

ON BIOTYPES OF THE CEREAL-ROOT EELWORM (*HETERODERA AVENAE*) AND RESISTANCE IN OATS AND BARLEY¹

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In the Netherlands four biotypes of cereal-root eelworm have been recognized by using ANDERSEN's series of test varieties. Three forms of *Avena sterilis* and 14 varieties of oats were found to be resistant to the four biotypes. In barley two varieties showed resistance to four biotypes and many varieties were found to be resistant to one, two or three biotypes.

THE OCCURRENCE OF BIOTYPES

The occurrence of biotypes of cereal-root eelworm was reported first from Denmark (ANDERSEN, 1959). ANDERSEN described two biotypes, a non-aggressive type or biotype 1 and an aggressive one, or biotype 2. Later work (ANDERSEN, 1961) defined race 1 as the one which did not produce cysts on 'Pajbjerg Drost' barley and 'Statsfrøkontrollens Alfa' barley. The eelworm which produced between 50 and 100% as many cysts on 'Pajbjerg Drost' and 'Statsfrøkontrollens Alfa' as on 'Abed Maja' barley or 'Weibulls Herta' barley, was called race 2.

From 1955 onwards research has been done in the Netherlands on the change in eelworm populations under the influence of different crops on two soil types (KORT & S' JACOB, 1956; KORT, 1959). These investigations, which involved a large number of fields, were carried out in closely limited regions. The results never suggested the existence of biotypes. Usually oats were severely attacked and the crop increased the degree of infestation of the soil, thereby limiting its development at a certain level of infestation. Barley was also affected and kept the eelworm population on a fairly high level, without being damaged too heavily. In rye symptoms of the attack were never found, and the degree of infestation of the soil decreased after growing this crop.

OOSTENBRINK (1961) found in some of his trial fields that cereal-root eelworm was able to multiply strongly on rye. This might suggest the occurrence of biotypes. In 1958, five randomly chosen populations of the eelworm were examined for the occurrence of biotypes by growing the test varieties used by ANDERSEN. The results of this test (Table 1) gave the first clear indication of physiological differentiation of the eelworm in the Netherlands.

METHODS AND MATERIAL

In 1960-1962 soil samples of ca. six kg were collected from 119 infested fields throughout the country. The sampling was not carried out according to a

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definite system. The populations were tested in fired, non-glazed drain pipes (length 30 cm, internal diameter 5 cm), which had been placed vertically in the soil. The bottom third of these pipes was filled with uninfested river sand, and the remainder filled up with the soil to be investigated to 5 cm from the top of the pipe. The top was covered with river sand (ANDERSEN, 1961).

In 1960 the following test plants were planted in five replications per population (three plants per pipe): 'Sun II' oats, 'Barley 191', 'Pajbjerg Drost' barley, *Avena sterilis* and spring rye. In 1961 and 1962 *A. sterilis* and spring rye were left out. In addition the number of replications was reduced from five to three. During the growing season the plants were dressed twice with a granular mixed fertilizer. The water supply was regulated by overhead irrigation.

SCORING

About 14 weeks after planting the development of cysts on the roots was examined. The above-ground parts of the plants were cut off and the drain pipes were soaked in a tray with water. Then the roots were rinsed with water and the number of cysts was counted.

RESULTS

Of 119 populations examined, 41 proved to have too small numbers of cysts to justify a classification. These have been left out of consideration. From the results of the remaining populations four biotypes of cereal-root eelworm can be distinguished. In Table 2 the results of the investigations in 1960-1962 are summarized.

Contrary to ANDERSEN's findings, no or only a few cysts developed on *Avena sterilis*. Spring rye, however, appeared to be a host for all biotypes. Biotypes A and B are more frequent than biotypes C and D. The number of populations examined was too small to give a correct picture of their relative occurrence. The geographical distribution of the biotypes in the Netherland is presented in Fig. 1.

It can be assumed that the populations under the double line in Table 2 are composed of mixtures of biotypes. Similar combinations have been encountered also in the case of potato-root eelworm in this country.

Some observations were made on morphological differences between the four biotypes, mainly by measuring the cysts, the vulval cone and the larvae. No reliable differences could be established from the figures obtained. Neglect-

TABLE 1. Test of five populations of cereal-root eelworm for biotypes in 1958. Total numbers of newly formed cysts in four replicates.

Population	'Sun II' oats	'Herta' barley	<i>A. sterilis</i>	'Pajbjerg Drost' barley	'Barley 191'
1	0	0	0	0	44
2	1	0	0	0	75
3	4	2	0	0	40
4	350	200	2	1	0
5	280	250	2	34	0

TABLE 2. Distribution of biotypes of cereal-root eelworm. Mean numbers of newly formed cysts on the roots of 15 plants (1960) or 9 plants (1961–1962).

Year	'Sun II' oats	'Barley 191'	'Pajbjerg Drost' barley	Spring rye	Number of populations	Biotype
1960	224	1	1	74	9	A
1961	208	1	1	—	24	
1962	121	1.6	1	—	15	
1960	1	35	1	135	17	B
1960	50	0	165	47	3	C
1960	2	0	2	93	3	D
1960	173	78	0	149	4	
1961	155	65	0	—	1	
1962	150	50	0	—	1	
1960	283	49	118		3	

ing a comparison with the races 1 and 2 described by ANDERSEN, the four biotypes found in the Netherlands would be defined as follows:

- Biotype A: Produces cysts on 'Sun II' and spring rye, but not on 'Barley 191', 'Pajbjerg Drost' barley and *Avena sterilis*.
 Biotype B: Produces cysts on 'Barley 191' and spring rye, but not on 'Sun II' oats, 'Pajbjerg Drost' barley and *Avena sterilis*.
 Biotype C: Produces cysts on 'Sun II' oats, 'Pajbjerg Drost' barley and spring rye, but not on 'Barley 191' and *Avena sterilis*.
 Biotype D: Produces cysts on spring rye only, but not on 'Sun II' oats, 'Barley 191', 'Pajbjerg Drost' barley and *Avena sterilis*.

Using these test plants, the above description can be summarized in the following diagram.

Test plant	Biotype			
	A	B	C	D
'Sun II' oats	s	r	s	r
'Barley 191'	r	s	r	r
'Pajbjerg Drost' barley	r	r	s	r
<i>Avena sterilis</i>	r	r	r	r
Spring rye	s	s	s	s

s = susceptible
r = resistant

RESISTANCE IN OATS AND BARLEY

As far back as the beginning of this century NILLSON-EHLE (1908) reported the occurrence of barley varieties resistant to the races of cereal-root eelworm occurring in South Sweden. The eelworm was called *Heterodera Schachtii* at that time. He mentioned the resistant barley varieties 'Honneken', 'Chevalier I' 'Chevalier II', 'Svanhals' and 'Primus'. In a later publication NILLSON-EHLE

(1920) described the favourable influence of a resistant barley variety as a trap crop for oats compared to a susceptible barley variety, and, to a certain extent, also for wheat. In 1915 he made his first crosses with resistant varieties; in the crosses 'Chevalier I' \times 'Gold' and 'Chevalier II' \times 'Gold' it was shown that the resistance was due to a single dominant factor.

Further results in breeding for resistance to *H. avenae* can be found only much later. In 1960–61 a number of publications on resistance to cereal-root eelworm was issued in Denmark. The most recent study was made by ANDERSEN (1961), who gave an extensive survey of the research conducted in Denmark. He mentions some sources of resistance in oats and barley. GAIR *et al.* (1962) state that cereal-root eelworm is widely distributed throughout England and Wales, where damage is most common on light soils. The existence of British biotypes of this eelworm has yet to be demonstrated. The Danish barley variety 'Barley 191' appeared to be resistant to the British populations of *H. avenae*. 'Proctor' and 'Herta' were better hosts and produced a higher final population of the eelworm than the Danish variety 'Kron'.

From the investigations carried out by KORT (1957) in the Netherlands, it is apparent that *H. avenae* occurs in many parts of the country. Most infestation is recorded from the light soils in the eastern and southern part of the country. KORT (1960), using a range of varieties including the oat 'Sun II', *Avena sterilis*, 'Petkus' spring rye and the barleys 'Pajbjerg Drost' and 'Barley 191', established the occurrence of four biotypes of cereal-root eelworm and thus laid a basis for breeding for resistance to the eelworm.

BREEDING FOR RESISTANCE

Since 1959 breeding for resistance to cereal-root eelworm in oats and barley has been included in the working programme of the Foundation for Agricultural Plant Breeding (S.V.P.). Using the above mentioned results obtained by KORT, a large number of varieties of oats and barley has been tested for resistance to cereal-root eelworm.

From the beginning it has been the intention to base the investigations as much as possible on the results obtained by ANDERSEN. However, it soon was shown that the physiological specialisation of *H. avenae* in the Netherlands is more complicated than it is in Denmark. Various varieties mentioned as resistant by ANDERSEN were attacked by one or more Dutch biotypes in our trials. This made us look for more sources of resistance. In the International Barley Disease Nursery, comprising some 150 barley varieties, obtained from Beltsville, USA, we conducted further tests for resistance. Various varieties were found to be resistant and crosses have now been made on this new basis. In the future we will try to study the genetic basis of this resistance.

EXPERIMENTAL RESULTS

In 1959 only one population of the eelworm derived from a light sandy soil in the surroundings of Wageningen was used for the experiment. In 1960 five soil samples were taken. The eelworm populations of these samples could, however, be determined only later in the year. One of these contained only biotype A; the others appeared to have mixtures of biotypes A and B. One of these

mixtures originated from the same field used in the 1959 experiment. In 1961–1962 the biotypes A, B, C and D, as found in the Netherlands, were used. In all experiments the plants have been tested in drain pipes, as described by ANDERSEN (1961).

Oats

In 1959–1961 some 100 oat varieties were tested for resistance. The only three types of *Avena sterilis* tested proved to be resistant to all four biotypes. The French variety 'Grise de Houdan', already mentioned by ANDERSEN (1961), which was resistant in Denmark, appeared to be susceptible to biotypes A and C. Many oat varieties, including 'Red Rustproof', 'Early Miller', 'Zwarte President', 'Garry' and 'Sun II', appeared to be resistant to biotypes B and D (like 'Grise de Houdan').

During these four years it was found that only one line of *Avena sterilis*, in our collection indicated as 'No. GH 6', showed no or few cysts; the varieties 'Malaga' and 'Rouda', however, gave some cysts per plant in many tests.

In 1962, 20 C.I.- and P.I.-numbers, mentioned as resistant in Denmark by ANDERSEN (1961: Table 6.8, p. 124), were tested for their behaviour against the Dutch biotypes. 'C.I.994', 'C.I.3444' and 'C.I.5195' were resistant to biotypes A, B and D, but susceptible to biotype C. The numbers 'C.I.3447', 'C.I.3452' and 'C.I.5171' appeared to be susceptible to biotypes A and C. The other 14 numbers listed in Table 3, were resistant to all four biotypes.

TABLE 3. Oat varieties which are resistant against four biotypes of cereal-root eelworm.

Variety	Origin	Variety	Origin
'C.I. 2154'	India	'P.I. 181003'	India
'3445'	India	'181004'	India
'3449'	India	'175022'	India
'5188'	India	'C.I. 2863'	Argentina
'5194'	India	'P.I. 185775'	Argentina
'P.I. 175021'	India	'C.I. 2095'	Australia
'175024'	India	'P.I. 194897'	Ethiopia

Only a few results are available on the inheritance of resistance of *A. sterilis*. They suggest that the resistance is incompletely dominant and presumably governed by more than one factor. In an experiment in 1961 'Sun II', for instance, had on an average nearly 30 cysts per plant; all plants of *A. sterilis* were free from cysts. The F1-plants from the cross 'Sun II' × *A. sterilis* had on an average 2.25 cysts per plant (ranging from 1 to 5).

Barley

In the first two years we worked with biotype A or a mixture of biotypes A and B; the results did not agree with those obtained by ANDERSEN. In Denmark he found several varieties, including 'Pajbjerg Drost', were resistant to the biotype, indicated as race 1, but only two varieties, 'Barley 14' and 'Barley 191', showed resistance to both biotypes found there, races 1 and 2.

In 1959 and 1960 we found these barleys, '14' and '191', to be susceptible

and 'Pajbjerg Drost' to be resistant. In 1961 some 50 barley varieties, mainly of West-European origin, and the International Barley Disease Nursery, were tested for their behaviour against biotypes B and C. From this collection of about 200 varieties, 57 were chosen for testing for resistance to biotypes A, B, C and D. The choice of these 57 varieties was based on the resistance against biotypes B and/or C found in the 1961 tests, or on their resistance against biotype A found in 1959 or 1960. The results from these trials are given in Table 4.

TABLE 4. Resistance of barley varieties to *H. avenae*.

Resistance to biotypes	Varieties
A B C D	'Morocco C.I. 3902' 'Marocaine 079 C.I. 8334'
A B C	'C.I. 3515'
A B D	'Pajbjerg Drost' 'Statsfrøkontrollens Alfa' 'Fero' 'Kron' 'Crieuener 403' 'Rex' 'Hanna Export' 'Goldfoil C.I. 928' 'C.I. 4226' 'Ogalitsee C.I. 7152' 'P.I. 253826' 'I.B.D.N. 61 No. 131'
A C D	'Barley 191'
A B	'Ariana C.I. 2524' 'Osiris C.I. 1622' 'I.B.D.N. 61 No. 14' 'C.I. 3725'
A C	'Quinn C.I. 1024'
B	Many well-known West-European marketvarieties as 'Herta', 'Balder', 'Ingrid', 'Proctor', 'Volla', 'Carlsberg', 'Delta', 'Kenia', 'Maja' and 'Opal'

Spring wheat

In 1962 six spring wheat varieties were also included in the experiments. The results obtained are shown in Table 5. In the same experiment the numbers of cysts (again as an average of three pipes) were counted on the roots of the series and some other varieties of oats and barley (Table 6).

From the results it appears that the spring wheat varieties tested are not only susceptible to three out of four biotypes of *H. avenae*, but that they also increase the eelworm population to an extent which at least equals the multiplication on susceptible oats and barley varieties.

TABLE 5. Number of cysts on the roots of spring wheat varieties grown in drain pipes. Numbers are an average of three replicates.

Variety	Biotype			
	A	B	C	D
'Peko'	12	0	7	50
'Carpo'	23	0	43	44
'Orca'	10	0	30	63
'Jufy I'	17	0	48	93
'Opal'	16	3	52	68
'Koga II'	28	4	37	95

TABLE 6. Number of cysts on roots of some oat and barley varieties grown in drain pipes. Numbers are an average of three replicates.

Variety	Biotype			
	A	B	C	D
<i>Test series</i>				
'Sun II'	17	0	10	0
<i>Avena sterilis</i>				
'Barley 191'	0	0	0	0
'Pajbjerg Drost'	0	0	46	0
Spring rye ('Petkus')	7	17	10	34
<i>Barley</i>				
'Herta'	12	0	56	32
'Delta'	26	0	30	54
'Carlsberg'	7	0	48	92
<i>Oats</i>				
'C.I. 3447'	19	0	96	0
'C.I. 3452'	8	0	43	0

CONCLUSIONS

The information obtained in 1958 that biotypes of cereal-root eelworm occur in the Netherlands was confirmed. It was established that there are four biotypes which are clearly distinguishable. They will be named provisionally A, B, C and D.

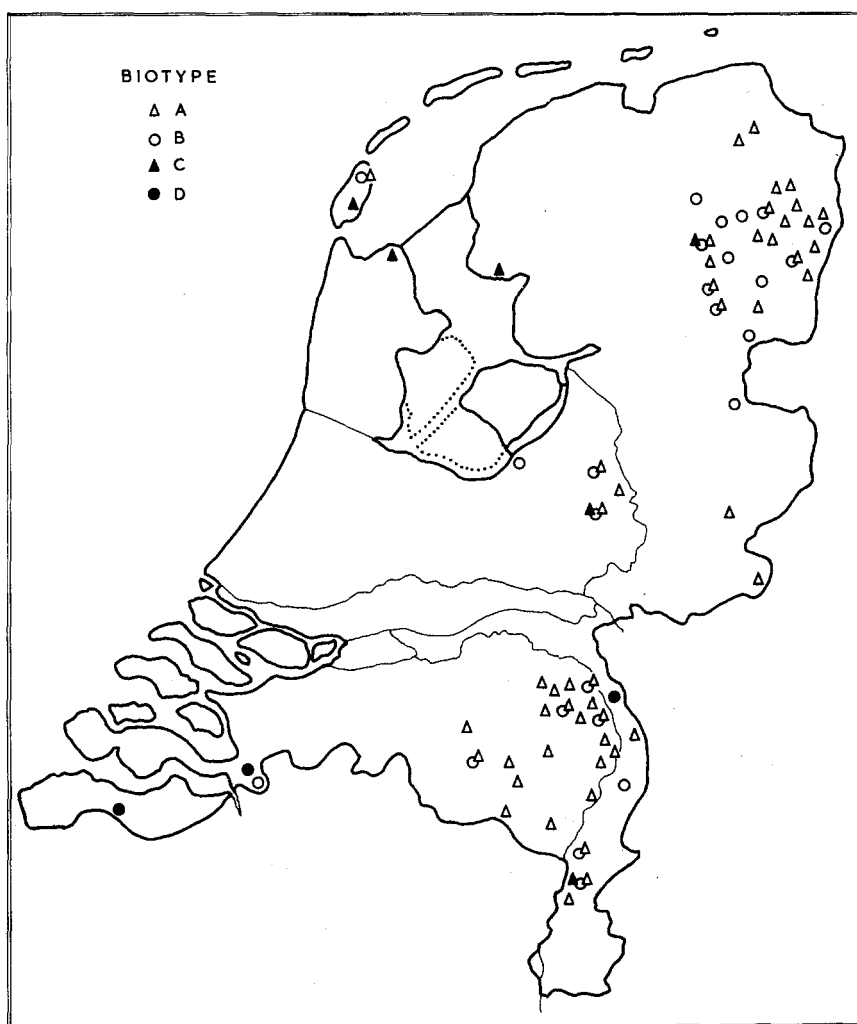
Biotype A is the most common in our country. Although it is encountered throughout the country, it predominates in the southeast. This is the area where the investigations were carried out in 1955-1958.

The number of plots examined is not large enough to give a reliable picture of the relative occurrence of the biotypes. On the field in Zeeuws-Vlaanderen (leftmost black dot in Fig. 1), where biotype D was found, no oats or rye had been grown since 1942. In the same period, however, wheat had been grown there at least ten times, most recently in 1958 and 1959. This high degree of infestation (4192 eggs/200 g of soil) had been accumulated presumably by frequent wheat cultivation. The susceptibility of wheat to biotype D was confirmed in 1962.

From the first part – the occurrence of biotypes- the conclusion can be drawn that biotype B, which in the Netherlands occurs particularly in the Reclaimed Peat Districts in the north, is not, or only rarely, present in Denmark. In addition it follows from the results obtained, that race 1 in Denmark is identical with biotype A and race 2 with biotype C.

From the second part – resistance in oats and barley –, however, it is apparent that this is not true, at least when considering the susceptibility of various oat varieties ('Grise de Houdan', some C.I.- and P.I.-numbers), which are resistant in Denmark. The two biotypes of cereal-root eelworm found in

FIG. 1. Geographical distribution of four biotypes of cereal-root eelworm, *Heterodera avenae*, in the Netherlands.
For explanation, see text.



Denmark are, therefore, different from those encountered in the Netherlands. It is not possible to compare this with the situation in England (see GAIR *et al.*, 1962), because the data from their experiments are too few. Both in oats and barley resistant varieties have been found which may serve as a starting point for breeding for resistance against cereal-root eelworm.

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