch model. This also occurs with the results from England in 1978 (fig. 1b). The Dutch model gives an accurate prediction of the observed results at the beginning of the season (unlike the English model which overestimates the population development) but declines early as the crop, in the model, ripens too quickly. The English model simulates reasonably well the shape of the curve of the observed results. Validation of the models using the field results from England in 1977 presents a further problem. The English model gives a reasonable fit to the data but the Dutch model underestimates the population growth. (fig. 1c). This is due to the lengthy continuous immigration period in this year, which is not taken into account in this simulation. In other years, when this is taken into account, the Dutch model gives better predictions eg. in the Netherlands 1975 (fig. 1d), 1976 (fig. 1e), while the English model gives a reasonable fit to the English data from 1976 (fig. 1f). This indicates that although our knowledge of the system is not complete we do know enough to gain insight by using the models.

Sensitivity Analysis

Sensitivity analysis can only be carried out with models which have been validated, otherwise the conclusions are not very meaningful. It can be done in two ways; by making small changes (the size of which is dictated by the standard deviation of the observed results) to initial conditions, rates, variables and parameters (fine sensitivity analysis) or by omitting processes from the system (coarse sensitivity analysis). Sensitivity analysis determines the importance of processes in the system so that research can be concentrated on the main ones. By increasing and decreasing values the symmetry of the response can be evaluated - if the response is asymmetrical then that variable has a complicated effect in the system. Firstly the effect of dispersion of development in the Dutch model was evaluated. This was done by running the model with and without it. The effect of removing the process is insignificant and this is explained by the small standard deviations associated with the development rates. It is therefore not necessary to include dispersion in the English model. The rest of the sensitivity analysis concentrates on the English model using the 1977 English field results (as this combination gives a good fit). There were very few predators and parasitoids in this year so the system is basically a host plant-aphid one. Attention is centred on the role of alates in the population build-up and collapse. Carter et. al. (in prep.) and Rabbinge et. al. (1979) discuss the results of sensitivity analysis on other processes, such as reproduction, survival and development. The sensitivity of the system to small changes in immigration was tested by altering the number of immigrating alates by +/- 20%. Next the initial crop development stage was changed by +/-2.0. This studies the effect of the timing of immigration in relation to the crop development stage. It is important to know how sensitive the system is to these changes as all the crops in an area will not be synchronous. The other important process concerning alates is the determination of the alatiform: apteriform ratio. This was tested in two ways; by altering the proportion of alatiform nymphs by +/- 20% and by removing the process (wing induction) from the system. It must be remembered however that there are no intra-specific competition effects in the model at present. If these were present then the effect of removing the alatiform section of the model would be smaller.

Altering the number of immigrants and the proportion of alatiform nymphs has much the same effect (fig. 2a, b). The timing and size of the peak density is affected. By decreasing immigration or the proportion of alatiform nymphs the data of the peak is delayed by over one week. This is



97 ह-

probably because in the original simulation the data of the peak is not very distinct. The aphids maintain a constant density for over one week. Increasing immigration or the proportion of alatiform nymphs does not alter the data of the peak. The peak density is changed by +/- 15%for a 20% change in immigration but the response to changes in the proportion of alatiform nymphs is asymmetrical. Decreasing the proportion increases the peak by 15% but increasing the proportion leads to a reduction of only 5%. This is because a proportion of 1.0 in the original model remains at 1.0 in the sensitivity analysis, ie. a proportion of 1.2 would lead to an artificial increase in reproduction. Altering the initial crop development stage changes the size of the peak density and its timing (fig. 2c). With the latter the response is complicated as both changes lead to a delay in the peak density. This is due to the dependence of alatiform determination on aphid density and crop development stage, and the effect of the latter on other processes in aphid biology, ie. reproduction and survival. The peak densities occur at different crop development stages. The peak density is altered asymmetrically, a lower initial development stage increases the peak density by 45% while a higher initial stage reduces the peak by 23%. Removing alate determination from the system has a very dramatic effect. The peak density is increased by more than five times and its timing is delayed by over one week (fig. 2d). Thus this is very important in determining the decline of the population.

Discussion

The models do not always give a good fit to data from a number of different places in different years. This is because several parts of the system are in need of further study, ie. aphid biology on wheat, the role of natural enemies and the effect of crop development. Simulation models are not an end in themselves but only a means to an end; and we believe the only means for a thorough aphid study. The models have already helped with experimental work. The English model has demonstrated the usefulness of the suction traps in determining the timing and size of immigration. The models a'so indicate the importance of alate determination in the decline of the aphid populations. This process can only be studied in the field by counting the number of apteriform and alatiform fourth instar aphids. It is unreliable to use counts of adult alates to measure this process as it appears that the alates leave the crop soon after moulting. As our knowledge of the system improves so the predictive value and usefulness of the models will increase. Simulation models are not a replacement of field and laboratory studies but they do help to pinpoint areas where attention should be centred. The models are reliable enough to be used for short term prediction purposes.

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EPIDEMICS AND DAMAGE EFFECTS OF CEREAL APHIDS IN THE NETHERLANDS.

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Abstract

During the last decade considerable efforts have been undertaken to study the population dynamics of cereal aphids and their damage effects. Explanatory simulation models of the population upsurge were developed which are used in simplified form in management schemes. Advice is supplied on a field by field basis making use of real time forecasts. Damage thresholds are nowadays based on the direct relations between peak density of the aphids and yield loss. The reliability of these relations for damage assessments is low and this may be due to the nature of the damage. Investigations of this damage show the relative importance of secondary aphid effects due to honeydew which promotes leaf senescence. Monitoring of the aphids is done by making use of simplified sampling and observation procedures, in which only the infestation of the tillers is determined. From this estimate average number of aphids per tiller around flowering is determined and introduced in the predictive simulation models.

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Introduction

The increasing importance of pests and diseases as limiting factors for reaching the potential yield levels of wheat has given rise to an increased spraying activity in many commercial fields. Reasons for the increased importance of maturation diseases and aphids during the last decade may be the lengthened kernel filling period and the increased nitrogen level in the plant during this period, due to a top dressing of nitrogen around flowering. The EPIPRE project, discussed shortly in this presentation was started to prevent the increasing tendency of preventive spraying. Briefly, EPIPRE aims at flexible crop protection, based on detailed knowledge of crop growth and prevailing pests and diseases. By integration of this knowledge in large computers, dynamic decision rules have been developed which are used in the field to spray only when it is really necessary, i.e. when the yield gains will at least cancel out the costs of biocide application. This flexible response limits biocide use but requires highly developed knowledge of intensive plant protection systems. These might limit the rigid, low knowledge systems in which biocides are applied according to fixed schedules. At present, field experiments and dynamic crop pest and disease simulation models are being used to develop dynamic threshold levels. These levels will, in the course of time, be combined with a system of monitoring and forecasting of aphid populations to develop a reliable warning and pest control system. Within the system, advice is given on a field basis and concerns stripe rust, Puccinia striiformis, powdery mildew, Erysiphe graminis and cereal aphids, especially the English grain aphid Sitobion avenae. The core of the system is a computer bank and an associated administrative office. The data bank contains specific data on each field including location, sowing time, cultivar, some soil characteristics and herbicide application, and nitrogen fertilization. Also included are reports from the farmers themselves on the occurrence of pests and diseases. The information is stored in the computer and updated whenever additional information on the field is supplied by the farmer or the research team. This information is sent to the administrative office on preprinted postcards. Decision rules for each disease or pest based on simplified pest control algorithms using current weather data as an input generate recommendations which are sent to the farmer. A copy of the field observations and the recommendations is also sent to the extension service so that they can update their written general warnings. The weather data are updated daily. When necessary the decision rules are adjusted. The farmers perform the field observations themselves, since EPIPRE aims at a user oriented approach that supplies recommendations when farmers send new information. Farmers receive training to recognise symptoms and get clear instructions for sampling their fields. In addition, farmers receive a set of slides with disease and pest symptoms, together with a viewer which can be used in the field. Furthermore the farmers are asked to send plant leaves with early symptoms of diseases or pests to the central office in preprinted envelopes. The way of sampling and monitoring aphids will now be described in some detail.

Monitoring and sampling aphids

Continuous monitoring of aphids is a very time consuming procedure and methods which may reduce sampling and monitoring acitivities were urgently needed. Population models which simulate the population curve of the aphids from immigration until the flattening of the curve may help in this. Detailed population models (Rabbinge et. al., 1979, Carter et. al., in prep.) explain the upsurge of the population and the period of flattening, but are still inadequate in explaining the collapse of the population. Based on a sensitivity analysis of these explanatory models decision models were developed which are used to produce short term predictions. Proper validation techniques have shown the reliability of the models for this job. Thus knowledge of the population densities around flowering suffice to start the simulation model and to predict the population upsurge when additional information on immigration is supplied. To assess the initial population densities and the size of immigration, Carter and Dewar, (in press), describe how suction trap catches may be used to determine the size and timing of immigration. These findings are at present being compared with the number of aphids collected in the field using an insect suction sampler. When this immigration has begun, farmers are advised to inspect their fields for aphids. The aphid assessments may be used to update the decision models of EPIPRE and enable prediction of the course of the aphid population in time. Advice whether spraying is needed is based on the expected population peak and the still unreliable corresponding damage predictions (see later). Estimates of population densities should be made using simple but reliable methods that are not labour intensive. To derive such methods, the distribution of the aphids in the field was considered. In 200 out of 225 cases the distribution of the aphids fits a negative binomial distribution, with k-values ranging from 0.5 to 2. When average numbers are lower than 0.3 per tiller determination of the distribution in the field requires more than 1,000 tillers to be searched, as the colonies are then scattered. Very rarely a Poisson distribution gives a better fit (20 out of 225 cases). Tests were made of the relation of the probit value of the infestation level and the logarithm of the average number of aphids per tiller for <u>S</u>. avenae, <u>Metopolophium dirhodum</u> and <u>Rhopalosiphum padi</u> and combinations of these species. Figure I.a. shows the relation between the average number of <u>M</u>. <u>dirhodum per tiller</u> and the percentage infected tillers, Figure 1.b. shows the relation between the average number of M.dirhodum, S.avenae and R.padi per tiller and the percentage infected tillers and Figure 1.c. shows the average number of S.avenae and R.padi per ear and the percentage infected ears.

In all cases the mentioned linear relationship exists (correlation coefficients in all cases > 0.92 number of cases > 225). The regression coefficient is scarcely different for all three cases (1.4, 1.51 and 1.54 respectively), so that it seems possible to use the same regression line for all cases. The presence of these linear relationships allow the use of a simple sampling method. The infestation level is determined and this gives the average number of aphids per tiller which is used to initialise the decision models. The procedure used in EPIPRE is now as follows. At flowering farmers are asked to determine the infestation level of aphids by inspecting 100 tillers taken at random over a diagonal of a field. When infestation levels are lower than 70% farmers may delay any action against aphids for two to three weeks. At infestation levels higher than 70% the damage threshold will definitely be exceeded (350 kg of wheat/ha), and farmers are advised to spray. However it should be realised that one determination of the percentage may give an under or overestimation of the population density. Therefore repetition of the monitoring is necessary. The timing of the second observation by the farmers depends on computer calculations with simplified simulation models. This period may vary from 10 days to 20 days after flowering. For the second observation, farmers are asked to determine the proportion of tillers with over ten aphids. These proportions, again after transformation, are linearly related to the average density per tiller. They provide supplementary information on the number of colonies and the potential for emigration, since population density is, as indicated by the models, one of the most decisive factors inducing wing formation. All field observations are entered on the preprinted cards and are sent to the forecasting team who recom mends whether to spray or not. The weakest point in the scheme is the determination of the damage threshold and at present is more or less guesswork. Additional research of the type discussed below is needed to improve this situation.

Damage effects of cereal aphids and damage thresholds

Yield losses of wheat due to aphids have varied considerably during the last decade, but have often exceeded 1000 kg of wheat per ha. These considerable yield losses explain the increasing research effort in understanding aphid population dynamics and their effect on the host plant. Although considerable yield losses due to aphids have been measured, a consistent relation between actual aphid density and yield loss seems absent. The relation between the peak density of the aphids, either S. avenae or M. dirhodum or a combination of both, and yield loss has a correlation coefficient of 0,69, figure 2, whereas the correlation coefficient of the relation between integrated aphid numbers (Rautapää index) and yield loss is even lower. This may be due to the nature of aphid damage. Direct aphid suction damage only explains part of the yield losses. Indirect effects due to honeydew seem at least of equal importance. Data gathered by Vereijken (1979) showed that when secondary effects were prevented by spraying activities this did result in a damage reduction of about 50%. This may be due the secondary effects caused by the honeydew and the stimulation of secondary perthotrophic fungi. Detailed laboratory studies of the light response of flag leaves covered with honeydew and flag leaves without honeydew show a decrease of total photosyntheticactivity per day of about 20% (Rabbinge et. al. in prep.). This result of decreased photosynthetic activity will only show up in the field when very high aphid densities are reached. Direct measurements under field circumstances with a mobile laboratory confirm this statement. Another effect induced by honeydew, which shows up at rather low honeydew quantities, is the promotion of blackmolds and other perthotrophic fungi (Cladosporium spp., Aureobasideum pullulans) and

white and red yeasts (Cryptococcus spp. and Sporobolomyces roseus). The direct effect of these black molds on photosynthetic productivity seems neglectable. (Rabbinge et. al. in prep.). Honeydew also affects the senescence of cereal leaves (Wratten, 1975). Detailed laboratory experiments demonstrate that the presence of honeydew on the flag-leaves may shorten the flagleaf duration by 3-4 days. This phenomenon is already present at relatively low honeydew quantities (coverage percentages of 30%). These effects were confirmed by field experiments. Detailed analysis under field conditions demonstrated that the direct effects of aphids and their excretion products on photosynthesis seems neglectable. Both, light efficiency and maximum photosynthesis, are not significantly affected and the indirect yield losses due to aphids which show up, clearly cannot be attributed to these effects of honeydew on the assimilation activity of the plant. Apparently the decrease in leaf area duration which is clearly demonstrated is the most important factor, besides the direct suction damage, which affect yield loss (Table 1). Within 12 days these differences between treated and untreated plots show up. (Drees et. al. in prep.). These results are confirmed by detailed analysis of ear diseases in winter wheat (Spiertz, 1978). The experiments in which these effects were measured were at a production level of 7500 kg wheat/ha. The yield losses due to aphids (maximum density 25 aphids, a combination of <u>S. avenae</u>, <u>M. dirhodum</u> and <u>R. padi</u>) were 800 kg of wheat per ha. Thus we may conclude that the causes of damage are of a complex nature direct effects and indirect effects both playing a role. Therefore the damage thresholds are difficult to define and additional research of the type discussed above is needed to improve these damage thresholds.

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THE OCCURRENCE OF AND DAMAGE CAUSED BY APHIDS IN CEREAL CROPS IN DENMARK

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Introduction

In the following pages we shall discuss: the importance of cereal aphids in Denmark and their effect on yield, with particular reference to barley; the possibilities for control of the aphids by use of insecticides in relation to the risk of yield reduction; which factors are most important with regard to the population increase in aphids and hence significant both for a system of prognosis of aphids and for the farmer in a situation in which he must decide whether or not to treat the crop.

The occurrence of aphids in cereal crops in Denmark

Since 1906 the occurrence of aphids in cereal has been registered. Stapel (1977) has given an estimate of the distribution and damage done by aphids on the basis of registration made by local advisors (figure 1).



Fig. 1. Occurrence and attack of aphids in cereal crops in Denmark from 1906 (after Stapel & Bagger).

107

The figure shows that occurrence and damage in the years 1910-20 were serious, but after that period only a few years show serious attack up to 1955. However, after that year damage by aphids has been quite common. No explanation has been given about the possible factors responsible for the variations in the attacks by aphids during this period.

Since 1906 the total area planted with cereals has increased. In 1906 the percentages of arable land devoted to cereal growing was 40%. In 1950 the area planted with cereals was increased to 42%, but in 1979 to 63%. At the same time the percentage of the cereal area devoted to barley was rising and in 1979 was 88% of the total area planted with cereal.

But according to the records of aphids the most serious attack was at the beginning and at the end of the period 1906 to 1979. In the same period crop growing methods have changed, the amount of fertilizers used - especially nitrogen - has risen very rapidly, new cereal cultivars have been introduced as have combine harvesters etc., but this seems to have had no direct effect on the life conditions of the aphids.

Control of aphids

The severe attacks of aphids around the year 1960 provides the background for a lot of field trials in which insecticides were used against aphids. Results from these field experiments showed yield increase from o to lo hkg per ha dependant on the number of aphids and the date of treatments. Because the counting of the actual number of aphids in these experiments was very limited, it was not possible from these early experiments to calculate the threshold level for the number of aphids doing damage.

Also factors other than the above-mentioned influence the damage done by aphids. Figure 2 shows results from a number of field trials where yield increase after control of aphids is correlated to the total yield.

The figure shows that yield increase is relatively higher on fields with low yield, and the reason may be that aphids cause more damage to weak than to healthy plants.



Fig. 2. Yield increase by treatment with insecticides in relation to the yield level.

Yield reduction in relation to the time of attack by and control of the aphids

To get a better idea about the importance of the time of attack and of control of aphids, experiments were carried out in small cages placed on an open field. Each cage (fig. 3) is made from two pieces of steel wire (5 mm) each of which is bent in a U.shape. The ends are pushed into the ground at a depth of 15 cm diagonally over the chosen plot - 35 cm x 35 cm. At the point where the two wires cross they are fixed together with a piece of tape. A thin nylon net (mesh holes 0.3 mm x 0.6 mm) made up like a bag is fixed over this frame. The net is fastened to the frame by digging it about 5 cm into the ground around the cage. The cages are placed in the field when the



The cages are placed in the field when the cereal is in growth stage 2 (Feekes scale). About 30 plants are kept in each cage. Respectively loo individuals of Sitobium avenae or Rhopalosiphum padi were introduced into the cages on certain dates (fig. 4). Also treatment with insecticides (parathion) was given on different dates (fig. 5). The temperature inside the cages was almost equal to the outside temperature (within 1° C).

Fig. 3.



Fig. 5. Grain yield in relation to the time of control of the aphids.

The results show that one treatment with parathion is able to prevent yield reduction caused by aphids, but it seems to be important that the treatment is carried out at the right time. In Denmark the "right time" for control of aphids is between June 15 and July 7.

In another experiment with Sitobium avenae, Rhopalosiphum padi and Metopolophium dirhedum, carried out in the same cages as mentioned above, the aphids were introduced on two dates - June 8 and 26 - and treated with parathion on two dates - July 3 and 18. In fig. 6 the results are given as an calculated average from four replicates.



1. Rhopalosiphum padi

2. Sitobium avenae

3. Metopolophium dirhodum

Fig. 6. Grain yield of barley by attack by and control of the aphids at two different dates.

A	1	control	L					
В	=	aphids	introduced	June	6,	treated	July	3.
С	=		п	71	6,	н	π	18.
D	=	ы	н	94	26,	11	n	3.
Е	=	51	и	I	26,	71	19	18.

How to decide when treatment is necessary?

In order to treat aphids with insecticides in an effective way, with regard to both economical and ecological considerations, it is necessary to know the correct time for application of insecticides and, even more important, the population density at which the use of insecticides becomes financially viable.

The threshold level for using pesticides corresponds to that number of aphids giving yield reduction of a value greater than the cost of treatment = "the economic threshold level".

In Denmark the cost of treatment per ha is equal to the value of $1 - 1 \frac{1}{2}$ hkg grains. If all fields with cereal in Denmark were treated as matter of course, the total annual cost would be around 200 mio. Dkr. Given this treatment, on an average, a yield increase of about 3 hkg per ha, then the economic gain will be about 550 \div 200 = 350 mio. Dkr.

But - as mentioned earlier in this paper - on an average in only one year out of three are the attacks of aphids serious in Denmark. Furthermore, in years with serious attacks of aphids in cereal there are great differences in the number of aphids in the fields, both between different parts of the country and also between fields within local areas.

Normally the most serious attacks of aphids in Denmark are concentrated in the South-Eastern part of the country.



Fig. 7. Distribution of aphids in cereal crops in Denmark, June 1976 (Bagger, 1977)

Figure 7 shows the attack of aphids on cereal in June 1976, and that distribution of occurrence in Denmark is typical. When deciding whether or not to apply treatment it is important that the decision is based on information about the number of aphids in every single field. Furthermore, it is not enough to know only the actual number of aphids, but also the risk of a population increase of the aphids in the following weeks.

How to manage these problems in practice?

To get a better idea about the possibility of developing systems, which provide more precise information about the risk of damage by aphids to cereal, a programme for registration and field experiment between advisory service and the Plant Protection Centre has been established.

The first step in this programme has been to register the occurrence of aphids (and other pests and diseases) weekly from the end of May to around July 20. In 1979 this registration was carried out in a number of field experiments in different parts of the country. Results from these field experiments, located on the islands south of Zealand (fig. 8), are given in table 1.



Fig. 8. Localities on Lolland-Falster with experiments in 1979 c.f. table 1 & fig. 7.

Table 1. Number of aphids and yield. Field experiments Lolland-Falster 1979.

Number of aphids^a) at dates: Exp.no. 30/5 6/6 13/6 20/6 27/6 4/7 11/7 19/7 26/7 lo lo.l lo.l lo.5 ll ll.l^{b)} hkg/ha^{d)} (fig.8) 5 7 8 0.9^{C)} 4 0.4 0 0.4 3 2 3 2 • 2 0 1.5^{C)} 2 <u>o.4</u> o -2 2 0 0 ο 0 7 o o.4 <u>o.8</u> 1 2 2 2 1.5 О 0 o.4 o o.4 <u>2</u> 2 3 0 2 2 2 1.6 6 0 0.5 2.5 6 1 3 1.5 2 2.5 0 2 2 1.5 O 3.3 5 o.5 o 4 0 0 2 1 2 6 1 0 _ 0 0 5 3.8

Winter wheat

Spring barley

_	-	6	5 8	lo	10.1	10.5	10.5	10.5	11.1	11.2 ^{b)}				
	7	0	0	0	0	<u>0.4</u>	2	5	6	6	5.7			
	3	0	0	0	0.4	2	l	6	8	7.6	8.5			
a)	Level	of	infesta	ation	Num	ber o:	f aph	ids (modif diere	ied afte	er Remau-			
			0	-	NO	No aphids								
 On a few plants less than 5 aphids per plant 							hids per							
			4	-	 Some populations with 6-25 aphids per plant or less than 5 aphids on many pla 									
6 - Some populations with 26-125 aphids plant or a lot of plants infested w 6-25 aphids							phids per ted with							
			8	-	- A lot of plants infested with more that 26 aphids									
			lo	-	Hea	wy ge	neral	infe	stati	.on				

- b) Development of the plant (according to Feeke)
- c) Also treated against mildew
- d) Yield increase after treatment with insecticides on the date underlined.

The figure in table 1 for occurrence of aphids shows good correlation between the number of aphids and the yield increase after insecticide treatment.

Unfortunately the number of aphids in the period during which one has to decide whether to treat - between 15.6 to 7.7 - only the number of aphids counted in experiment no. 6 was so high that it gave reason for treatment.

This data illustrates that it is not always enough just to observe the number of aphids to get the necessary information. Other observations or information may also be necessary to support the decision - to treat or not to treat.

The results from the observation given in table 5 also show that there can be an important difference between the occurrence of aphids in fields located near each other.

In experiment no. 1 the yield increase paid for the cost of the treatment more than twice over, whereas in experiment 2 the cost of treatment was equal to the value of the yield increase. Remarkable among the results shown in table 5 is the yield increase in winter wheat. In spite of the late attack of aphids - in the beginning of July - the yield increase was lo to 15 percent with treatment.

Which pesticides to use?

When the number of aphids gives reason to apply insecticides, it is important to use the type of insecticide which is most efficient in the particular situation. In Denmark up until now the type of insecticide most used against aphids has been the non-selective "parathion" and "fenitrothion". But when that non-selective type is used, there is a serious risk of killing most of the aphid predators and parasites. Sometimes it is necessary to use this type of pesticide because of pests other than aphids such as midges and leaf beetles occur. Otherwise it is preferable to use selective types.

Results from field experiments in 1978-79 show that it is not always the case. Table 2. Field trials 1978-79. Treatment with different types of insecticides against aphids in spring barley. (Johs. Olesen, 1979).

	Number of aphids ^{x)}								
Treatment	per ha	before treatm.	3 days after	14 days after	yield hkg/ha				
untreated		6	7	6	48.8				
Sumithion 50	l litre	-	0	1	51.6				
Croneton	1 "	-	0	2	50.1				
Pirimor G	0.25 kg	-	0	0	51.4				
PLK-Penncap M	2 litre	-	0	0	52.4				
					LSD 1.8				

x) as in table 1.

ų,

The results show that the selective insecticide Croneton in these experiments was not so efficient as the other selective insecticide Pirimor G or PLK-Penncap M, a non-selective insecticide.

Dosage of insecticides

Another question when using insecticides against aphids is the dosage. Results from field and laboratory experiments seem to indicate that under these circumstances it is possible to reduce the doses to as little as 1/4 or even 1/8 of the dose recommended by the manufacturer.

In order to obtain good results with lower doses than recommended it is important to be careful when applying the pesticides. Using reduced doses could be a way of maintaining the population of predators and parasites of aphids even when non-selective insecticides are used.

-	insectic	ides aga	inst Rhopa	alosiphum	padi.	
Field exper	iment					
	p. dmun	irimicar er of B	b badi per	fe tiller a	nitrothi fter•	on ^{b)}
Dose	l day	4 days	12 days	1 day	4 days	12 days
untreated	75	60	4o	75	35	15
1/1	0	0	0	0	0	0
1/2	0	0	0	0	0	0
1/4	3 ^{C)}	0	0	15 ^{C)}	0	0
1/8	5 ^{C)}	0	0	35 ^{C)}	5 ^{C)}	15 ^{C)}
Laboratory I Number of a	experim pirimican aphids k	ent rb ^{d)} fe illed af in perc	nitrothion ter 24 nou ent	n ^{e)} Jrs		
untreated	29		17			
1/1	100		loo			
1/2	100		loo			
1/4	100		lœ			
1/8	56		loo			
1/16	83		64			
1/32	38		27			
1/64	0		38			
a) 1/1 dos	e " 0.3	kg Pirin	or G per l	ha		
b) 1/1 ¶	1 1i	tro Foli	thion 50 i	oor ha		

Table 3. Field and laboratory experiments with reduced doses of

" 1 litre Folithion 50 per ha b) 1/1

c) Number of aphids on the plants and on the soil around the plants.

d) 1/1 dose . o.3 kg pirimicarb per ha

e) 1/1 " _ 1 litre fenitrothion per ha

Summary

Results from field and other experiments in Denmark show that it is possible to control aphids in cereals with one treatment with insecticides between June 15 and July 7.

In a year when the occurrence of aphids in cereal in Denmark is

below the economic threshold level , and even in years where the occurrence is more widespread, not every single field should be treated, because there is a considerable variation between the number of aphids in the fields.

There can be situations where it is difficult, on the basis of the population density of aphids, to decide whether to treat or not, because the population of aphids can rise very rapidly.

It is therefore important also to take into consideration; the weather forecast, the health and the development of the crop, the occurrence of aphid predators and parasites etc.

More experiments, registrations and investigations are required to give more information about all these interactions between the aphids, the crops and the environment.

A programme developed between the advisory service in Denmark and the plant protection research stations could be one way of attempting to solve some of the problems.

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