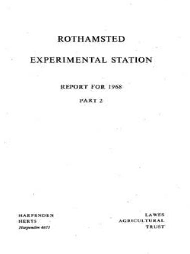
Rothamsted Experimental Station Report for 1968 - Part 2



Full Table of Content

10. Weed Studies on Broadbalk

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10. WEED STUDIES ON BROADBALK

JOAN M. THURSTON

The Latin names used here are those given to the species in Clapham, Tutin and Warburg, *The Flora of the British Isles*, 2nd edition, 1962, and are not always the same as those in the original records or early publications. The common names are those used in the *Weed Control Handbook*, 5th edition (Fryer & Evans, 1968).

Historical

In the early years of the experiment the wheat was sown in 12½-inch rows (Table 2·2), permitting inter-row cultivation by hand or horse-drawn implements and hand-pulling of weeds not eliminated by cultivation. Weeds are first mentioned in 1854, when they were hoed in April and hoed and hand-picked from mid-May to early June. The first weeds recorded by name, wild oats, were picked out from 13 to 27 July 1854, but we are not told whether they were *Avena fatua*, *A. ludoviciana* or both. Wild-oat pulling is mentioned at intervals from then on.

TABLE 10·1

Species present in stubble, 20 September, 1869

Latin name	Common name	Plot													
		2	3	5	6	7	8	9	10	11	12	13	14	15	16
**Agrostis tenuis*	Common bent-grass		+	+	+	+	+	+	+	+				+	
Alopecurus myosuroides	Blackgrass	+													
Anagallis arvensis	Scarlet pimpernel							+			+	+	+	+	
**Anthemis cotula*	Stinking mayweed		+						+						
Capsella bursa-pastoris	Shepherd's purse									+					
Cirsium arvense	Creeping thistle	+	+	+	+	+	+		+	+	+	+	+	+	+
Convolvulus arvensis	Field bindweed	+	+	+	+	+	+	+	+	+	+	+	+	+	+
Equisetum arvense	Horsetail		+	+	+	+	+		+	+	+	+	+	+	
Knautia arvensis	Field scabious	+	+	+	+	+	+		+						
Myosotis arvensis	Forget-me-not	+		+	+	+	+	+		+	+	+	+	+	+
Plantago lanceolata	Ribwort									+					
Plantago major	Greater plantain							+		+					+
Polygonum aviculare	Knotgrass			+	+	+	+	+		+	+	+	+	+	+
Ranunculus repens	Creeping buttercup										+	+	+	+	
Rumex obtusifolius	Broad-leaved dock									+					
Senecio vulgaris	Groundsel	+						+		+	+	+	+	+	
Sonchus arvensis	Perennial sow-thistle								+	+					
Stellaria media	Chickweed	+		+	+	+	+	+	+	+	+	+	+	+	+
Trifolium pratense	Red clover	+													
Tussilago farfara	Coltsfoot		+												
Veronica agrestis	Procumbent speedwell	+						+	+	+			+	+	+
Veronica arvensis	Wall speedwell	+						+	+	+			+	+	+
Viola arvensis	Field pansy	+		+	+	+	+		+	+	+	+	+	+	

* Some of the identifications evidently caused trouble. Possibly *Anthemis cotula* is a mis-identification of *Tripleurospermum maritimum*. The plant described then as *Agrostis vulgaris* (now *A. tenuis*) was probably *A. stolonifera*, which still occurs on Broadbalk.

The first plot-by-plot list of weed species in the original record-book is in 1869 (Table 10·1), accompanied by a note that 'a very little time could be spared for the observations, these notes are necessarily imperfect, many plants existing which are not noticed here and probably the prominence given to a particular species is not always correct'. (This could often be

https://doi.org/10.23637/ERADOC-1-2

said of more recent records!) The assessment of abundance is not in absolute terms, so only presence is shown in Table 10·1. Some of the identifications evidently caused trouble, as shown by alterations in different ink, often by the same hand. All show that the writer confused the plant with another species similar in general appearance, e.g. *Hippuris vulgaris* for *Equisetum vulgare*; *Cerastium viscosum* or *C. vulgatum* for *Stellaria media*; *Veronica chamaedrys* for *V. agrestis* and *V. arvensis*. Possibly *Anthemis cotula* should have been corrected to *Tripleurospermum maritimum* ssp. *inodorum*, as scentless mayweed is common on Broadbalk now but stinking mayweed has not occurred on Rothamsted farm in the last 25 years, although it is occasional on the lighter soil of the adjacent Scout Farm. *Agrostis stolonifera* is also more probable on Broadbalk than *A. tenuis*. The other species still occur on Broadbalk, although their distribution between plots, and relative adundance, differ considerably from the 1869 list. e.g. *Anagallis arvensis* is characteristic of plot 10 now, and in some years occurs only there, *Viola arvensis* is much less widespread and *Tussilago farfara* has invaded many more plots. *Trifolium* spp. (clovers) still tend to occur on plot 2, presumably introduced as seeds in the farmyard manure. *Papaver* spp. (poppies) are absent from this list. The stalks are not easily recognisable in stubble and they are under-estimated in the modern stubble-surveys where every species seen is recorded and assessed, so they may have been present in 1869. They are unlikely to have been abundant, because they are not named in any of the early records; the species most often noted are perennials (creeping thistle, creeping sowthistle, bindweed, coltsfoot) although three annuals are mentioned (knotgrass, mayweed and, most frequently, wild oats).

With the introduction of narrower-spaced rows, and the labour-shortage of the 1914–18 war, hand-weeding and hoeing lapsed, and by 1925 the field had become very weedy (Warington, 1924). Hormone herbicides were unknown, and much of the field was fallowed between 1926 and 1929 to diminish the weed-population. In 1931 a scheme was introduced whereby one-fifth of the field was fallowed each year (Table 2·2).

Brenchley and Warington (1930, 1933) took the opportunity of studying the effect of fallow on the weed-seed population in the soil of selected plots (see Special Weed Investigations, p. 190).

Routine plot-by-plot surveys of weeds on Broadbalk were started by 1930 and have continued ever since (see p. 188). With the advent of herbicides, a return to continuous wheat-growing was attempted, starting in 1956 on section IA and in 1963 on section VB. Weed species and their abundance on these and on the corresponding half-sections IB and VA remaining in the fallow cycle were compared (see p. 191).

Since 1963 the whole field except section VA has been sprayed in spring with an appropriate herbicide against dicotyledons, giving a comparison of weed control with fallow and without herbicide, without fallow and with herbicide, and with both. Herbicides have been used less regularly and rather ineffectively against perennial grasses, and only on section IA. Wild oats are hand-pulled every year, but no herbicide has been used against *Alopecurus myosuroides* (blackgrass) (Table 2·2).

In addition to the studies of weed populations, individual species have

https://doi.org/10.23637/ERADOC-1-2

also been investigated, starting with wild oats in 1944 and particular situations including the effect of combine-harvesting on the distribution of weed-seeds, after the change from cutting and stooking in 1957, and the use of blank rows to guide the combine in taking experimental cuts (see Special Weed Investigations, p. 190).

Routine visual surveys

The method has been constant throughout and care is taken to ensure that different people contributing records score similarly. The recorder enters the plot-section at one end and walks zig-zag up it, listing all the species seen except those within 18 in. of the edges of the plot, as weed-seeds are occasionally introduced from the paths. Then each species is assigned a score for abundance. Originally these scores were verbal descriptions indicated by signs, but the ease with which a newcomer could be taught to use the system accurately suggested that it must have a quantitative basis. Samples from parts of headlands with different and characteristic weed-scores for five common and abundant species showed that the scores were almost identical with the logarithm of the number of weeds present per unit area (Table 10·2), and that for every weed plant seen there were two

TABLE 10·2

Relation of visual scores to logarithm of number of weed plants per unit area. (*Mean of five common and abundant species*)

Visual score	Plants per $\frac{1}{3}$ m²	Logarithm
P	3·1	0·49
P+	12·5	1·10
PP	43·0	1·63
PP+	70·9	1·85
PPP	195·8	2·29

or more small plants hidden by the crop or other weeds. The relationship to dry weight of weed tops per unit area was less definite, as the weight of an individual plant varied with species, fertiliser and competition from the crop and from other weeds.

Routine surveys of all species on all plots have been made twice yearly since 1930. The first survey is in late May, or in an exceptionally late season early June, after the spring-germinating weeds have grown large enough to be clearly recognisable without kneeling down, and before the crop is tall enough to be damaged by walking through it and parting it to see the weeds. The second survey is after the crop has been cut and carted, but before cultivations or herbicides have destroyed the weeds in the stubble. This shows late-germinating species.

Supplementary surveys are made in the same way, as required for special purposes. Wild oats and blackgrass, better seen in the standing crop when they are flowering than in May or in the stubble, have been surveyed in July since work began on them at Rothamsted. *Papaver* spp. and *Vicia sativa* were recorded in July 1957.

https://doi.org/10.23637/ERADOC-1-2

Use of routine records

The routine records are unique in their long continuity, with sporadic records reaching back over 100 years. Their value is greatly enhanced by association with complete agricultural information (cultivation, sowing, weeding and harvest dates, and yields) and a long run of Rothamsted meteorological measurements (p. 209). The fertiliser treatments provide a wide range of soil fertility and hence of associated weed-species under identical weather and management, with only minor differences in soil-type. Information on soil nutrient status, and attacks on the crop by pests and diseases, comes from other departments studying these aspects of Broadbalk, and help in identifying pests and diseases of the weeds can be obtained from the same specialists. Nothing comparable exists elsewhere, e.g. the Agricultural Research Council's Weed Research Organisation took over its own farm only in 1960 and it has no plant pathologists or entomologists.

The routine observations on about 30 species were used by Warington (1958) in a study of changes in the weed-flora over a 25-year period since the fallowing cycle was introduced. Five of the most widely-distributed annual species had become less abundant, seven had increased and seven fluctuated in numbers. All five perennials diminished when the fallow was first introduced, but two re-established themselves before 1955 and two more have done so since. The general conclusion from this study is that weed species differ greatly in their responses to a given set of conditions and that it is unwise to generalise about weed behaviour without accurate observations on the species concerned.

Information on numerous aspects of weed biology can be extracted from the accumulated Broadbalk observations even if individual records are scarce, frequently indicating which factors to investigate first, if not actually answering the enquiry. For example, the Leguminosae *Vicia sativa* and *Medicago lupulina* are characteristic of plots receiving no or only small amounts of N fertiliser, especially if P and K are also given; *Stellaria media* is often the only prostrate species on plot 8 (N_3PKNaMg) although on the soil of the equally heavy-yielding and densely shaded plot 2 (FYM) it is joined by several others; *Anagallis arvensis* is more plentiful on plot 10 (N_2 only) than on any other plot; *Atriplex patula* is characteristic of the no-K plots 11, 12 and 14, although it also occurs elsewhere; *Valerianella dentata* is almost confined to plot 3 (unmanured) and plots 17 and 18 (N_2 in alternate years, PKNaMg in the others); *Myosotis arvensis* is more prevalent after wet summers and *Tripleurospermum maritimum* ssp. *inodorum* after dry ones because of the effect of season on seed-setting.

The relationship of the abundance of the semi-parasite *Odontites verna* to fallowing, nitrogenous fertiliser and crop-competition, as shown by Broadbalk surveys for the 21 years 1933–53, was worked out for comparison with *Striga hermonthica*, a semi-parasite of sorghum in the Sudan. Abundance of *Odontites* was only slightly affected by the fallowing-cycle; the scores in four successive years after fallow were 70, 47, 56 and 62, but it was most abundant in the first year after fallow and least in the second, indicating that many seeds remain dormant for more than a year and that

https://doi.org/10.23637/ERADOC-1-2

the presence of the crop, a suitable host-plant, may stimulate germination. Laboratory and glasshouse studies show that, in the absence of wheat plants, about 55% of *Odontites* seeds present in field soil after harvest germinate in the first year, 40% in the second and 5% in the third or subsequent years, that germination is confined to a period of about 5 weeks, mainly in March, either in soil or on filter paper, and that germination does not require the presence of wheat as host, although the possibility of stimulation by its presence is not excluded. The abundance of March-germinating *Odontites* is probably determined by crop-competition (represented by grain yield in Table 10·3) rather than by the combination of fertilisers that produced it.

TABLE 10·3

Abundance of Odontites verna *in 21 years, 1933–53 in relation to fertilisers and grain yield*

Plot	Treatment[1]	Total score 4 cropped sections × 21 years	Mean grain yield cwt/acre 1935–64
3	None	73	11·3
5	P K Na Mg	47	12·8
7	N_2 P K Na Mg	7	19·7
17 & 18	N_2 } alternate years	34	19·4
18 & 17	P K Na Mg } alternate years	74	10·8

[1] For full details see tables 2·1 and 2·2.

Special weed investigations on Broadbalk

1. The effect of fertilisers and fallowing on the buried weed-seed content of the soil, and observations on their natural dormancy. (Brenchley and Warington, 1930, 1933, 1936, 1945; Warington, 1936). These classic papers describe the effect of the intensive fallowing of 1926–29 on the numbers of viable seeds of annual weeds in Broadbalk soil, and their distribution on plots receiving contrasting fertiliser-treatments. Soil-samples of known volume were taken from undisturbed stubble of all five sections of seven plots soon after harvest. They were concentrated by washing to remove stones and some of the clay fraction, while retaining all the weed-seeds and enough soil to grow them in. The soil containing seeds was kept moist in shallow earthenware pans in a cool glasshouse for three years. Seedlings were indentified, removed and counted every six or seven weeks, when the soil was thoroughly cultivated, burying seeds that had been near the surface and bringing up those that had been buried. The quarterly totals for October–December, January–March, April–June and July–September showed differences between species in periodicity of germination, and the yearly totals the differences in longevity. The three-year totals approximated to the total viable weed-seeds present, although a few seedlings of some species, e.g. *Tripleurospermum* and *Anagallis*, appeared in the fourth and subsequent years in pans that were kept; it was assumed that except for these, all viable seeds had produced identifiable seedlings.

The first paper (Brenchley & Warington, 1930) describes periodicity and longevity of 27 species, grouping them into autumn-germinating (October–December), so-called winter-germinating (January-March),

https://doi.org/10.23637/ERADOC-1-2

which appear in spring out-of-doors, and those germinating immediately the soil was brought in, or showing little or no periodicity but germinating throughout the year.

The second paper (Brenchley and Warington, 1933) using the method and information on germination-behaviour from the first, investigates the response of annual weed-seeds to two consecutive years of frequently-cultivated fallow. Species were placed in one of five groups, A to E, according to whether the buried seeds at the end of the first year's fallow (1926) were over 100%, 61–80%, 41–60%, 31–40% or 10–30% of the number originally present. After two years fallow (1926–27) the numbers in these five groups had decreased to 90–100%, 41–50%, 21–40%, 13–20% and less than 12%, with one species in each group falling outside these limits.

Two factors were concerned in maintaining the viable seed population during the two-year fallow. One, characteristic of group A, e.g. *Capsella* was the ability to set seed within a few weeks of germination, i.e. in the short period between successive cultivations, or very early in the year, while the clay soil was too sticky to cultivate. The other was a long period of innate dormancy, shown particularly by groups B and C, e.g. *Tripleurospermum*. *Alopecurus myosuroides* is typical of the easily-controlled group E, with short innate dormancy and a long growing-period between autumn germination and summer seed-shedding.

This work depended on accurate seedling-identification. The species characteristics used for this and subsequent Broadbalk investigations are incorporated in a book on seedling-identification prepared at the A.R.C. Weed Research Organisation (Chancellor, 1966).

Species differed in their response to times of cultivation of the fallow, according to their growth-cycles (Brenchley & Warington, 1936). They also differed in the ease with which they re-established themselves when cropping with winter wheat was resumed, e.g. *Alopecurus myosuroides* reasserted itself quickly but *Papaver* spp. did not. (Brenchley & Warington, 1945).

2. A comparison of bare fallow and herbicides for weed-control. The re-introduction of continuous wheat-growing on Broadbalk provided an opportunity to study its effect, and that of the herbicides used with it, on the weed flora, and to compare it with the degree of control obtained by fallowing one year in five on the corresponding half-sections. From 1964 to 1967, section IB was treated with herbicides as well as being in the fallow-cycle (Tables 10·4 and 10·5). All herbicides were applied at the manufacturer's recommended dose for the formulation used (Table 2·2).

This investigation gives background information required in interpreting Broadbalk yields, but it also provides additional information on weed biology and competition with the crop. The long-term record of weed-seed content of the soil, starting before herbicides were used, is unique. It is of great interest to farmers who are asking whether they can safely discontinue spraying against broad-leaved weeds in cereals after using herbicides annually for many years, on the grounds that weed-seed stocks in the soil should be depleted by now.

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TABLE 10·4

Relation of grain yields and total weediness to herbicides and fallowing, sections IA and IB, 1955–67

		No herbicides		Herbicides on section IA only							Herbicides on both IA and IB			
	Section	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967
Herbicides[1]	IA			MCPA	Mecoprop	MCPA/ TBA	Mecoprop	MCPA/ TBA	MCPA/ TBA	Mecoprop/ 2,4-D	MCPA/ Dicamba	MCPA/ Dicamba	Mecoprop/ Ioxynil	Mecoprop/ Ioxynil
Fallow years (F)	IB	—	F	—	—	—	—	F	—	—			F	
Grain yields														
Mean of all plots cwt/acre at 85% dry matter	IA	17·1	15·4	15·7	21·5	19·2	17·6	14·3	22·3	18·7	15·7	16·0	22·0	14·8
	IB	17·6	—	23·2	18·9	18·6	16·7	—	24·9	18·5	17·6	16·9	—	23·4
Total weed score, visual survey of all plots														
May, approx. 50 species	IA	353	298	396	247	460	357	396	262	289	337	423	369	269
	IB		—	434	390	480	518	—	489	543	401	520	—	346
Stubble, approx. 60 species	IA	258	471	358	234	407	361	381	355	322	139	316	228	278
	IB		—	312	241	419	419	—	298	345	179	398	—	279
Mean number of weed species per plot														
May	IA	11·5	9·8	12·8	9·2	15·1	10·8	13·2	8·5	10·1	10·9	14·2	13·6	9·2
	IB		—	14·0	13·0	15·3	15·1	—	14·8	14·6	11·9	15·1	—	10·2
Stubble	IA	8·6	14·6	13·9	9·3	14·5	12·1	13·5	11·6	10·9	4·8	9·2	7·5	9·9
	IB		—	11·8	8·8	13·7	12·1	—	9·3	11·3	5·8	12·1	—	10·0

[1] Doses, dates and concentrations are listed in Table 2·2

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TABLE 10·5

Relation of grain yields and total weediness to herbicides and fallowing, sections VB and VA, 1962–67

	Section	No herbicide 1962	Herbicide on section VB only 1963	1964	1965	1966	1967
Herbicides	VB	—	Mecoprop/ 2,4-D	MCPA/ Dicamba	MCPA/ Dicamba	Mecoprop/ Ioxynil	Mecoprop/ Ioxynil
Fallow years (F)	VA	—	F	—	—	—	—
Grain yields							
Mean of all plots cwt/acre at 85% dry matter	VB	16·3	15·4	15·3	18·0	22·3	15·3
	VA	17·6	—	16·5	20·7	21·3	13·2
Total weed score, visual survey of all plots							
May, approx. 50 species	VB	438	323	391	408	409	379
	VA	416	—	491	411	387	363
Stubble, approx. 60 species	VB	339	371	122	323	283	293
	VA	323	—	117	286	280	306
Mean number of weed species per plot							
May	VB	11·6	9·5	10·8	11·4	12·1	10·9
	VA	10·7	—	12·9	10·9	10·7	11·1
Stubble	VB	11·6	11·2	4·8	10·9	9·5	10·2
	VA	10·2	—	4·1	9·3	8·9	9·8

The weeds visible on all plots in the field were studied from the routine survey records (Tables 10·4, 10·5, 10·6, 10·7). The weed-seed content of soil from five plots (2B, 5, 7, 9, 18) selected to cover a wide range of species and fertility, was investigated by the method of Brenchley and Warington (1930) (Tables 10·8, 10·9, 10·10). The results obtained by the two methods agree where they overlap, but each gives some information not obtainable by the other. The interim results for sections IA and IB have been summarised (Thurston, 1964a). Field records are complete up to 1967, but because pans are kept for three years the final results of the weed-seed investigation will not be obtained until after September 1970.

The grain yields for sections IA, IB, VA and VB (Tables 10·4 and 10·5) show no consistent effect of weeds on yield. Yield and fallow-cycle are correlated, especially on section IB, but the weed scores and mean number of species do not closely correspond to yield, so it probably depends more on other factors affecting growth of winter wheat than on diminished weed-growth in the first year after fallow. Section VA showed only a slight increase in yield in 1964, after fallowing in 1963. Wheat bulb fly attack in 1964 was moderate (Fig. 7·2) and take-all also seems unlikely to have restricted yields more in this year than in others (p. 139). However, the weed-scores and number of species in May were larger on VA in 1964 than in any of the years 1962–67, and also larger than on VB in the same year. The winter 1962–63 was unusually severe and the field was under snow from 26 December 1962 to the first week in March 1963, and was too wet to cultivate for the rest of March. Autumn and winter-germinating

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TABLE 10·6

Scores based on visual surveys for abundance of some of the most serious weeds on Broadbalk

(Scores 0–5 for increasing abundance on 18 plots, therefore highest possible score = 90)

			No herbicides		Herbicides on section IA only							Herbicides on IA and IB			
Species	Scored	Section	1955	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966	1967
ANNUALS															
Ranunculus arvensis	May	IA	47	39	61	45	50	50	15	37	23	28	30	17	20
(Corn buttercup)		IB		—	65	57	60	61	—	73	63	56	57	—	50
Vicia sativa	May	IA	34	28	39	3	20	0	2	1	1	1	8	4	6
(Common vetch)		IB		—	36	27	29	30	—	23	25	6	30	—	9
Medicago lupulina	May	IA	3	10	9	2	25	6	9	2	10	1	11	6	0
(Black medick)		IB		—	14	29	23	25	—	24	47	3	23	—	0
	Stubble	IA	42	45	42	42	35	46	38	17	22	6	16	11	29
		IB		—	51	60	56	57	—	65	55	11	29	—	33
Papaver rhoeas and P. argemone	May	IA	20	23	16	9	41	25	30	6	13	8	22	29	14
(Poppies)		IB		—	30	33	43	45	—	26	39	13	28	—	34
Tripleurospermum maritimum	Stubble	IA	7	31	23	9	34	28	49	35	39	27	43	14	25
(Scentless mayweed)		IB		—	17	10	30	30	—	19	24	42	45	—	28
Alopecurus myosuroides	May	IA	32	35	14	20	23	65	73	59	44	52	59	45	50
(Blackgrass)		IB		—	13	13	22	63	—	49	30	58	58	—	55
Poa annua	Stubble	IA	0	2	2	0	11	7	11	7	10	0	8	19	14
(Annual Meadow Grass)		IB		—	1	0	3	1	—	0	0	1	3	—	6
PERENNIALS															
Cirsium arvense	Stubble	IA	40	34	26	26	22	13	13	7	7	3	4	8	7
(Field thistle)		IB		—	26	29	42	40	—	18	23	28	23	—	10
Tussilago farfara	Stubble	IA	12	3	7	6	7	5	4	8	4	9	10	13	12
(Coltsfoot)		IB		—	12	10	13	13	—	12	11	13	20	—	12
Equisetum arvense	Stubble	IA	13	4	2	3	5	4	6	12	12	19	19	20	29
(Field horsetail)		IB		—	3	3	6	6	—	11	16	22	33	—	34
Agrostis stolonifera	Stubble	IA	1	6	4	6	25	13	24	31	26	13	23	5	0
(Creeping bent grass)		IB		—	1	2	5	6	—	4	5	3	8	—	0
Poa trivialis	Stubble	IA	0	0	16	13	5	5	17	16	18	10	19	7	5
(Rough stalked meadow grass)		IB		—	5	2	2	0	—	1	3	1	18	—	4

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TABLE 10·7

Scores based on visual surveys for abundance of some of the most serious weeds on Broadbalk

(Scores 0–5 for increasing abundance on 17 plots, therefore highest possible score = 85)

Species	Scored	Section	Herbicides on section VB only 1962	1963	1964	1965	1966	1967
ANNUALS								
Ranunculus arvensis (Corn buttercup)	May	VB	34	19	37	32	14	27
		VA	38	—	44	33	30	30
Vicia sativa (Common vetch)	May	VB	33	4	19	30	18	17
		VA	24	—	36	31	37	29
Medicago lupulina (Black medick)	May	VB	26	18	11	16	8	7
		VA	23	—	14	17	5	5
	Stubble	VB	56	43	10	22	17	34
		VA	42	—	13	41	42	41
Papaver rhoeas and P. argemone (Poppies)	May	VB	40	7	23	33	56	45
		VA	31	—	45	28	49	38
Tripleurospermum maritimum (Scentless mayweed)	Stubble	VB	42	41	36	39	13	31
		VA	43	—	15	33	25	35
Alopecurus myosuroides (Blackgrass)	May	VB	63	53	60	61	45	60
		VA	60	—	63	63	41	55
Poa annua (Annual meadow grass)	Stubble	VB	2	19	2	13	24	15
		VA	6	—	0	8	13	13
PERENNIALS								
Cirsium arvense (Field thistle)	Stubble	VB	15	17	4	6	6	9
		VA	12	—	1	2	4	10
Tussilago farfara (Coltsfoot)	Stubble	VB	0	0	0	1	0	1
		VA	1	—	1	2	1	3
Equisetum arvense (Field horsetail)	Stubble	VB	2	3	4	7	8	11
		VA	16	—	21	24	22	37
Agrostis stolonifera (Creeping bent grass)	Stubble	VB	12	27	16	11	36	28
		VA	14	—	1	1	2	7
Poa trivialis (Rough stalked meadow grass)	Stubble	VB	23	32	8	29	25	21
		VA	13	—	1	5	5	6

TABLE 10·8

Viable weed-seeds per sq ft in sections IA, IB, VB and VA in the year before continuous wheat started on IA and VB

	1955 IA	1955 IB	1962 VB	1962 VA
All species	503	690	3219	2540
Ranunculus arvensis (Corn buttercup)	29	31	14	16
Vicia sativa (Common vetch)	32	15	56	68
Medicago lupulina (Black medick)	43	72	327	180
Papaver rhoeas and P. argemone (Poppies)	157	207	1307	961
Tripleurospermum maritimum (Scentless mayweed)	3	5	480	442
Alopecurus myosuroides (Blackgrass)	38	72	397	288
Myosotis arvensis (Forget-me-not)	3	6	2	2

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TABLE 10·9

Viable weed-seeds in soil from sections IA (continuous wheat) and IB (fallow 1956 and 1961) of 5 plots (2B, 5, 7, 9, 18) as percentage of seeds present in 1955 before section I was sub-divided

Species	Section	No herbicides		Herbicides on section IA only							Herbicides on IA and IB
		1955	1956	1957	1958	1959	1960	1961	1962	1963	1964
All species	IA	100	193	136	133	160	319	361	223	172	200
	IB	100	69	88	119	272	275	134	310	472	188
Ranunculus arvensis	IA	100	110	59	59	27	42	16	5	12	2
(Corn buttercup)	IB	100	100	174	147	206	171	80	244	163	80
Vicia sativa	IA	100	66	33	30	6	5	<1	<1	<1	<1
(Common vetch)	IB	100	74	143	87	54	108	53	95	58	13
Medicago lupulina	IA	100	158	81	111	79	108	64	41	168	20
(Black medick)	IB	100	99	81	203	444	309	190	192	1050	52
Papaver rhoeas and P. argemone	IA	100	168	114	129	128	190	84	136	85	48
(Poppies)	IB	100	65	54	129	276	171	160	190	308	145
Tripleurospermum maritimum	IA	100	156	363	538	2756	1513	16963	7438	7013	2669
(Scentless mayweed)	IB	100	77	85	212	2777	1342	527	8246	12058	1519
Alopecurus myosuroides	IA	100	145	121	176	478	802	1675	426	141	481
(Blackgrass)	IB	100	27	130	87	363	501	70	208	92	298
Myosotis arvensis	IA	100	2031	1031	815	307	3115	454	392	638	146
(Forget-me-not)	IB	100	45	90	224	1186	1566	348	1038	1162	114

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TABLE 10·10

Viable weed-seeds in soil from sections VB (continuous wheat) and VA (fallow every 5th year) of 5 plots (2B, 5, 7, 9, 18) as percentage of seeds present in 1962, before continuous wheat-growing began on section VB

Species	Section	1962	1963	1964
All species	VB	100	33	34
	VA	100	36	59
Ranunculus arvensis	VB	100	42	45
(Corn buttercup)	VA	100	54	61
Vicia sativa	VB	100	16	6
(Common vetch)	VA	100	35	84
Medicago lupulina	VB	100	23	7
(Black medick)	VA	100	48	25
Papaver rhoeas and P. argemone	VB	100	38	26
(Poppies)	VA	100	43	47
Tripleurospermum maritimum	VB	100	23	16
(Scentless mayweed)	VA	100	28	105
Alopecurus myosuroides	VB	100	26	64
(Blackgrass)	VA	100	11	53
Myosotis arvensis	VB	100	40	20
(Forget-me-not)	VA	100	91	18

species, especially *Alopecurus* and *Ranunculus*, were scarce on cropped plots in April, and spring-germinating species were late starting, so probably more seeds remained dormant in fallow soil than in most years, germinating in the crop in the more usual soil and weather conditions of 1964. Except for the 1964 figures for section VA, both it and section IB show the same tendency for total weed scores and number of species to increase by the fourth year after fallow. A clear instance of weeds not affecting the crop is on section VA in 1967, when both weed score and crop yield were well below average, probably because 6 weeks' drought in March and early April stunted the seedlings of spring-germinating weeds and heavy rain in May leached out spring-applied nitrogen.

Sections IA and VB show no steady trend towards increased yield nor decreased weed score or number of weed species since the return to continuous wheat with herbicides. As the 11 years' treatment of section IA has given no obvious cumulative benefit in weed-control, it is not surprising that the 4-year period 1964–67 is too short to demonstrate decreased weediness in the combination of herbicides plus fallow-cycle on section IB.

From 1957–63, the number of weed species on the sprayed section IA increased between May and harvest, in contrast to the unsprayed section IB, largely by establishment of wind-borne and late-germinating species in the gaps left by removal of indigenous weeds (Thurston, 1964a). By contrast, from 1964 to 1967, when both sections were sprayed, this trend was reversed. Section VB showed it less clearly.

Tables 10·6 and 10·7 examine the response of some individual weed-species to herbicides and fallowing. No species has been eliminated by spraying, even for 11 consecutive seasons, but *Vicia sativa* was below 5% of its original abundance for 6 of the 11 years on section IA, increasing to 15–20% in 1965–67. The decrease on section VB was less spectacular. *Ranunculus arvensis* has been less than its initial abundance for seven years,

https://doi.org/10.23637/ERADOC-1-2

starting with 1961 when January sowing greatly diminished this winter-germinating species. 1966 was another January-sown crop, and this is reflected in the small May score for *Ranunculus arvensis* on sections IA and VB, though not on VA. Fallowing does not control it or *Vicia*. In contrast to these two species, *Medicago lupulina* has a small but important proportion of seeds germinating after herbicides have been applied in May. The resulting plants flourish in the space left by removal of earlier-germinating competitors and their seeds maintain the population. There is no evidence of declining fertility on no-nitrogen plots where *Vicia* and *Medicago*, and hence their root-nodules (with nitrogen-fixing bacteria), have been decreased by herbicides (see p. 100). Fallow does not control *Medicago*.

Papaver spp. and *Tripleurospermum* also have sufficient late-germinating seeds to avoid elimination by herbicides. These species are decreased by fallow but soon reassert themselves, especially on any plots where Wheat Bulb fly (see p. 148) causes gaps in the crop in the first year after fallow. The small seedlings of these species benefit from lack of crop-competition in the early stages and the resulting plants grow large, quickly replenishing the stock of seeds in the soil.

The two annual grasses, *Alopecurus* and *Poa annua*, were not controlled by the herbicides used. *Alopecurus* was always abundant; the less abundant *Poa annua* showed a distinct increase under continuous wheat with herbicides, compared with the fallowed plots. The fallow year decreased *Alopecurus* except in 1964 on section VA (as with total weed scores) but it soon increased to its former numbers. Throughout this period wild oats (*Avena fatua* and *A. ludoviciana*) have been controlled by annual hand-pulling of whole plants before any seeds are shed, and are therefore not included here.

Two perennial dicotyledons, *Cirsium arvense* and *Tussilago farfara*, were better controlled by herbicides than by fallow. *Equisetum arvense* and the two perennial grasses *Agrostis stolonifera* and *Poa trivialis* were not susceptible to the herbicides applied in May, and increased steadily under continuous wheat. The fallow year controlled the grasses well, but *Equisetum* increased steadily from 1962 at both ends of the field, favoured by a succession of wet seasons. Its rhizomes are deep in the soil, whereas the two grasses are stoloniferous and therefore more easily damaged by cultivations.

The numbers of weed-seeds in the soil of five plots, under continuous wheat and in the fallow-cycle, are presented up to 1964, the last year for which there are complete figures at the time of writing.

Species differed greatly between sections in abundance (Table 10·8); numbers in comparable sub-sections were not identical, although they were of the same order of size. Initial differences have been taken into account and comparisons between species facilitated by giving numbers in later years as % of those originally present (Tables 10·9 and 10·10).

Section IA shows the disastrous effect on total weed-seeds in the soil of omitting the fallow in 1956 without using a herbicide. This mistake was not repeated when section VB reverted to continuous wheat. It also illustrates the decrease in viable weed-seeds in soil after a fallow year, and the

https://doi.org/10.23637/ERADOC-1-2

subsequent return to the original numbers, or even an increase, found by Brenchley and Warington (1936). The success of herbicides and failure of fallow to control *Vicia* and *Ranunculus* shows up more in weed-seed counts than in the visual scores, and so does the replenishment of *Medicago* seeds in the soil by plants developed from seeds germinating after the herbicide had been applied. *Tripleurospermum* was resistant to the herbicides used before 1966; hence the great increase in seed content of the soil. It also set more seeds in dry summers e.g. 1959, than in wet ones. In contrast, *Myosotis* set more seeds after wet seasons. It was less affected by herbicides than expected for a species germinating mainly before spraying and moderately susceptible to MCPA, which was a component of most of the herbicides used. Probably the small plants that did survive e.g. *Aphanes arvensis* (parsley piert), *Legousia hybrida* (Venus-Looking Glass), *Veronica arvensis* (wall speedwell) and *Euphorbia exigua* (dwarf spurge), benefited from the removal of larger competitors. *Alopecurus* was decreased in the first year after fallow, but the next year's figures show how much seed those few plants produced. Fluctuations in seed production following differences in sowing-date of the crop are discussed on p. 206.

The proportion of seeds germinating in the three years for which the pans were kept, explains the different responses of some species to the one-year fallow (Table 10·11). *Alopecurus* and *Stellaria* have little innate

TABLE 10·11

Percentage of seeds germinating in pans in each of the three years they remain in the glasshouse, for some of the abundant species

Species	Years after sampling		
	1st	2nd	3rd
Alopecurus myosuroides (blackgrass)	94	6	<1
Stellaria media (chickweed)	95	4	1
Papaver rhoeas and *P. argemone* (poppies)	63	32	5
Tripleurospermum maritimum (scentless mayweed)	70	23	7
Aphanes arvensis (parsley piert)	69	28	3
Ranunculus arvensis (corn buttercup)	54	44	2
Medicago lupulina (black medick)	45	39	16
Vicia sativa (common vetch)	48	26	26

dormancy and are greatly decreased by one year during which fresh seeds are not returned to the soil. Species with 30% of seeds germinating in the second or third year are better able to survive and those with half their seeds heavily dormant are scarcely affected.

After 8 years' spraying, there was no evidence of selection for late-germinating strains of weeds able to germinate after the herbicide had been applied, although seeds of susceptible species in the soil of sprayed plots presumably come from late-germinating individuals. However, the 6-week gap between germination records may be too long to show small changes in time of germination. There was, however, a tendency for herbicides to decrease the dormancy of weed-seeds. Damage to the parent plant may have hindered seed-development. Deformed seedlings, especially of *Veronica hederifolia*, from seeds developing at the time of spraying, sometimes occur in pans of soil from sprayed plots. The factors controlling the onset of innate dormancy may also be affected. In the 4-year period up to

https://doi.org/10.23637/ERADOC-1-2

1960, 10% more of all weed-seeds germinated in the first year of the 3-year period in soil from section IA than from IB. This was caused by changes in dormancy of some species, and not by decreasing the proportion of very dormant species present. *Vicia sativa, Ranunculus arvensis, Papaver* spp. and *Odontites verna* were the most affected, but not all four in the same year nor one species in all years. Increases, from 10% to 49%, were usually at the expense of second-year germination, but in *Odontites* more of the difference came from the third year. It will be interesting to see if the final counts from the pans confirm these observations.

3. Correction of grain and straw yields for contamination by weed-seeds and rubbish. Broadbalk grain yields have always been based on weights taken directly from the threshing-machine (up to 1956) or combine-harvester (from 1957), without attempting to remove weed-seeds and rubbish as a seed-merchant would do with his specialised machinery. This introduces errors varying in size between years, plots and sections (Table 10·12).

TABLE 10·12

Contamination of 1st grade grain (straight from the combine-harvester) by weed-seeds and rubbish (% to the nearest whole number)

Year	Plot	Section VA			Section VB		
		Wheat	Weeds	Rubbish	Wheat	Weeds	Rubbish
1964	2	97	3	1	99	1	1
	5	88	9	3	97	2	1
	7	100	0	0	100	0	0
	9	99	1	0	99	0	0
	18	74	26	1	99	1	0
	Mean	92	8	1	99	1	0
1965	2	97	1	2	98	0	2
	5	81	17	2	92	7	1
	7	91	7	2	97	1	2
	9	87	11	2	97	2	1
	18	67	27	6	98	0	2
	Mean	85	13	3	96	2	2
1966	2	95	3	2	98	1	1
	5	71	26	3	96	3	1
	7	92	6	2	98	1	1
	9	90	9	1	98	1	1
	18	47	48	5	98	1	1
	Mean	79	18	3	98	1	1
1967	2	97	2	2	98	0	1
	5	82	17	1	98	2	1
	7	97	2	1	98	1	1
	9	95	5	1	100	0	0
	18	88	11	1	98	1	1
	Mean	92	7	1	98	1	1

Herbicide-treated plots are less contaminated than those fallowed but not sprayed. Thus, mean errors are less since 1964 when all sections except VA have been sprayed. The greatest errors are on plots where *Vicia* is present, in those years when it ripens late enough for many well-developed but undehisced pods to be present at harvest, including both seeds and pods in the first-grade grain. Most of the rubbish is *Vicia* pods, plus other weed-

https://doi.org/10.23637/ERADOC-1-2

seed heads, e.g. *Papaver*, *Cirsium*, *Tripleurospermum*, with some chaff and broken pieces of stalk. Occasionally, especially in wet seasons, the wheels of the combine-harvester sink into the soil, lowering the cutter-bar until soil and flints are harvested. The bar may also be lowered to get under a lodged crop. Pieces of soil and flint are then bagged with the grain and as their density is greater they increase the % by weight of rubbish; they are often unevenly distributed between sub-samples. It is impossible to do purity-tests for all plot-sections, but five or more samples have been examined in each year since 1958. These are generally taken from plots where the information is required in connection with another investigation, e.g. when the weed-seed content of the soil is also being estimated (Table 10·12). Comparable information can be extracted from records taken in the course of studies on the fate of weed-seeds in combine-harvesting (see p. 202) and from a comparison of three methods of sub-sampling grain for weed-seed content, using grain from six Broadbalk plots with different species and amounts of weed-seeds. Occasionally when no such information was available, grain from plots expected to have the most weed-seeds has been sampled to estimate the maximum contamination for that year. These figures are now published with Broadbalk yields in the Numerical Results of Rothamsted Field Experiments.

Five plots of section II sampled in 1959, unsprayed, in its 2nd year after fallow, had only 0·1–0·8% weed-seeds in the grain, but 0·2–1·3% rubbish. 1958 was also a clean year with not more than 4·6% weeds and 0·25% rubbish in any of the five plots sampled, although one of them was plot 18 section II, which might have been expected to show *Vicia* contamination had the weed been abundant in that year. In contrast, in 1963 four *Vicia*-infested plots (5, section II; 6, section IV; 17, section II; 18, section IV) had 22–26% weed-seeds and up to 1% rubbish in the grain, thus resembling the records in Table 10·12, but not equalling the 53% contamination on plot 18 section VA in 1966, the most recorded. Plot 14, section IV, characterised by small-seeded weed species, had only 4% weeds and 0·2% rubbish in the grain in 1963.

TABLE 10·13

Contamination of baled straw by weed stalks and seeds

	Plot	Section	% by weight: Stalks	% by weight: Seeds
1958	3	II	5·1	0·1
	10	II	3·5	0·1
	11	III	7·5	0·1
	18	II	3·6	0·04
	10	IV	5·0	0·1
1959	2A	II	6·3	0·06
	3	II	1·9	0·1
	10	II	0·9	0·05
	17	II	4·6	0·1
	18	II	5·3	0·1

Straw contamination by weed stalks has been less frequently examined, although during the 1940s wild oat straw must have accounted for a large proportion of the Broadbalk straw yields. The grain/straw ratios for those years are suspect. Wild oat seeds are shed as they ripen, and most have fallen before winter wheat is harvested, so the grain yields for those years would not have been augmented by including corresponding weights of wild oat seeds.

The per cent by weight of weed stalks and seeds in baled straw on five plots for 1958 and 1959 can be calculated from the records obtained during the combine-harvesting study (Table 10·13). In those records, weed-contamination was from 1–8%, but the corresponding grain contamination figures warn us that they were unusually clean years. At the other extreme, in 1968 straw from three plots in the first year after fallow contained 46%, 55% and 90% weed stalks, mostly *Polygonum aviculare*. This species had not been controlled by the herbicides used and had flourished in the open spaces left by removing susceptible species from the gaps caused by a severe attack of Wheat Bulb Fly. Similar contamination probably occurred in some previous years.

4. Fate of weed-seeds in combine-harvesting. Broadbalk was combine-harvested for the first time in 1957. The change from cutting and stooking sheaves to be threshed off the field, to combine-harvesting and baling the straw on the plots, seemed likely to affect the distribution of weed-seeds. More could ripen and shed before the later harvesting-date. Weed-seeds thrown out with the straw and chaff from the 10 ft 6 in. combine-cut, including weeds between the 16 crop-rows harvested and the larger and more numerous weeds from the adjacent blank rows were concentrated into a 3-ft strip the length of each plot. Seeds could also be transferred from one plot to another in straw bales, as the machine moves on to another plot before discharging its completed bales. Unfortunately the dispersal of weed-seeds in binder harvesting had not been studied, and the number of weed-seeds shed before harvest on these plots was not estimated, but it still seemed worthwhile to investigate the distribution of weed-seeds present at combine-harvesting, to help us to understand what was happening on Broadbalk and elsewhere as harvesting machinery was modernised.

In 1958 (Thurston 1964a) and 1959, samples of 1st grade wheat grain, seconds and dusty rubbish were collected from the three spouts of the Massey-Harris 780 combine-harvester during harvesting of four or five plots, chosen because they had weed-seeds of different sizes and the crop was not lodged. Samples of the straw and chaff deposited by the combine were collected on a cloth carried behind it on part of each plot; on the remainder the straw and chaff were allowed to fall on the ground and were subsequently picked up and baled in the usual way. Weed-seeds were identified and counted in sub-samples of all grain fractions and of straw and chaff from both cloth and bales. Total grain and straw yields were known, so the numbers of weed-seeds per acre harvested could be calculated. The number left on the ground after baling was obtained by the difference in weed-seed content between 'collected' and 'baled' straw.

Because of the need to avoid lodged plots and those from which grain or straw were required for other investigations, only three plots from section II (3, 10 and 18) were sampled in both years. Even these were not

https://doi.org/10.23637/ERADOC-1-2

strictly comparable as they were in their first crop after fallow in 1958 and in their second in 1959, and the harvest dates differed by three weeks.

The first-grade grain was sub-sampled from the grab-samples taken by the Farm Recorders for dry weight determination and chemical analysis. Subsequent work showed that this method tends to over-estimate large rubbish, e.g. *Vicia* pods and underestimate small weed-seeds, e.g. *Papaver* spp. However, these differences are small compared to the error introduced by multiplying laboratory results to give thousands of weed-seeds per acre, relevant to farming practice. No replication was possible, so to average out errors, only the means for all plots sampled in each year are given (Table 10·14), and in making between-year comparisons the

TABLE 10·14

*Weed-seeds per acre (thousands) at harvest, 10 September, 1958 * and 20 August, 1959 **

Species	Year	Removed					Left
		In grain			In straw	Total	on ground
		1st grade	2nd grade	Rubbish			
All species	1958	6839	11824	4100	1355	24115	1104
	1959	3227	2796	5116	3773	14911	100087
Medicago lupulina	1958	5323	8275	2123	1116	16836	?
(Black medick)	1959	119	1038	286	1024	2467	3411
Vicia sativa	1958	574	18	1	2	595	?
(Common vetch)	1959	Many seeds broken, so no counts					
Papaver spp.	1958	4	58	582	36	680	547
(Poppies)	1959	2790	636	3408	1249	8084	72699
Polygonum aviculare	1958	174	1199	134	80	1587	111
(Knotgrass)	1959	42	425	98	205	770	1051
Myosotis arvensis	1958	0	4	51	1	56	8
(Forget-me-not)	1959	1	1	16	4	22	201
Chenopodium album (Fat hen) and	1958	167	2008	734	86	2995	132
Atriplex patula (Orache)	1959	37	123	150	101	411	573
Alopecurus myosuroides	1958	10	52	18	46	126	74
(Blackgrass)	1959	29	205	54	344	633	4446
Tripleurospermum maritimum	1958	2	30	173	12	217	127
(Scentless mayweed)	1959	11	249	955	301	1515	22566
Aethusa cynapium	1958	23	40	4	1	68	3
(Fool's parsley)	1959	32	54	3	25	114	152
Odontites verna	1958	13	22	115	8	158	65
(Red bartsia)	1959	51	31	84	42	208	4310

* Plots sampled.

10 September 1958 Plot	section	*20 August 1959* Plot	section
—		2	II (2nd crop)
3	II (1st crop)	3	II ,, ,,
10	II (1st crop)	10	II ,, ,,
11	III (3rd crop)	—	
—		17	II ,, ,,
18	II (1st crop)	18	II ,, ,,

difference in position in the fallow-cycle and in plots sampled must be remembered. However, these difficulties do not affect comparisons of distribution of species, which were the main purpose of the investigation.

The total weed-seeds per acre at harvest differed greatly between years (Table 10·14), and also their percentage distribution between fractions (Table 10·15). The weed-seed content of baled straw differed between seasons much less than that of the grain fractions and the seeds left on the ground, and contained less than 10% of the weed-seeds present at harvest. Although 1959 was an earlier harvest than 1958, it had the greater percentage of weed-seeds left on the ground. Its large total of seeds may have been because it was the second crop after fallow on the plots sampled,

TABLE 10·15

Percentage of all weed-seeds of some abundant species occurring in each fraction

Species	Year	Removed: In grain: 1st grade	2nd grade	Rubbish	In straw	Total	Left on ground
All species	1958	27	47	16	6	96	4
	1959	3	2	4	3	12	88
Medicago lupulina	1958			* Not calculated			
(Black medick)	1959	2	18	5	17	42	58
Vicia sativa	1958			* Not calculated			
(Common vetch)	1959			* Not calculated			
Papaver spp.	1958	<1	5	47	3	55	45
(Poppies)	1959	3	1	4	2	10	90
Polygonum aviculare	1958	10	70	8	5	93	7
(Knotgrass)	1959	2	23	6	11	42	58
Myosotis arvensis	1958	0	6	80	2	88	12
(Forget-me-not)	1959	<1	<1	7	2	10	90
Chenopodium album (Fat	1958	5	64	24	3	96	4
hen) and *Atriplex patula* (Orache)	1959	4	13	15	10	42	58
Alopecurus myosuroides	1958	5	26	9	23	63	37
(Blackgrass)	1959	1	4	1	7	13	87
Tripleurospermum mariti-	1958	1	9	50	3	63	37
mum (Scentless mayweed)	1959	<1	1	4	1	6	94
Aethusa cynapium	1958	33	56	6	1	96	4
(Fool's parsley)	1959	12	20	1	10	43	57
Odontites verna	1958	6	10	51	4	71	29
(Red bartsia)	1959	1	1	2	1	5	95

* 1958 more *Medicago* and *Vicia* picked up by baler than cut by combine-harvester. 1959 many *Vicia* seeds broken.

whereas in 1958 three of the plots were carrying their first crop after fallow. It is also possible that by the later harvest of 1958 a greater percentage of the weed-seeds had fallen from the plants before harvesting started.

Papaver species contributed 66% of the additional seeds found in 1959 and *Tripleurospermum* another 21%. Both were more abundant on plot 10, section II, sampled in both years, but plot 2, section II, sampled in 1959 only, also contributed to the increase. All the other species showed the same difference between years, to a lesser extent. As *Papaver* and *Tripleurospermum* seeds are small, the proportion of weed-seeds in the 'rubbish' fraction of the grain was greater in 1959 than 1958. *Myosotis* nutlets are slippery and easily escape from their calyces, but *Odontites* capsules containing seeds are sometimes found in first-grade grain. Medium-sized weed-seeds, e.g. *Medicago lupulina*, *Polygonum aviculare*, *Atriplex patula*, *Alopecurus myosuroides* and *Aethusa cynapium* are usually concentrated in the seconds grain, but larger units containing slightly unripe seeds, e.g. pairs of *Aethusa* seeds that have not separated, pieces of *Alopecurus* spikes, whole seed-heads of *Medicago* and undehisced *Papaver* capsules may occur in the first-grade grain and contribute to the contamination discussed above (p. 200). The only species in Table 10·14 with seeds large enough to occur mainly in first-grade grain is *Vicia sativa*, but wild oats, especially spikelets of *Avena ludoviciana*, also do so.

https://doi.org/10.23637/ERADOC-1-2

Straw often contains *Polygonum aviculare*, *Chenopodium album*, and *Atriplex patula*, in which ripe seeds are not easily detached from the persistent perianths, and *Medicago lupulina*, which seems to lack abscission mechanism for its 1-seeded pods. *Alopecurus* in straw is mainly unripe spikes with seeds still firmly attached.

In 1958, but not in 1959, the baler picked up uncut stalks of *Medicago* and *Vicia* with seeds attached. It was therefore impossible to calculate how many seeds of these species had been left on the ground. And in 1959 the seconds and rubbish contained so many broken pieces of *Vicia* seeds that accurate counts were impossible. Some of the percentages for these species are therefore omitted from Table 10·14.

5. Weed development in blank rows. Two rows were left blank on each plot to guide the combine-harvester for the cut taken for yield, the position of which varied from year to year. In these 14-in. wide strips, twice the normal row-spacing, weeds flourished unless they were destroyed by herbicides.

To compare the number and size of weeds in August 1962 in equal areas of the blank and normally-spaced rows, all weeds were removed from 12 sample strips each $\frac{1}{3}$ m wide at right-angles to the rows, located in unsprayed cross-headlands that were not lodged and where rows were not gappy. The weeds from the blank-row area, from between the normally-spaced rows either side of it, and between the next rows to them, were identified, counted, dried and weighed separately (Table 10·16).

TABLE 10·16

Weeds in blank rows left to guide the combine-harvester, and in adjacent and normal-spaced rows (August 1962)

Species	Number of weed plants per 1·25 sq ft			Total dry weight, g. of weed shoots per 1·25 sq ft			Mean shoot dry-weight, g per plant		
	Blank row	Adjacent rows	Normal spacing	Blank row	Adjacent rows	Normal spacing	Blank row	Adjacent rows	Normal spacing
Tripleurospermum maritimum (Scentless mayweed)	6·0	6·2	5·3	1·46	0·58	0·83	0·24	0·09	0·16
Medicago lupulina (Black medick)	21·5	16·0	13·2	5·65	3·96	3·28	0·26	0·25	0·25
Aphanes arvensis (Parsley piert)	2·3	1·8	1·7	0·24	0·14	0·13	0·10	0·08	0·08
Polygonum aviculare (Knotgrass)	6·4	3·5	2·3	0·34	0·17	0·13	0·05	0·05	0·06
Vicia sativa (Common vetch)	1·4	1·3	0·7	1·93	1·50	1·15	1·38	1·15	1·64
Papaver spp. (Poppies)	2·3	2·3	1·8	0·25	0·10	0·11	0·11	0·04	0·06
Alopecurus myosuroides (Blackgrass)	5·8	3·7	3·7	3·07	1·42	1·36	0·53	0·38	0·37
Odontites verna (Red bartsia)	0·8	2·0	1·1	0·78	1·35	0·76	0·98	0·68	0·69
All species, including some not listed above	50·8	40·0	32·9	15·70	10·16	8·82	0·31	0·25	0·27

Weed-plants were most numerous in the blank rows and least in normal-spaced rows flanked on both sides by 7-in. spacing. The mean weight of weed shoots per plant was also slightly more from 14-in. than from 7-in. spacing. Resulting from these two differences, the total dry weight of weed shoots per unit area in the blank rows was 165% of that in the same area of normally-spaced rows. Weeds were more numerous in 7-in. spaced rows

https://doi.org/10.23637/ERADOC-1-2

adjacent to blank rows than in those flanked on both sides by 7-in. spacing, but the mean shoot-weight per plant was unaffected by proximity to the blank row.

The semi-parasite *Odontites verna*, in contrast to the other weeds, was slightly less abundant in the blank rows, although such plants as became established grew larger than in normal-spaced rows. Presumably the roots of seedlings near the middle of the blank row failed to reach wheat roots and did not parasitise other weeds.

The two legumes, *Medicago* and *Vicia*, showed little or no increase in shoot weight per plant in the blank rows, probably because their nodule-bacteria freed them from competition with the crop for nitrogen. *Polygonum aviculare* plants were very small and showed no benefit from lessened crop-competition in the blank rows. This is one of the late-germinating Broadbalk weeds and in April its emerging seedlings would have to compete with established plants of autumn-germinating species, e.g. *Alopecurus myosuroides*, as well as with the crop.

6. Biology of wild oats (*Avena ludoviciana* and *A. fatua*). Starting in 1944 when the wild oat infestation was severe, the biology of these annual grass weeds has been studied on Broadbalk, and subsequently in laboratory, glasshouse and field experiments devised to follow up ideas arising from the Broadbalk observations. This work has already been summarised (Thurston, 1963).

Very few of the wild oats on Broadbalk resembled the predominantly spring-germinating *Avena fatua* infesting the continuous spring barley on the adjacent Hoosfield. Most had larger spikelets than *A. fatua*, and the two or three seeds of each remained firmly attached to each other when the mature spikelets fell from the plant. This wild oat was not then described in any British flora, but was identified by Mr. C. E. Hubbard of Kew Herbarium as *Avena ludoviciana*, which had been recorded from a few sites in England, but was not at that time recognised as an agricultural problem. Its winter germination, the successive germination of the three seeds in the spikelet, the dormancy of the second and third seeds enabling it to survive the fallow year, and the similarity of response to fertiliser by it and winter wheat were all observed for the first time on Broadbalk. *A. ludoviciana* is now described in the Flora of the British Isles (Clampham, Tutin and Warburg, 1962) and is recognised as a serious weed of winter cereals and winter beans in Britain.

7. Biology of blackgrass (*Alopecurus myosuroides*). Blackgrass, another annual grass prevalent on Broadbalk, is now being studied in the same way as wild oats (Thurston, 1968). Broadbalk routine observations show that blackgrass increases when wheat is sown in early October, remains at the same amount as in the previous year when wheat is sown in late October or early November, and usually decreases when the crop is sown from late November onwards, i.e. most of the blackgrass seeds germinate between 23 October and 8 November. In a very wet autumn, germination may be delayed until the soil dries again in spring; January-sown wheat may then be heavily infested with blackgrass. In pans of naturally-infested Broadbalk

https://doi.org/10.23637/ERADOC-1-2

soil in a glasshouse, germination-behaviour of blackgrass was the same in 1955–61 as in 1925 (Thurston, 1964b); the per cent of the total seedlings appearing in the four quarters October–December, January–March, April–June, and July–September was 82, 10, 1, 7. This agrees with the field germination. About 95% of the blackgrass seeds germinated in the first year in pans and less than 1% survived into the third year.

Because the seeds lack dormancy, the reserve of blackgrass seeds in Broadbalk soil is severely decreased by one fallow year (Tables 10·9 and 10·10). However, the first crop after fallow is often thinned by Wheat Bulb fly attack (p. 148) and a few blackgrass plants grow very large in the gaps,

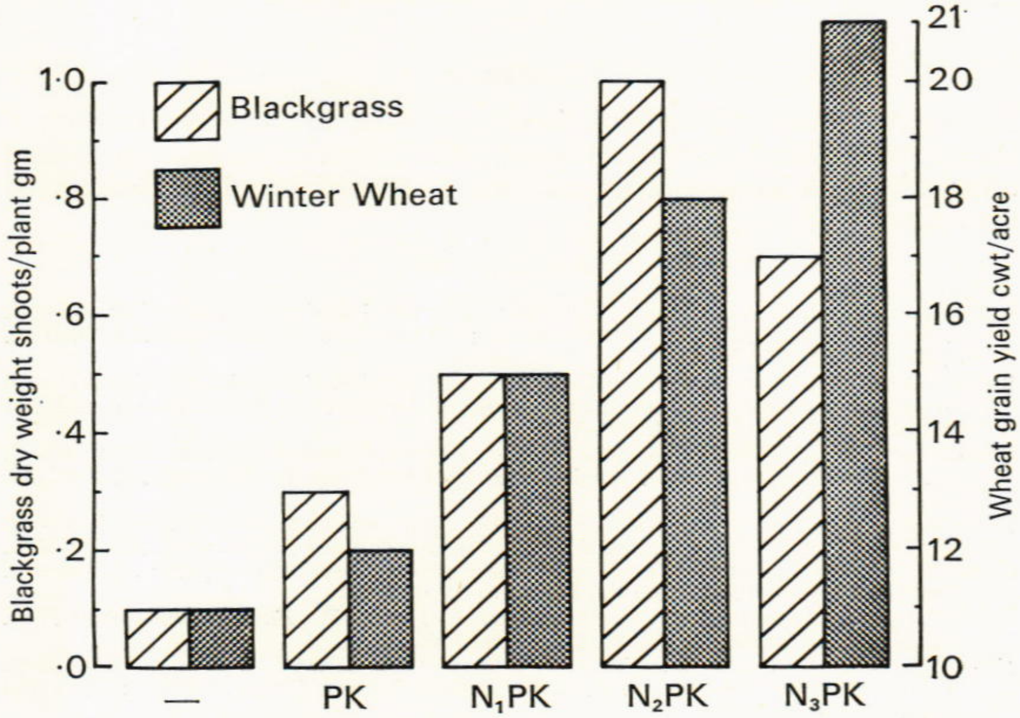

FIG. 10·1. Effect of fertilisers on competition between blackgrass and winter wheat on Broadbalk.

where they are free from crop-competition during seedling-establishment. They produce so many shoots and ears that the amount of blackgrass recorded after fallow in visual surveys is often almost as great as after crop, and may occasionally be slightly greater (Tables 10·6 and 10·7). In consequence, the seed-content of the soil at the end of the first year after fallow may equal or exceed that of the corresponding continuously-cropped plot (Table 10·9).

Observations on Broadbalk suggest that, in contrast to wild oats, the response of blackgrass to fertilisers may differ from that of winter wheat (Fig. 10·1). Blackgrass seems to respond more to phosphate and potash and less to a large dose of nitrogen, than does wheat. Indeed, increasing N from 86 to 129 lb/acre actually decreases the dry weight of blackgrass

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tops, while increasing the yield of wheat with which it is competing. This differential response to fertilisers requires further investigation.

The effect of fertilisers on the growth of blackgrass on Broadbalk is complicated by the presence of 'twist' caused by the fungus *Dilophospora alopecuri*. This deforms and blackens flowering shoots and causes sterility of part or all of the affected inflorescences. It is most prevalent on the fertile plots 8 (N_3PKNaMg) and 2 (FYM) and absent from the unmanured plot 3. It decreased the per cent viable seeds from plot 8, compared to plot 3, by 7–19% in 1961 and 1962 (Thurston, 1964b) although the total seed-production was greater on plot 8, with three times as many plants per acre as on plot 3, each with twice as many inflorescences and three times as much dry matter in its shoots as an unmanured plant.

Conclusion

The weed studies on Broadbalk have contributed to our understanding of the factors affecting its yield, and their interaction, and have also produced information on weed biology relevant to weed control in commercial agriculture.

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