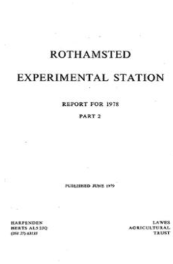
Rothamsted Experimental Station Report for 1978 Part 2


ROTHAMSTED
EXPERIMENTAL STATION

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The Rotation–Fumigation Experiment, Woburn Experimental Farm, 1969–77

T. D. WILLIAMS, J. BEANE, MARGARET M. BERRY and R. M. WEBB

Cereal yields at Woburn, where fields are infested with the cereal cyst-nematode, *Heterodera avenae* Woll., and a range of other root endo- and ectoparasitic species, are much increased by soil sterilants, the benefits of which sometimes persist into the year after application (Williams & Salt, 1970). Yields of potatoes after sterilant treatment are also greatly increased on sites infested with potato cyst-nematodes, *Globodera rostochiensis* (Woll.) and *G. pallida* (Stone), or with the needle nematode, *Longidorus leptocephalus* Hooper (Evans, 1979). The increases in yields of sugar beet after sterilants are smaller. Although aldicarb and dichloropropene at Woburn in 1968 improved the shape and yield of beetroot and significantly decreased nematode numbers, the beet cyst-nematode, *Heterodera schachtii* Schm., is absent and noticeable injury from root ectoparasitic species is uncommon (Mojica, 1969).

To compare the yield benefits from sterilants applied every year in a three-course rotation of sugar beet: barley: potatoes, with a sterilant applied to one of these crops only, from which residual effects in the 2 intervening years could be assessed, a rotation–fumigation experiment was begun in 1969 and terminated in 1977 after completing three cycles. In 1968 a preparatory crop of spring barley was sown over the whole trial area.

The experiment was sited in Butt Close, a field which lies on the Cottenham Series of the Lower Greensand (Hodge & Seal, 1966). This loamy sand is well drained so that nutrients are readily leached from the plough layer; it also readily forms a plough pan (Catt, King & Weir, 1975). Textural analysis of soil from the site area indicated 70% coarse sand, 14% fine sand, 5% silt, 7% clay, 1·2% organic C, pH 6·8, total N 0·14%. The crop sequences are in Table 1.

TABLE 1

The rotation sequence, 1969–77

1968—Preparatory year, Spring barley

	Block I	Block II	Block III
1969	Potatoes	Sugar beet	Barley
1970	Barley	Potatoes	Sugar beet
1971	Sugar beet	Barley	Potatoes
1972	Potatoes	Sugar beet	Barley
1973	Barley	Potatoes	Sugar beet
1974	Sugar beet	Barley	Potatoes
1975	Potatoes	Sugar beet	Barley
1976	Barley	Potatoes	Sugar beet
1977	Sugar beet	Barley	Potatoes

Design and treatments

There were three series, each of two blocks of three nitrogen plots each with seven subplots for sterilants. 'D-D' liquid (dichloropropane-dichloropropene mixture) at 448 kg ha^{-1} was injected 15 cm deep in the autumn/winter preceding the year's crop. From the second year (1970) dazomet (tetrahydro-3,5-dimethyl-1,3,5-thiadiazine-2-thione) at 224 kg ha^{-1} was broadcast as prill containing 98% a.i. and rotavated 15 cm deep also in the autumn/winter preceding the year's crop. Both 'D-D' and dazomet were applied to designated subplots before every crop and 'D-D' was also applied once in the rotation

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(i.e. once every third year) before each crop (i.e. before sugar beet, barley and potatoes). From 1974 benomyl (methyl-1-(butyl-carbamoyl)-benzimidazol-2-yl carbamate) was broadcast as 50% wettable powder at 22·4 kg a.i. ha^{-1} and also rotavated to 15 cm deep into the seedbed before every crop. For the last 2 years, 1976–77, winter weather was so unfavourable that 'D-D' treatments were replaced by spring applications of aldicarb (2-methyl-2-(methylthio)-propylideneamino methylcarbamate) broadcast as 10% granules at 5·6 kg a.i. ha^{-1} and rotavated to 15 cm deep in the seedbed. In 1977, again because of bad winter weather, dazomet was also replaced by aldicarb applied in the spring.

Throughout the text abbreviations for treatments are:

0—untreated
P—'D-D' before potatoes only
SB—'D-D' before sugar beet only
B—'D-D' before barley only
ALL—'D-D' before every crop
DAZ—dazomet before every crop
BEN—benomyl before every crop

The cultivars, sown once in 3 years on the two blocks in each series were:

	Sugar beet	Barley	Potatoes
1969	Klein E	Zephyr	King Edward
70	Klein E	Zephyr	Pentland Crown
71	Klein E	Julia	Pentland Crown
72–77	Klein E	Julia	Pentland Crown

Nitrogen was applied as follows:

Potatoes and sugar beet	N1, N2, N3—75, 150, 225 kg N ha^{-1}
Barley	N1, N2, N3—38, 75, 113 kg N ha^{-1}

Basal manuring ha^{-1}:

Potatoes and sugar beet 1076 kg (0–14–28)
Barley 314 kg (0–20–20)

In addition the sugar beet received 2·5 t ha^{-1} magnesian limestone and boron, 7·4 kg B_2O_3 ha^{-1}, as 'Solubor' applied with summer insecticide. Herbicides, fungicides and insecticides were applied as necessary in accordance with standard farm practice.

Harvesting procedure and nematode sampling

Each subplot was 0·0020 ha; harvested areas were: barley and potatoes 0·0005 ha, sugar beet 0·0016 ha. Yields were recorded as: barley, grain and straw 85% DM t ha^{-1}; potatoes, ware crop (3·8 cm riddle), t ha^{-1}; sugar beet, total sugar, t ha^{-1} (derived from weight of washed roots × sugar percentage). Crop yields for each nitrogen rate are in Table 2. Total tubers ha^{-1}, % ware and other details are in Rothamsted Experimental Station (1969–77).

Soil and root samples for cyst-nematodes were taken before and after cropping. Counts of cysts, eggs and juveniles of *H. avenae* and *G. rostochiensis* were made by standard methods (Southey, 1970). Those of *G. rostochiensis* are given in Table 3 for N2 rate only. For estimates of viable *G. rostochiensis* air-dried samples were placed in 9 cm clay pots in the following year, plunged in sand and planted with single eyes of Arran Banner. In 1973–77, populations were excessive, so the soil was diluted 1:1 with sterile loam. After 4 weeks roots were weighed and stained with methylene blue, macerated and invading juveniles counted (Southey, 1970). Estimates of the numbers of free-living and endo-parasitic migratory nematodes were based on bulked samples from 20

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TABLE 2

Yields of the Rotation–Fumigation experiment, 1969–77

		Barley grain t ha⁻¹ (85% DM)							Potatoes t ha⁻¹ (ware > 3·8 cm)							Sugar beet (sugar t ha⁻¹)						
		0	P	SB	B	ALL	DAZ	BEN	0	P	SB	B	ALL	DAZ	BEN	0	P	SB	B	ALL	DAZ	BEN
1969	N1	2·46	2·42	2·07	1·90	2·65	(2·30)	(2·49)	24·2	32·1	24·6	21·2	30·0	(24·0)	(25·2)	7·45	7·55	7·27	7·89	6·57	(7·30)	(7·11)
	N2	**4·76**	4·35	4·19	4·59	4·46	(3·90)	(4·45)	32·1	34·4	30·0	31·6	39·8	(32·6)	(34·1)	8·22	7·47	7·62	7·33	8·46	(8·40)	(7·61)
	N3	4·27	4·10	4·07	4·36	3·82	(4·09)	(4·20)	**46·2**	43·1	42·6	43·8	44·8	(38·6)	(43·3)	7·99	8·08	7·33	7·67	**8·71**	(7·89)	(8·69)
1970	N1	0·92	1·46	0·79	1·26	1·27	2·12	(0·92)	32·4	37·6	42·6	39·3	40·0	42·1	(37·8)	4·54	5·93	4·71	5·14	4·81	7·23	(4·60)
	N2	1·31	2·17	1·72	1·79	**2·18**	1·96	(1·23)	45·2	48·8	48·0	43·3	51·1	48·9	(45·4)	6·42	6·29	6·62	5·98	6·90	7·01	(6·46)
	N3	1·67	2·13	1·49	2·04	1·97	1·88	(1·76)	42·7	47·8	50·1	46·2	**54·7**	49·3	(35·7)	5·44	6·60	6·32	**7·40**	6·52	7·19	(6·26)
1971	N1	2·71	4·03	4·25	3·24	2·61	5·19	(3·43)	19·2	27·5	24·8	24·1	33·9	36·5	(21·6)	7·80	8·54	8·37	8·57	7·93	**9·34**	(8·27)
	N2	4·71	4·59	**5·30**	3·96	4·67	**5·30**	(4·71)	23·1	43·9	35·9	42·9	43·6	43·9	(22·0)	7·76	7·96	8·19	9·14	8·86	7·88	(7·59)
	N3	4·81	5·07	4·87	4·22	4·38	4·83	(4·23)	34·2	49·4	46·6	46·8	53·7	**54·8**	(29·1)	8·26	8·51	8·89	9·04	8·46	8·34	(8·36)
1972	N1	2·61	1·98	3·30	1·97	3·72	4·10	(2·90)	23·0	28·2	25·7	28·5	26·2	33·5	(23·5)	5·62	6·47	5·78	7·52	4·89	6·94	(6·11)
	N2	3·35	4·56	4·98	4·02	3·45	3·36	(4·41)	28·9	35·3	36·8	34·1	36·3	35·4	(30·7)	6·42	**7·74**	6·89	6·98	6·36	6·90	(6·85)
	N3	3·04	3·46	4·41	4·06	4·04	4·86	(2·43)	36·6	35·1	37·1	35·9	**39·7**	31·5	(34·6)	6·50	7·43	6·16	7·00	6·37	7·12	(6·83)
1973	N1	3·80	4·65	4·39	3·66	3·34	4·63	(3·58)	25·8	39·2	35·2	37·5	37·9	40·1	(30·4)	3·56	4·57	4·19	3·71	3·90	4·72	(3·58)
	N2	4·24	5·29	5·35	4·44	4·38	4·98	(4·23)	36·1	45·1	46·2	38·7	50·9	50·8	(36·3)	5·95	**6·42**	5·92	5·72	5·79	5·47	(5·67)
	N3	4·89	5·09	**5·61**	4·92	4·99	5·21	(5·12)	30·2	50·3	51·7	44·7	**55·0**	53·2	(23·8)	4·85	5·21	5·68	5·97	5·47	5·18	(5·42)
1974	N1	2·28	2·78	2·02	2·26	1·49	3·65	2·66	31·5	31·9	35·6	34·7	37·4	39·9	41·0	2·06	2·22	2·31	2·39	2·11	2·97	2·17
	N2	4·35	4·44	4·54	3·55	4·13	3·99	4·66	36·5	44·0	52·1	42·4	54·2	62·0	58·4	2·70	**3·24**	2·71	3·11	3·01	3·08	2·86
	N3	4·98	4·34	4·96	4·66	4·11	**5·06**	4·62	38·6	52·9	50·0	56·5	63·9	**69·5**	56·4	3·20	3·09	2·89	3·23	2·26	3·14	3·09
1975	N1	1·19	1·51	1·30	1·19	1·41	1·30	1·52	8·8	21·5	18·2	18·3	13·6	24·1	12·0	0·99	1·02	1·11	1·36	0·74	1·16	1·37
	N2	1·73	1·72	1·72	1·29	1·40	**2·16**	1·73	9·6	30·3	18·7	25·8	35·6	29·8	19·1	1·63	1·54	1·59	0·61	0·68	1·20	**1·73**
	N3	0·65	1·62	1·94	1·61	2·05	1·61	1·41	18·3	24·1	**36·7**	34·1	35·3	30·4	22·9	1·40	1·69	1·13	1·43	1·25	1·17	0·62
1976†	N1	2·02	1·90	2·12	2·24	1·68	2·24	2·13	8·5	26·2	21·7	15·1	**28·5**	25·8	19·9	4·54	4·04	4·77	4·45	5·00	5·00	3·98
	N2	1·91	2·58	2·70	2·69	2·24	1·68	2·13	9·2	23·8	21·1	15·8	26·8	23·5	10·7	4·78	4·58	5·43	4·28	5·47	4·00	3·78
	N3	2·35	2·24	3·03	3·25	**3·36**	1·56	2·57	8·3	17·2	18·6	9·5	23·8	23·6	8·8	4·15	4·26	**5·58**	4·69	5·38	4·70	4·82
1977*†	N1	2·13	2·35	2·03	2·03	1·51	1·94	2·04	4·0	15·2	10·8	8·1	17·2	18·5	16·1	4·13	4·61	5·70	5·08	5·35	6·05	4·87
	N2	3·17	3·08	3·49	2·68	**3·56**	3·06	3·19	23·7	30·8	18·2	25·8	27·9	33·7	20·4	5·98	7·15	**7·47**	6·46	6·58	6·32	5·76
	N3	2·85	3·44	3·47	3·35	2·82	3·45	2·74	22·9	33·4	33·2	28·6	37·9	**41·5**	28·3	6·10	6·47	7·22	6·82	7·17	6·30	6·01

† 'D-D' replaced by aldicarb   * Dazomet replaced by aldicarb
NB: Plot yields in parentheses were untreated, equivalent to 0
Bold numerals: largest yields of each year

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TABLE 3

Globodera rostochiensis *post-crop populations (eggs g^{-1} soil) and viability tests (juveniles g^{-1} Arran Banner root), Woburn 1969–77, N2 plots only*

			0	P	SB	B	ALL	DAZ	BEN	
						Block I				
	Crop									
(Pre-crop popn. 1969)			4·4	7·5	30·4	0·4	1·6	2·2	0·4	Reserve plots, 1969–73, no benomyl applied
1969	P	eggs	38·2	16·0	37·5	21·3	10·0	25·2	13·0	
		juveniles	784	602	1423	1212	413	802	1303	
1970	B		10·8	9·4	23·2	2·8	3·0	12·2	4·6	
						No Test				
1971	S		7·2	5·0	8·2	2·2	1·9	1·2	6·0	
			143	148	95	68	28	8	57	
1972	P		39·4	18·0	62·7	33·6	8·0	4·0	27·0	
			978	898	1310	1384	326	108	1232	
†1973	B		29·4	17·1	46·7	23·1	10·0	8·2	19·6	
			662	1363	906	244	56	41	864	
1974	S		17·2	8·9	4·2	2·3	1·0	1·2	13·8	Benomyl applied 1974–77
			577	170	167	54	9	3	128	
†1975	P		52·4	60·4	88·6	42·5	14·4	13·2	61·3	
			692	882	984	708	90	183	647	
†1976	B		8·4	14·0	26·5	12·2	2·9	0·5	30·4	
			730	599	1088	205	36	26	636	
†1977	S		3·0	2·4	5·1	1·2	0·4	0·1	3·6	
			483	360	413	201	33	17	535	
						Block II				
	Crop									
(Pre-crop popn. 1969)			0·8	1·9	3·8	1·4	2·9	4·4	2·9	Reserve plots 1969–73, no benomyl applied
1969	S	eggs	0·4	2·8	0·7	1·3	2·0	0·7	2·3	
		juveniles	14	68	7	81	36	24	64	
1970	P		15·6	7·5	10·4	17·4	18·9	6·7	28·2	
						No Test				
1971	B		9·0	4·8	3·8	4·4	3·4	5·2	14·2	
			264	204	98	204	24	1	376	
1972	S		6·3	4·2	0·5	6·4	2·5	2·8	7·8	
			300	114	52	52	39	111	586	
†1973	P		71·7	61·4	41·8	54·4	26·4	20·5	84·8	
			1079	818	858	1098	344	952	946	
1974	B		33·8	38·4	22·0	24·2	2·7	1·8	42·2	Benomyl applied 1974–77
			1290	740	655	233	195	45	81	
†1975	S		48·9	17·5	8·8	21·9	2·2	5·9	45·2	
			292	214	84	163	24	20	366	
†1976	P		39·1	8·5	34·1	31·7	4·2	7·9	39·3	
			659	232	773	711	89	307	1060	
†1977	B		2·7	2·0	5·7	2·7	0·3	1·4	5·3	
			476	429	655	307	62	199	775	
						Block III				
(Pre-crop popn. 1969)			47·4	81·8	75·7	82·5	63·5	81·7	74·8	Reserve plots 1969–73 no benomyl applied
1969	B	eggs	60·7	63·1	70·4	42·4	60·4	51·0	48·0	
		juveniles				No Test				
1970	S		40·8	51·6	42·4	26·1	29·6	41·4	51·4	
						No Test				
1971	P		76·0	84·6	95·0	81·2	53·8	48·4	79·7	
			1030	1215	1538	563	644	404	685	
1972	B		63·2	59·9	73·4	33·8	22·2	43·0	66·8	
			1075	2396	924	350	280	218	1450	
†1973	S		40·1	38·4	26·6	21·2	19·6	9·4	26·0	
			374	485	125	114	30	22	460	
1974	P		83·1	84·4	92·0	94·7	57·2	36·8	50·6	Benomyl applied 1974–77
			2163	1551	1969	1953	1469	757	175	
†1975	B		51·7	62·0	127·6	52·7	79·3	20·3	25·3	
			621	937	870	589	208	59	390	
†1976	S		35·1	55·7	33·5	27·8	15·4	9·4	12·4	
			1154	1360	815	587	212	55	433	
†1977	P		91·3	37·5	49·1	42·5	2·6	0·4	9·0	
			1851	153	2264	1227	88	178	1195	

† Samples diluted 1:1 with sterile loam for pot tests.

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random cores containing soil or soil and roots during early crop growth (May/June). Nematodes in the soil were extracted from 250 ml subsamples of sieved moist soil by the tray method (Whitehead & Hemming, 1965). Numbers of *Pratylenchus* spp. in roots were estimated after maceration and extraction on nylon mesh tissue for 48 h (Southey, 1970). *Pratylenchus* spp. and free-living ectoparasites were counted in 1969, and in 1971, 1974 and 1977 at the end of each 3-year phase.

The yields

The success of each chemical treatment sequence is best gauged from the 'productivity' (summed yields) of the 9 years (three full rotations). Unfortunately no treatment sequence is complete. The 'D-D' sequences were interrupted by adverse winter weather; aldicarb replaced 'D-D' in the last 2 years (1976, 1977). Dazomet was not applied in the first year (1969) but was then applied (1970) continuously to all crops until 1977 when it also had to be replaced by aldicarb because of heavy autumn and winter rains.

Benomyl was not introduced until 1974. The most meaningful comparison is between benomyl in the last 3 years of the experiment and the untreated plots.

The results can also be considered annually, relating yields to the nematode population levels in soil and roots; however it must be remembered that the crop concerned is sown on a different block each year of the 3-year cycle. Statistical comparison of each cycle is not possible nor of the total 'productivity' over three cycles because of the incompleteness of the treatment sequences. The cycles can only be compared in the light of experience acquired during the 9 years.

TABLE 4

Yields and nematode counts, 1969

		0	P	SB	B	ALL	Mean
Barley (t ha^{-1})		3·70	3·68	3·44	3·62	3·65	3·62
Potatoes ware		33·1	36·6	32·4	32·0	38·2	34·4
Sugar (t ha^{-1})		7·86	7·70	7·41	7·63	7·92	7·74
H. avenae (eggs g^{-1} soil), post-crop after:		[Pre-crop mean 2·3 eggs g^{-1}.] N2 plots					
Potatoes	†I	1·4	1·7	0·8	2·3	0·9	1·4
Sugar beet	II	1·7	2·5	0·5	1·1	0·7	1·4
Barley	III	1·2	1·8	1·0	0·0	0·9	1·0
G. rostochiensis (eggs g^{-1} soil), post-crop after:		[Mean pre-crop population 27·2 eggs g^{-1}]					
Potatoes	I	28·7	16·0	37·5	21·3	10·0	23·7
Sugar beet	II	0·9	2·8	0·7	1·3	2·0	1·5
Barley	III	55·2	63·1	70·4	42·4	60·4	57·8

† Roman numerals are block numbers

Tables 4, 7–14 summarise the yields (means of three nitrogen rates) of each crop, year by year. These are then considered as 3-year cycles and finally reviewed for all 9 years. After the 1968 barley crop *H. avenae* was uniformly but thinly present (nowhere exceeding 4 eggs g^{-1} soil). *G. rostochiensis* populations averaged 27 eggs g^{-1} soil but the densest populations were in block III.

In 1969, 'D-D' was the only treatment applied. Its effects on vermiform nematodes in soil and in roots during May are in Table 5. Numbers of most species were too few or too variable for statistical analysis, but 'D-D' decreased numbers to about one-third of untreated. There were consistently more nematodes in the roots of the sugar-beet crop than in those of potatoes or barley and somewhat more in the soil under barley than under sugar beet or potatoes (Tables 5 and 6).

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TABLE 5

Numbers of vermiform nematodes, May 1969

Roots—numbers g^{-1} fresh weight
Soil—numbers 20 ml^{-1}

1969 Crop	O		P		SB		B		ALL	
	Roots	Soil	Roots	Soil	Roots	Soil	Roots	Soil	Roots	Soil
Potatoes Block I										
Pratylenchus	23	30	8 †	7	28	35	14	37	5 †	3
Paratylenchus	0	2	0	1	0	3	0	6	0	0
Tylenchorhynchus	1	15	2	5	1	9	1	14	0	1
Rotylenchus } *Helicotylenchus*	0	1	0	0	0	1	0	0	0	0
Tylenchus } *Ditylenchus*	6	39	3	16	6	64	5	68	1	18
Heterodera/Globodera	1	6	0	2	0	11	1	10	0	0
Aphelenchus } *Aphelenchoides*	1	3	0	0	0	1	0	2	0	0
Dorylaimus	0	3	0	0	1	6	0	3	1	1
Trichodorus	0	0	0	0	0	1	0	3	0	0
Others (mainly Rhabditids)	42	79	22	45	50	97	33	100	14	31
Total	74	178	35	76	86	228	54	243	21	54
Sugar beet Block II										
Pratylenchus	164	69	74	30	42 †	6	70	40	17 †	7
Paratylenchus	3	9	1	1	1	0	0	10	0	1
Tylenchorhynchus	0	14	1	8	0	0	0	12	0	2
Rotylenchus } *Helicotylenchus*	1	1	0	0	0	0	0	1	0	0
Tylenchus } *Ditylenchus*	50	56	16	44	15	21	63	61	12	16
Heterodera/Globodera	0	12	0	9	0	2	0	7	0	3
Aphelenchus } *Aphelenchoides*	12	1	3	0	1	0	7	3	0	1
Dorylaimus	3	6	1	3	2	1	1	5	0	1
Trichodorus	0	0	0	0	0	0	0	3	0	1
Others (mainly Rhabditids)	602	92	378	89	146	35	310	112	70	40
Total	835	260	474	184	207	65	451	254	99	72
Barley Block III										
Pratylenchus	8	18	7	13	9	21	1 †	1	3 †	1
Paratylenchus	0	8	0	6	0	4	0	0	0	2
Tylenchorhynchus	1	15	1	14	0	13	0	1	0	1
Rotylenchus } *Helicotylenchus*	0	0	0	0	0	0	0	0	0	0
Tylenchus } *Ditylenchus*	5	77	7	60	4	70	4	33	3	28
Heterodera/Globodera	0	29	0	76	0	63	0	7	0	8
Aphelenchus } *Aphelenchoides*	0	1	0	1	1	1	0	1	0	1
Dorylaimus	0	9	0	10	0	4	0	1	0	0
Trichodorus	0	0	0	0	0	1	0	0	0	0
Others (mainly Rhabditids)	29	183	31	140	42	106	10	86	41	61
Total	43	340	46	320	56	283	15	130	47	102

† 'D-D'-treated plots, all others untreated in first year

1969 (Tables 2 and 4). 'D-D' had no significant effect on the yields of barley or of sugar beet but significantly increased those of potatoes given least nitrogen. *H. avenae* populations were not significantly affected although they were least after 'D-D'. *G. rostochiensis* was significantly less in the 'D-D' treated potato plots, and populations were so small in block II (sugar beet) that 'D-D' had no detectable effect. Where there was most *G. rostochiensis* (block III), barley was planted. Here 'D-D' had no significant effects, presumably because there were no opportunities for multiplication. *Pratylenchus* spp. were controlled by 'D-D' in all crops but numbers were insufficient to damage any

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TABLE 6

Total numbers of vermiform nematodes in soil and root samples, May 1969

	Untreated		'D-D' treated	
	† Soil	Roots	Soil	Roots
Potatoes	217	72	64	28
Beet	233	586	69	153
Barley	314	48	117	32
Mean	255	235	83	71

	Soil (means of treated and untreated)	Roots
Potatoes	140	50
Beet	151	369
Barley	216	40
Mean	169	153

† Roots, numbers g^{-1} fresh weight; soil, numbers 20 ml^{-1}

untreated crop. Numbers of *Tylenchus/Ditylenchus* in the soil were also decreased by 'D-D'.

1970 (Tables 2 and 7). Dazomet ('Basamid') at 224 kg ha^{-1} was applied in autumn/early winter on certain plots before all crops. It increased barley grain yields by 0·7 t ha^{-1}

TABLE 7

Yields and nematode counts, 1970

	O	P	SB	B	ALL	DAZ	Mean
Barley (t ha^{-1})	1·31	1·92	1·33	1·70	1·80	1·99	1·62
Potatoes ware (t ha^{-1})	39·9	44·7	46·9	42·9	48·6	46·8	44·2
Sugar beet (t ha^{-1})	5·62	6·27	5·88	6·17	6·07	7·14	6·11
G. rostochiensis (eggs g^{-1}) pre- and post-crop							
Potatoes II							
pre	0·9	2·8	0·7	1·3	2·0	1·5	1·5
post	15·6	7·5	10·4	17·4	18·9	6·7	12·8
Sugar beet III							
pre	60·7	63·1	70·4	42·4	60·4	49·6	57·8
post	40·8	51·6	42·4	26·1	29·6	41·4	38·7
Barley I							
pre	38·2	16·0	37·5	21·3	10·0	19·1	23·7
post	10·8	9·4	23·2	2·8	3·0	12·2	10·2

as did 'D-D' applied to potatoes (1969) preceding the barley. Potato yields were significantly improved by 'D-D' applied to the previous sugar-beet crop. These results were the first of many to show that the residual effects of 'D-D' were often more beneficial than the current ones. This is probably because, at the rate used, the phytotoxic effects of newly applied 'D-D' more than outweighed the benefits of nematode control. This effect was most consistently seen in the barley crop. Both 'D-D' and dazomet checked the rate of increase of *G. rostochiensis* on the potato crop. Sterilant applications also decreased numbers (30 July) of *Pratylenchus*, *Tylenchus*, *Ditylenchus* spp.

1971 (Tables 2 and 8). The best barley yields followed dazomet but they were almost equalled after 'D-D' applied to the 1969 sugar-beet crop. Barley yields were least after current 'D-D'. Potato yields were almost doubled by continuous dazomet and 'D-D' (untreated 26·4 t ha^{-1}), and were significantly improved by 'D-D' applications to preceding barley and sugar-beet crops. Sugar production was best after 'D-D' applied to

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TABLE 8

Yields and nematode counts, 1971

	0	P	SB	B	ALL	DAZ	Mean
Barley (t ha^{-1})	4·10	4·56	4·81	3·80	3·89	5·11	4·34
Potatoes (t ha^{-1})	26·4	41·8	37·2	40·0	45·9	47·0	37·8
Sugar (t ha^{-1})	8·01	8·33	8·49	8·92	8·42	8·52	8·38
G. rostochiensis (eggs g^{-1}) pre- and post-crop							
Potatoes III							
pre	15·6	7·5	10·4	17·4	18·9	6·7	12·8
post	79·9	84·6	95·0	81·2	53·8	48·4	74·1
Sugar beet I							
pre	40·8	51·6	42·4	26·1	29·6	41·4	38·7
post	6·6	5·0	8·2	2·2	1·9	1·2	4·2
Barley II							
pre	10·8	9·4	23·2	2·8	3·0	12·2	10·2
post	11·6	4·8	3·8	4·4	3·4	5·2	5·5

Vermiform nematodes 20 ml^{-1} soil, 12 November 1971

	0	P	SB	B	ALL	DAZ	Mean
Potatoes							
Pratylenchus	18	6	—	2	2	2	6
Tylenchus + *Ditylenchus*	18	12	—	2	13	6	10
Sugar beet							
Pratylenchus	10	104	35	89	5	0	41
Tylenchus + *Ditylenchus*	3	37	14	27	5	0	14
Barley							
Pratylenchus	295	303	4	0	22	14	106
Tylenchus + *Ditylenchus*	29	23	3	0	2	16	12

the previous barley crop but generally the response was less than in barley and potatoes (11% as against 24% and 78% respectively).

These results confirmed those of 1970 (and other experiments at Woburn) which suggested that 'D-D' can be phytotoxic in the year of application but residual effects may be beneficial for at least 2 years. *Heterodera avenae* pre- and post-crop soil counts barely differed, the nematode appeared to be controlled by the rotation alone. In the 1971 potato crop only dazomet (every year) and 'D-D' (every year) controlled *G. rostochiensis* (48 and 54 eggs g^{-1} post-crop instead of 78 eggs g^{-1} untreated). The application of 'D-D' before the potato crop only, failed to control numbers, there being a 12-fold increase from 7 eggs g^{-1} pre-crop to 85 eggs g^{-1} post-crop. The largest numbers of *Pratylenchus* found in November (15 000 litre^{-1} soil) were in untreated barley plots or in plots treated and sown with potatoes in 1970. There were few or no *Pratylenchus*,

TABLE 9

Yields and nematode counts, 1972

	0	P	SB	B	ALL	DAZ	Mean
Barley (t ha^{-1})	3·12	3·33	4·23	3·35	3·73	4·10	3·57
Potatoes (t ha^{-1})	29·5	32·9	33·2	32·8	34·1	33·5	32·1
Sugar (t ha^{-1})	6·38	7·21	6·28	7·17	5·87	6·99	6·61
G. rostochiensis (eggs g^{-1}) pre- and post-crop							
Potatoes I							
pre	6·6	5·0	8·2	2·2	1·9	1·2	4·2
post	33·2	18·0	62·7	33·6	8·0	4·0	26·6
Sugar beet II							
pre	11·6	4·8	3·8	4·4	3·4	5·2	5·5
post	7·1	4·2	0·5	6·4	2·5	2·8	3·9
Barley III							
pre	77·9	84·6	95·0	81·2	53·8	48·4	74·1
post	65·0	59·9	73·4	33·8	22·2	43·0	49·6

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Tylenchus, *Ditylenchus* spp. in the 'D-D'-treated barley plots and very few in the dazomet plots. Small numbers of ten other genera of plant-parasitic nematodes were present in untreated plots but mostly absent in treated ones.

1972 (Tables 2 and 9). Barley responded best to dazomet and to 'D-D' applied to sugar beet in 1970. Potato yields were best after 'D-D' or dazomet applied every year but were almost as good when 'D-D' had been applied to the previous sugar-beet crop (1971). Sugar yield was significantly improved by applications of 'D-D' to earlier potato and barley crops but not by other treatments, even continuous dazomet. *H. avenae* numbers decreased further and no significant comparisons could be made. No plots exceeded the mean initial population in 1969 of 1·3 eggs g^{-1}. The most effective control of *G. rostochiensis* was by newly applied 'D-D' and dazomet, there being only 8 and 4 eggs g^{-1} respectively compared with five- or eight-fold increases in untreated plots. Most *G. rostochiensis* were in the barley plots after potatoes the preceding year.

1973 (Tables 2 and 10). The best barley yields followed earlier applications of 'D-D'; the poorest were after continuous 'D-D' (4·23 t ha^{-1}). The best potato yields (49·5 t ha^{-1})

TABLE 10

Yields and nematode counts, 1973

		0	P	SB	B	ALL	DAZ	Mean
Barley (t ha^{-1})		4·31	5·01	5·12	4·34	4·23	4·94	4·61
Potatoes (t ha^{-1})		31·8	46·3	45·4	41·5	49·6	49·5	42·3
Sugar (t ha^{-1})		4·84	5·40	5·26	5·14	5·05	5·12	5·09
G. rostochiensis (eggs g^{-1}) pre- and post-crop)								
Potatoes	II							
	pre	7·1	4·2	0·5	6·4	2·5	2·8	3·9
	post	78·3	61·4	41·8	54·4	26·4	20·5	47·1
Sugar beet	III							
	pre	65·0	59·9	73·4	33·8	22·2	43·0	49·6
	post	33·1	38·4	26·6	21·2	19·6	9·4	24·7
Barley	I							
	pre	33·2	18·0	62·7	33·6	8·0	4·0	26·6
	post	24·5	17·1	46·7	23·1	10·0	8·2	21·6

were given by continuous 'D-D' and dazomet. Potato yields were smaller after 'D-D' applied to preceding crops, barley (1971) and sugar beet (1972); the more recent the 'D-D' treatment the better the yield. Although not significantly so, the best-sugar yields followed 'D-D' to potatoes 2 years previously and next to the current crop. The largest *H. avenae* post-crop count was no more than 1 egg g^{-1}. *G. rostochiensis* was best controlled in the potato crop by continuously applied dazomet and 'D-D', although the rates of increase were about the same (ten-fold) in untreated and treated plots.

1974 (Tables 2 and 11). The second rotation was completed and the remaining reserve plots were treated with benomyl ('Benlate') at 22 kg a.i. ha^{-1}, broadcast, then rotavated in. The best barley yield (4·23 t ha^{-1}) was after dazomet; barley newly treated with 'D-D' yielded less than the untreated plots. Whereas benomyl did not change barley or sugar-beet yields it significantly increased those of ware potato by 46%, from 35·5 to 51·9 t ha^{-1}. The best potato yields, 71 t ha^{-1}, were from the dazomet plots that received most nitrogen. Dazomet also gave most sugar. Sugar beet usually responded better to newly applied 'D-D' but not in this year.

H. avenae was almost undetectable, never exceeding 0·7 eggs g^{-1} soil. After the potato crop, most *G. rostochiensis*, 95 eggs g^{-1} soil, was in plots which were last treated with

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TABLE 11

Yields and nematode counts, 1974

	0	P	SB	B	ALL	DAZ	BEN	Mean
Barley (t ha^{-1})	3·87	3·85	3·84	3·49	3·24	4·23	3·98	3·79
Potatoes (t ha^{-1})	35·5	42·9	45·9	44·5	51·8	57·1	51·9	47·1
Sugar (t ha^{-1})	2·65	2·85	2·64	2·91	2·46	3·06	2·71	2·75
G. rostochiensis (eggs g^{-1}) pre- and post-crop								
Potatoes III								
pre	40·1	38·4	26·6	21·2	19·6	9·4	26·0	25·9
post	83·1	84·4	92·0	94·7	57·2	36·8	50·6	71·3
Sugar beet I								
pre	29·4	17·1	46·7	23·1	10·0	8·2	19·6	22·0
post	17·2	8·9	4·2	2·3	1·0	1·2	13·8	6·9
Barley II								
pre	71·7	61·4	41·8	54·4	26·4	20·5	84·8	51·6
post	33·8	38·4	22·0	24·2	2·7	1·8	42·2	23·6

Vermiform nematodes

	0	P	SB	B	ALL	DAZ	BEN	Mean
Potatoes								
Pratylenchus	42	8	17	12	3	2	64	21
Tylenchus + *Ditylenchus*	99	67	54	49	30	43	49	56
Sugar beet								
Pratylenchus	16	20	7	10	11	0	32	14
Tylenchus + *Ditylenchus*	28	18	8	17	12	6	14	15

	0		P		SB		B		ALL		DAZ		BEN		Mean	
	†Roots	Soil	Roots	Soil	Roots	Soil	Roots	Soil	Roots	Soil	Roots	Soil	Roots	Soil	Roots	Soil
Barley																
Pratylenchus	158	74	229	46	456	49	27	23	9	21	4	4	93	40	139	37
Tylenchus + *Ditylenchus*	2	42	4	37	4	40	0	37	1	36	1	10	6	17	3	31

† Roots, numbers g^{-1}, barley only; soil numbers 20 ml^{-1}, potatoes, sugar beet, barley

'D-D' in 1972. It was least in those continually treated, although numbers increased four-fold from the pre-plant numbers of 9·4 eggs g^{-1}. The next most effective treatments were benomyl, first applied this year and continuous 'D-D'. In May, *Pratylenchus* was by far the most numerous migratory endoparasite in barley roots, 456 g^{-1}, in plots which grew sugar beet treated with 'D-D' in 1972. 'D-D' in the current crop and continuous dazomet gave the most effective control of *Pratylenchus* in roots, decreasing numbers to 9 and 4 g^{-1} root respectively. '*Heterodera*' juveniles were particularly plentiful in soil in the untreated barley plots, 19 000 litre^{-1} compared with only 800 litre^{-1} in the dazomet plots. They were less abundant in the potato plots and least in sugar-beet plots. Some of the '*Heterodera*' juveniles in the barley (1974) plots may have been *G. rostochiensis* derived from the preceding 1973 potato crop. Most free-living stages of plant-parasitic nematodes were controlled by continuous 'D-D' and dazomet; benomyl was least effective.

1975 (Tables 2 and 12). All yields were severely limited by summer drought. Barley grain averaged only 1·53 t ha^{-1}, and potatoes and sugar beet all yielded less than half the 1974 averages whether treated or not. The best of the poor barley yields, 1·69 t ha^{-1}, followed dazomet or 'D-D' applied to 1973 sugar beet. Newly applied 'D-D' gave no increase and benomyl that received N3 gave barley yields smaller than for any other treatment, these were nevertheless a significant improvement on the controls. The best potato yields, 29·2 t ha^{-1}, followed continuous 'D-D' and dazomet. The response to benomyl, an increase of 6 t ha^{-1}, was proportionately the same (50%) as in 1974 but

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TABLE 12

Yields and nematode counts, 1975

	0	P	SB	B	ALL	DAZ	BEN	Mean
Barley (t ha^{-1})	1·19	1·62	1·66	1·37	1·62	1·69	1·55	1·53
Potatoes (t ha^{-1})	12·1	25·3	24·5	26·1	28·2	28·1	18·0	23·2
Sugar (t ha^{-1})	1·34	1·42	1·28	1·14	0·89	1·18	1·24	1·21
G. rostochiensis (eggs g^{-1}) pre- and post-crop								
Potatoes I								
pre	17·2	8·9	4·2	2·3	1·0	1·2	13·8	6·9
post	52·4	60·4	88·6	42·5	14·4	13·2	61·3	47·5
Sugar beet II								
pre	33·8	38·4	22·0	24·2	2·7	1·8	42·2	23·6
post	48·9	17·5	8·8	21·9	2·2	5·9	45·2	21·5
Barley III								
pre	83·1	84·4	92·0	94·7	57·2	36·8	50·6	71·3
post	51·7	62·0	127·6	52·7	79·3	20·3	25·3	59·8

this was far smaller than the 16 t ha^{-1} improvement that year. Contrary to some previous results, 'D-D' before preceding barley and sugar beet did not significantly affect potato yields. In both barley and potato crops some treatments at the N3 rate yielded less than expected (Table 2). Sugar beet failed to respond significantly to any treatment. *H. avenae* had all but disappeared from untreated or treated plots, the largest count being no more than 0·5 egg g^{-1} soil. *G. rostochiensis* was most numerous, 89 eggs g^{-1} soil, in potato plots last treated with 'D-D', a 20-fold increase. The continuously treated dazomet and 'D-D' plots had the smallest post-potato crop egg counts, 13 and 14 g^{-1} respectively, but these still represented a 13–14-fold increase over pre-crop levels. In block I planted with potatoes in 1975, the population of *G. rostochiensis* had decreased greatly after the preceding sugar beet and barley but recovery was rapid, even in 'D-D' treated plots (8·9–60·4 eggs g^{-1}). The smallest *G. rostochiensis* numbers (2–6 eggs g^{-1}) were in the continuous 'D-D' and dazomet plots currently sown with sugar beet and which last bore potatoes in 1973. *G. rostochiensis* was most numerous in the barley plots which were planted with potatoes in 1974.

1976 (Tables 2 and 13). In one of the severest droughts on record the average potato yields were even less than in 1975 and only one-third of those in 1974; barley yields averaged only 2·31 t ha^{-1} and were just over half those of 1974 but surprisingly 50%

TABLE 13

Yields and nematode counts, 1976

	0	P	SB	B	ALL	DAZ	BEN	Mean
Barley (t ha^{-1})	2·09	2·24	2·62	2·72	2·43	1·83	2·28	2·31
Potatoes (t ha^{-1})	8·7	22·4	20·5	13·5	26·4	24·3	13·1	18·4
Sugar (t ha^{-1})	4·49	4·29	5·26	4·47	5·29	4·57	4·19	4·65
G. rostochiensis (egg g^{-1}) pre- and post-crop								
Potatoes II								
pre	48·9	17·5	8·8	21·9	2·2	5·9	45·2	21·5
post	39·1	8·5	34·1	31·7	4·2	7·9	39·3	23·5
Sugar beet III								
pre	51·7	62·0	127·6	52·7	79·3	20·3	25·3	59·8
post	35·1	55·7	33·5	27·8	15·4	9·4	12·4	27·0
Barley I								
pre	52·4	60·4	88·6	42·5	14·4	13·2	61·3	47·5
post	8·4	14·0	26·5	12·2	2·9	0·5	30·4	13·6

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more than in 1975. Even more pronounced was the decrease in yields at the N3 rate irrespective of sterilant treatment. The best barley yields in this most unusual year, when 'D-D' had to be replaced by aldicarb because of adverse autumn weather, were in the aldicarb treated plots although the residual effects of 'D-D' before the sugar-beet crop in 1974 were still beneficial. Benomyl had no effect and dazomet decreased yields, mostly at the maximum N rate. The latter effect, already noted on a lesser scale in 1975 may be related to the extra mineralised nitrogen produced by sterilant action and some nitrogen derived from the dazomet molecule itself. Loss of cereal yield associated with large amounts of nitrogen in light soils has previously been noted in dry years (Widdowson, Penny & Slope, 1965).

Potato yields, though poor, were much increased by aldicarb and dazomet (three- to four-fold). The residual effects of 'D-D', applied before sugar beet in 1975, more than doubled potato yields but 'D-D' in 1974 (and benomyl treatment) increased yields by only 50%. Sugar-beet yields were increased by aldicarb only. *H. avenae* could now barely be traced. Unlike 'D-D' and benomyl, aldicarb and dazomet prevented *G. rostochiensis* from increasing. Probably because of the extraordinary drought, there was a slight decline in numbers after the untreated potato crop; populations also decreased after the sugar beet and barley, particularly in the dazomet plots.

1977 (Tables 2 and 14). In the last year of the trial, because of the exceptionally wet autumn and winter, it was impossible to apply the dazomet or 'D-D'. Instead, aldicarb

TABLE 14

Yields and nematode counts, 1977

		0	P	SB	B	ALL	DAZ	BEN	Mean
Barley (t ha^{-1})		2·72	2·96	2·99	2·68	2·63	2·82	2·66	2·78
Potatoes(t ha^{-1})		16·9	26·5	20·7	20·8	27·7	31·2	21·6	23·6
Sugar (t ha^{-1})		5·40	6·08	6·79	6·12	6·37	6·22	5·55	6·08
G. rostochiensis (eggs g^{-1}) pre- and post-crop									
Barley	II								
	pre	39·1	8·5	34·1	31·7	4·2	7·9	39·3	23·5
	post	2·7	2·0	5·7	2·7	0·3	1·4	5·3	2·9
Potatoes	III								
	pre	35·1	55·7	33·5	27·8	15·4	9·4	12·4	27·0
	post	91·3	37·5	49·1	42·5	2·6	0·4	9·0	33·2
Sugar beet	I								
	pre	8·4	14·0	26·5	12·1	2·9	0·5	30·4	13·6
	post	3·0	2·4	5·1	1·2	0·4	0·1	3·6	2·3
Pratylenchus spp. (g^{-1} root)									
Potatoes	III	127	1	10	5	0	0	12	22
Barley	II	5	2	2	0	0	3	8	3

at 5·6 kg a.i. ha^{-1} was applied just prior to spring plantings. Barley yields were unaffected by any treatment. Since aldicarb at 5·6 kg a.i. ha^{-1} has no known phytotoxic effect and 'D-D' was replaced by aldicarb in 1976, the benefits of residual 'D-D' treatment were not repeated. Aldicarb applied before the potato crop increased the ware potato yield by 8–9 t ha^{-1}. In the ex-dazomet series the increase due to aldicarb in 1977 was even greater, 14·8 t ha^{-1}. Benomyl plots yielded almost 5 t ha^{-1} more than the untreated but this increase was not significant. All treatments did however significantly increase the percentage of ware tubers.

The response of sugar beet generally resembled that of the potato crop except that the

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aldicarb treatment which replaced dazomet failed to have a significant effect. The additional response of the potato crop to the dazomet/aldicarb sequence was most probably due to the control of fungal pathogens in the previous 7 years of continuous dazomet treatment, as well as nematode control. Improvements in sugar-beet yields were more likely to be due to the control of root ectoparasitic nematodes or insects attacking the seedling stages, than to control of fungal pathogens.

By 1977 *H. avenae* had ceased to be detectable on the site, both in treated and untreated plots. *G. rostochiensis* had been very effectively controlled in potato plots which were continually treated (all crops) with 'D-D' 1969–75, aldicarb 1967–77, or dazomet 1970–76/aldicarb 1977. The plots which were treated with 'D-D'/aldicarb (1 year in 3) all had significantly fewer *G. rostochiensis* than the untreated plots but more than the continuously treated plots. The combination of rotation and sterilants was probably responsible. Benomyl also appeared to have had a highly significant controlling effect on *G. rostochiensis*.

'Productivity' of each treatment sequence 1969–77 (Tables 15, 16 and 17). This cannot be statistically evaluated because of the different years of introduction of some treatments,

TABLE 15

Mean yields ($t\ ha^{-1}$) of crops in each rotation cycle

	Potatoes	Barley	Sugar
		All untreated	
1969–71	33·3	3·12	7·10
1972–74	31·9	3·73	4·54
1975–77	12·6	2·00	3·74
		All dazomet treated	
1969–71	41·2	3·46	7·84
1972–74	46·2	4·43	5·06
1975–77	27·9	2·11	3·99

TABLE 16

Summaries of cumulative yields (9 years) ($t\ ha^{-1}$), 1969–77

				'D-D' 448 kg ha^{-1} before					
	0			P			SB		
	N1	N2	N3	N1	N2	N3	N1	N2	N3
Barley	20·1	29·5	29·5	23·1	33·0	31·5	22·3	34·0	33·9
Potatoes	177·3	244·4	277·2	258·9	336·2	352·7	237·9	306·6	366·5
Sugar	40·7	49·9	47·9	45·0	52·4	51·3	44·2	52·4	51·2

	B			ALL		
	N1	N2	N3	N1	N2	N3
Barley	19·8	29·0	32·5	19·7	30·5	31·5
Potatoes	226·6	300·0	345·9	264·6	366·0	409·3
Sugar	46·1	49·6	53·3	41·3	52·1	51·6

e.g. dazomet 1970, benomyl 1974, and adverse winter weather which forced the replacement of 'D-D' by aldicarb in 1976 and 1977, and dazomet by aldicarb in 1977. However, the 'productivity' of each system can be compared by considering the crop responses over the 9 years. The 'D-D' sequences (aldicarb in the last 2 years) were the most complete.

The best barley yields (as yearly results so often showed) came from 'D-D' applications 2 years and 1 year prior to the barley crop. The poorest yields were in the untreated or continuously treated plots confirming, over 9 years, that the beneficial effects of current

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TABLE 17

Summaries of cumulative yields (t ha^{-1})

	Untreated			Treated		
	N1	N2	N3	N1	N2	N3
				Dazomet 224 kg ha^{-1}, 1969–77		
Barley	20·1	29·5	29·5	27·5	30·4	32·6
Potatoes	177·3	244·4	277·2	284·1	360·6	392·2
Sugar	40·7	49·9	47·9	50·7	50·3	51·0
				Benomyl 5·6 kg a.i. ha^{-1}, 1974 only		
Barley	2·3	4·4	5·0	2·7	4·7	4·6
Potatoes	31·5	36·5	38·6	41·0	58·4	56·4
Sugar	2·1	2·7	3·2	2·2	2·9	3·7
				Benomyl 5·6 kg a.i. ha^{-1}, 1975–77		
Barley	5·3	6·8	5·9	5·7	7·1	6·7
Potatoes	21·3	42·5	49·5	48·0	50·2	60·0
Sugar	9·9	12·4	11·7	10·2	11·3	11·5

applications were nullified by phytotoxicity. The yield benefits, over the 9 years totalled 2–3 t ha^{-1} for a 1 in 3 year application at the N2 and N3 rates. The response to N2 nitrogen was consistent (with or without sterilant treatment) totalling about 9 t ha^{-1}, there being no further response to N3.

The potato crop gave the best response to 'D-D' treatments and was unaffected by phytotoxicity; by far the best responses (9-year total) were to continuous 'D-D' application (+132 t ha^{-1}) at the N3 nitrogen rate. Responses to 'D-D' applied 1 year in 3 to the potato crop were also better than to treatments of the preceding sugar beet or barley crops. The response to 'D-D' applied 1 year before to sugar beet was also better than 'D-D' applied to the barley crop 2 years earlier: the converse of the response of barley. Unlike barley yields, the potato yields were increased by the highest nitrogen rate. In addition to better nematode control by continuous 'D-D' applications, the extra N it made available (Williams & Salt, 1970; Draycott & Last, 1971) may have contributed to the greater yields in this sequence.

The response of the sugar beet crop to 'D-D' was slight and did not differ between the 1 year in 3 sequence and the continuous applications. All 'D-D' sequences gave an extra sugar yield of 3–4 t ha^{-1} at each nitrogen rate over the 9-year period. Yields were not further increased by N3 nitrogen whatever the treatment.

The dazomet sequence of treatments was almost complete and any yield lost from its absence in the first year was a small part of the total. The effects of continuous dazomet on barley yields were no different from those of continuous 'D-D' and of the untreated plots receiving N3, but from those receiving N1 there was a total increase of 7 t ha^{-1}. This suggests that NH_4–nitrogen accumulation following the dazomet treatment was responsible, as there was little evidence of pest damage.

The response of potatoes to dazomet (Tables 15, 17) was similar to that of 'D-D' (maximum increase at the N3 rate, 155 t ha^{-1} in 9 years) and largely reflected the effective control of *G. rostochiensis*. The further increase of 20 t ha^{-1} over continuous 'D-D' at N1, is again attributable to the increase in NH_4–nitrogen after dazomet.

The effects of dazomet on sugar production were negligible at N2 and N3 and only amounted to 7 t ha^{-1} in 9 years at the N1. Again, in the absence of serious pest attacks this response was presumably also the result of increased NH_4–nitrogen.

The effects of benomyl are best assessed in the last complete rotation cycle (1975–77) although the first applications were in 1974 (Table 17). Barley did not respond to benomyl but potato yields were more than doubled at N1. Sugar production was unaffected. Benomyl did not appear to have removed the Oomycetous fungus that controls *H.*

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avenae (Crump & Kerry, 1977). It partially controlled *G. rostochiensis* and may have controlled some fungal pathogens of potatoes (Hide & Corbett, 1974).

Cereal and potato yields were depressed by the summer droughts of 1975 and 1976. The sugar-beet crop was badly hit by drought in 1975 but recovered after the 1976 drought, aided by the heavy autumn rains.

In 1974, sugar yield was depressed by a severe attack of virus yellows and was the second worst of the 9 years despite ample rainfall (Heathcote, 1978). Cereal yields were average to good. Although the responses of barley and sugar beet to benomyl were similar in the years 1975–77 inclusive, the response of potatoes to benomyl at N1 in 1974 was less than in 1976 or 1977. In the much more suitable growing conditions of 1974 limited nitrogen may not have been such a restriction on growth.

The relationship between nematode numbers and crop yields. For two reasons the relationship between nematode numbers and crop yield is complex in this experiment. First, general soil sterilants were used which affected more than one kind of pest or pathogen. So, changes in yield may be related to factors other than those studied in detail. Thus 'D-D' and dazomet, besides killing nematodes may have depressed pathogenic fungi, and aldicarb as well as being a powerful nematicide is an equally potent insecticide. Benomyl, although known best as a fungicide can act as a nematicide (Hide & Corbett, 1974). Some treatments benefited barley and sugar beet in which there were few parasitic nematodes and the improvements may have been due to increased NH_4–nitrogen, control of fungi, other soil fauna and insect virus vectors.

The second factor affecting yields is the sequence of crops in the blocks (Table 3). If numbers of *G. rostochiensis* are studied in relation to the potato crops only, then the yield/nematode relationships are measured in different plots in successive years. If attention is confined to one block of plots then sequences of different crops are involved.

G. rostochiensis in untreated plots reached peak numbers after each potato crop then decreased until the first potato crop in the next cycle was planted. *Heterodera avenae*, never very numerous, decreased to almost undetectable numbers; similarly the numbers of *Pratylenchus* decreased as the experiment proceeded or were controlled without measurable yield benefit. *Trichodorus* and *Longidorus* spp. were in small numbers and other migratory and ectoparasitic species occurred so erratically that no clear relationships with yields emerged.

Only *G. rostochiensis* occurred in numbers sufficient to show clear relationship with yield but it was unevenly distributed between blocks. Block III had by far the most, block II the least and block I was intermediate.

Changes in *G. rostochiensis* populations are in Table 2 and Figs. 1 and 2. In certain years, reserve plots were untreated, i.e. dazomet 1969, benomyl 1969–73. Also in the first 2 years some 'D-D' plots had not yet been treated. Data from these plots were pooled with those of untreated control plots. In block I and II, where the experiment ended with non-host crops, the *G. rostochiensis* populations were slight although in the interim there were peaks after each potato crop followed by a decrease in the two succeeding crops. In block III, where populations were largest to begin with and potatoes were the last crop grown, the effects of the treatment sequences are best seen. The most effective treatments were continuous dazomet and 'D-D', with benomyl a close third. Next, and intermediate in effectiveness, were the 'D-D' sequences before one crop (1 year in 3). The crop before which the nematicide was applied, i.e. the position in the rotation, seemed to have little effect. The peak reached by *G. rostochiensis* after each untreated potato crop in block III was about the same, in block II it was highest in 1973 (but of the same order as block III). In block I, these peak densities seem not to have been reached in the three cycles of the three-course rotation.

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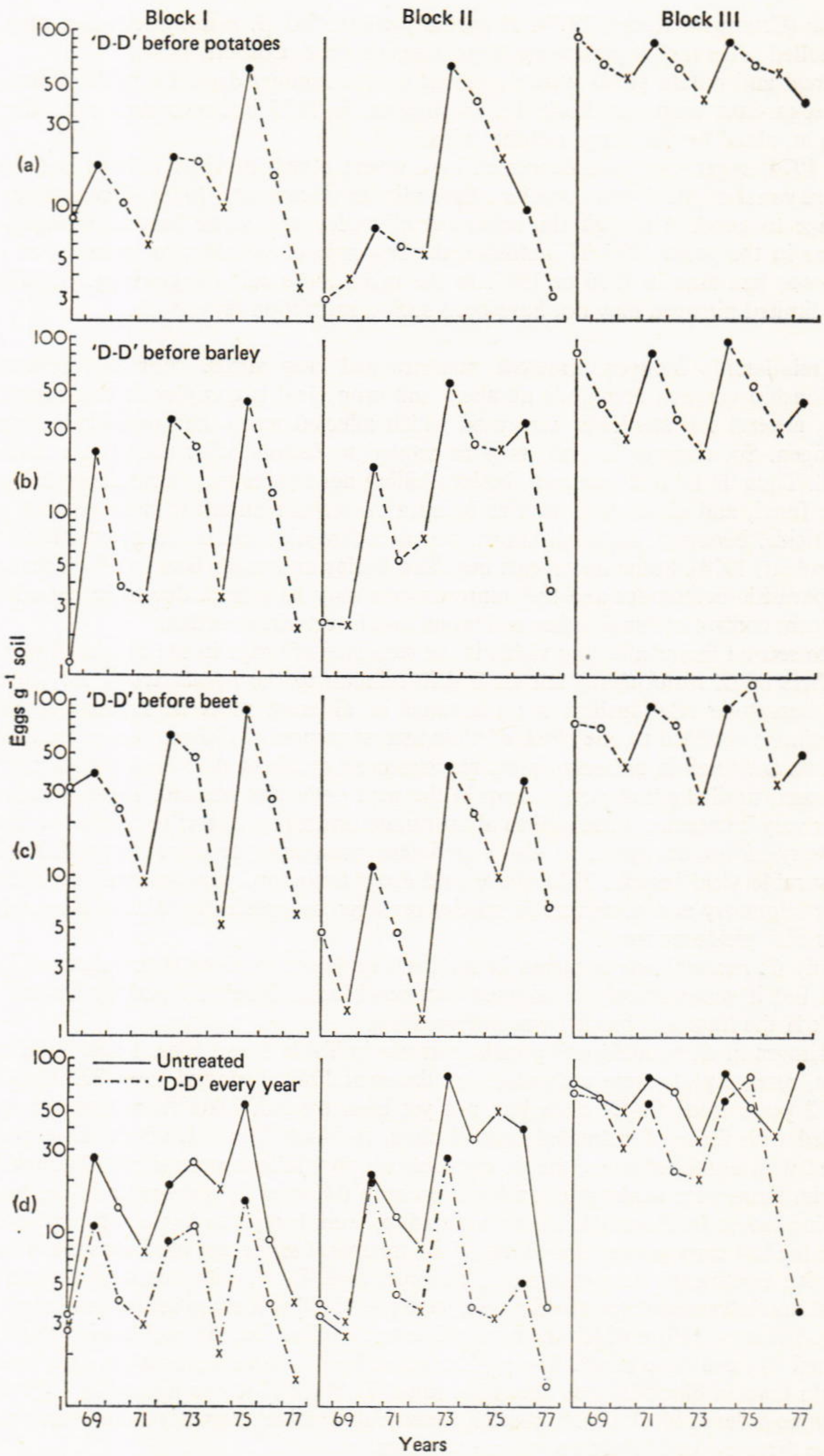

FIG. 1.

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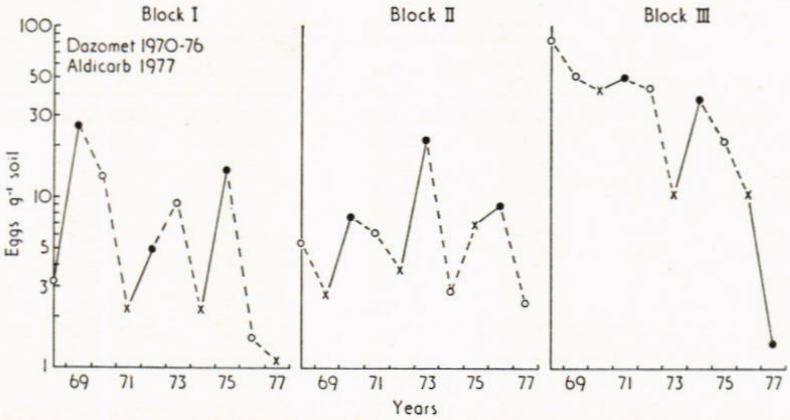

FIG. 2. Effects of dazomet applied before all crops, 1970–76, on the population density of *G. rostochiensis*. No treatment was applied in 1969 and aldicarb was substituted in 1977.

○—Barley
●—Potatoes
×—Sugar beet
—— Hot crop
--- Non-host crop

The effects of the intrinsically higher populations of *G. rostochiensis* in block III and the weather differences between 1974 (a wet year) and 1975–76 (drought years) can be clearly seen in all three blocks.

An additional check on the population fluctuations in each block was based on numbers of juveniles of *G. rostochiensis* g^{-1} root in post-crop samples tested the following year. Generally the correspondence between eggs g^{-1} soil and juveniles g^{-1} root is good and confirms the assessments of treatment effects based on the egg counts.

Discussion and conclusion

The aim of the experiment was to compare the benefits from continuously applied nematicides in a three-course rotation with those applied only once and to observe residual effects in the succeeding crops. Williams (1969a, b) had previously assessed the effects of continuous treatments.

The yield data can be considered for each 3-year cycle although comparisons between cycles are affected by weather and the incidence of pests and of diseases due to organisms other than nematodes. Thus, 1975 and 1976 were exceptionally dry, especially the latter. The relevant rainfall data for the spring and summer months are in Table 18. The time of rainfall can be as important as total amounts; drought situations can arise in years like 1975 yet monthly totals and averages may conceal the severity and timing of soil moisture deficits. These have been calculated for most of the period of this experiment and show the times and extent of maximum water stress more precisely. Drought conditions

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FIG. 1. Effects of 'D-D' applied before planting potatoes, sugar beet and barley (once in the rotation) and before each crop (every year) compared with untreated, on the population density of *G. rostochiensis* eggs g^{-1} soil. Note that aldicarb was substituted for 'D-D' in 1976 and 1977 and that 1975 was dry and 1976 exceptionally so.

○—Barley
●—Potatoes
×—Sugar beet
—— Host crop
--- Non-host crop } Figs. 1a,b,c

(Sequences of host and non-host crops in Fig. 1d same as in Figs 1a,b,c.)

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TABLE 18

Woburn rainfall, 1969–77

	March–September		June–August	
	Amount (mm)	Deficit/surplus (mm)	Amount (mm)	Deficit/surplus (mm)
1969	330	−43	152	−25
1970	300	−64	138	−31
1971	339	−23	207	+38
1972	277	−85	109	−59
1973	344	−13	140	−26
1974	416	+57	219	+53
1975	407	+46	74	−95
1976	201	−162	45	−121
1977	378	+16	241	+77

occurred in 1970, 1975 and 1976 when peak deficits (for 100% ground cover) were 204, 238 and 425 mm respectively.

The poor barley yields during the last cycle are attributable to drought. In 1974 virus yellows was unusually severe (Heathcote, 1978), this disease being both much less prevalent and further checked by aldicarb applications in 1976 and 1977.

Potato yields were greatly increased by some treatments, undoubtedly due to control of the most injurious pest, *G. rostochiensis*. Barley and sugar-beet yields were much less improved because pests amenable to control by the chemicals used were few or absent. Where improvements occurred, they were probably due to control of relatively small numbers of migratory and ecto-parasitic nematodes and other soil fauna. The beet cyst-nematode *H. schachtii*, an injurious pest of sugar beet, has never been found at Woburn.

Fumigants that must be applied in autumn or early winter to soil in seedbed condition and free of trash and then require a period for phytotoxic gas to disperse before crops can be planted are agriculturally inconvenient under British conditions, even on sandy soils. Difficulties and delays were often experienced in injecting the 'D-D' liquid fumigant and it rarely went in under ideal conditions: in 2 years out of 9 it had to be abandoned. Applying dazomet prill was somewhat easier but had similar disadvantages: it was abandoned in 1 year out of 9. Aldicarb and benomyl granules were applied to the seedbed in spring without any special difficulties other than safety precautions.

As is well substantiated by field experience, a three-course rotation (2 years' rest between potato crops) failed to control potato cyst-nematode populations, though it did control the cereal cyst-nematode *H. avenae*. Better control of *G. rostochiensis* was obtained by a combination of rotation and 'D-D' or dazomet, especially when these were applied before every crop in the rotation. When 'D-D'/aldicarb was applied only 1 year in 3 the choice of crop treated had no over-all effect on nematode numbers though barley yields were least after 'D-D' in the same year and potato yields best after treatment in the same year. Whitehead (1975) has shown that under British conditions the oxime carbamate granular nematicides are more convenient to apply, are effective on a greater range of soil types and give better population control than do fumigant nematicides.

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APPENDIX FIGURE 1

Plan of the Rotation Fumigation Experiment (Woburn, 1969–77)

BLOCK I

1	01 N2 DAZ	02 N1 ALL	03 N3 P	04 N3 DAZ	05 N2 O	06 N1 P
2	ALL	SB	DAZ	SB	B	O
3	B	DAZ	BEN	B	BEN	B
4	BEN	BEN	ALL	BEN	ALL	BEN
5	P	O	SB	P	DAZ	DAZ
6	SB	P	B	O	P	SB
7	O	B	O	ALL	SB	ALL

BLOCK II

1	07 N1 SB	08 N2 B	09 N3 BEN	10 N2 B	11 N1 ALL	12 N3 BEN
2	P	ALL	O	ALL	B	B
3	DAZ	SB	SB	DAZ	SB	P
4	B	P	DAZ	O	P	DAZ
5	O	O	B	BEN	BEN	SB
6	BEN	BEN	P	SB	DAZ	ALL
7	ALL	DAZ	ALL	P	O	O

BLOCK III

1	13 N3 O	14 N1 B	15 N2 ALL	16 N1 SB	17 N2 DAZ	18 N3 BEN
2	BEN	O	O	BEN	O	P
3	ALL	SB	P	ALL	BEN	B
4	SB	ALL	B	DAZ	P	DAZ
5	DAZ	BEN	BEN	O	SB	SB
6	B	DAZ	SB	B	ALL	ALL
7	P	P	DAZ	P	B	O

For key see page 48. Sub-plots are shown with the designated treatments, not all were applied at the start of the experiment and some were changed in the last two years. (For details see text.)