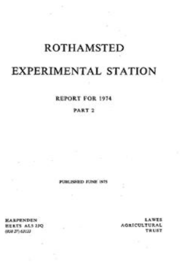
ROTHAMSTED RESEARCH

Rothamsted Experimental Station Report for 1974 Part 2


ROTHAMSTED
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Cultivation Weedkiller Experiment, Rothamsted, 1961-72

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Cultivation Weedkiller Experiment, Rothamsted, 1961–72

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Cultivation experiments have been done at Rothamsted since 1926 to measure the effects of different cultivation treatments on crop yield; when they were started herbicides were unknown. The early experiments showed that yields were quite consistent but unexpected in that yield did not increase with the number of cultivations done, and that any more than necessary to control weeds did no good and often decreased yield.

The results of a six-year rotation experiment done at Rothamsted (Russell & Keen, 1941) showed that crop yields were independent of the cultivation treatment given if the land was clean, but were lessened by any treatment which gave a weedy seedbed. This meant, in effect, that the plough, by inverting the furrow slice and burying the weeds, produced a seedbed with few weeds; other methods of seedbed preparation that did not bury weeds were only of limited use.

A criticism of these experiments was that they were done for relatively short periods and it was felt that an experiment should be conducted on the same piece of ground year after year. Although chemicals for the control of some weeds in cereal crops had been introduced about 1945, when materials to control a wider range of weeds in most crops were introduced, the time seemed ripe to start a long-term rotation experiment.

In 1961 an experiment was started on the clay-loam at Rothamsted, mainly on the Batcombe and Winchester series, and the main objects were:

1. to measure the immediate and residual effects of herbicides on crop yields,
2. to see how far weed control by chemicals can simplify field cultivations and so lessen the power requirements and expedite the field operations,
3. to measure the long-term effects of herbicides on crop yields, and
4. to study the long-term effects of the same cultivation treatments or the continuous use of herbicides, especially the relatively insoluble, persistent materials like simazine, on (a) soil compaction, (b) changes in microflora able to degrade herbicides, (c) change in the number and species of soil-living organisms, (d) the amount of disease on crops and (e) the possible dominance of certain weed species.

The four-course rotation chosen was wheat, potatoes, barley and beans; when conditions were suitable wheat and beans were sown in autumn but since 1966 spring beans were sown each year.

The three primary cultivations tested on each crop were:

P the land was mouldboard ploughed followed by seedbed-producing operations,
R the land was rotary cultivated once or twice but was not mouldboard ploughed,
T the land was worked with a deep-tined cultivator two or three times followed by seedbed-producing operations; it was not mouldboard ploughed or rotary cultivated.

In combination with the primary cultivations were three systems of post-planting weed control in beans and potatoes:

M mechanical cultivations,
Sx persistent herbicides,
Sy persistent herbicides but differing from Sx in material, time of application or extra cultivations.

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The M plots got only mechanical operations appropriate to the bean and potato crops. The Sx plots had no mechanical operations and the Sy potato plots were rotoridged each year since 1966 just before the crop met in the rows.

In addition there was a test of post-emergence selective herbicide (H) *v.* none (O) on wheat and barley, and from 1967 an autumn test of paraquat (G) *v.* none (O) to stubbles. All treatments were cumulative; herbicide rates are given in terms of active ingredients.

The experimental area consisted of four series of 24 plots, one for each crop of the four-course rotation. Each series consisted of two randomised blocks of 12 whole plots, each split into halves for the tests of (O) *v.* (H) and (O) *v.* (G), the interaction of these factors being confounded. Nine plots carried the nine combinations of P, R and T with M, Sx and Sy, while the remaining three plots were kept in reserve until later and meanwhile had the PM treatments.

Starting in 1964, one reserve plot (A) per block was ploughed in autumn for autumn-sown crops, and for spring crops was rotary cultivated in spring only. The object was to see whether delaying cultivations for spring crops affects yields, and whether, in a dry spring, the moisture conserved by giving only one cultivation just before sowing is beneficial. In 1965/66 another reserve plot (B) was used to compare existing treatments with a system of minimum cultivations, with sprays, for all four crops. In order to lessen the number of passes over the ground when baling and carting straw, the wheat and barley straw was burnt on plots of this treatment from 1969 onwards; the bean straw was raked and carted off as there was too little to burn satisfactorily. In 1969 the third reserve plot (C) was allocated to treatments that are usual farm practice for each crop.

The plots were 50 ft long by 42 ft wide. There was a 7-ft discard between them and each had a 7-ft sideland each side, making 21 ft for turning implements when working across the plots. The remaining 28-ft width was split into two sub-plots for the tests of hormone herbicides on cereals and paraquat to stubbles, and these sub-plots were harvested separately for all crops. Cereal rows were 7 in. apart, and the centre 16 rows were combine-harvested on each sub-plot. Potato rows were 28 in. apart, and the four centre rows of each sub-plot were taken for yield. Spraying was done on a rounded surface left by a ridge roll. Beans were drilled at 21-in. spacing except in 1964 when the Sx and Sy plots were drilled at 10½ in., the M remaining at 21 in. to permit inter-row cultivations. At 21-in. spacing, five rows per sub-plot were combine-harvested and 11 rows at 10½ in. spacing. In autumn 1964 the barley stubble would not pass between the drill coulters on the TSx and TSy plots, and these had to be drilled at 21-in. spacing. Other operational difficulties encountered were the lack of suitable soil in most years for earthing up potatoes on the TM plots, and the difficulty in obtaining suitable seedbeds on the plots receiving minimum cultivations.

The experiment began on a field ploughed in December 1960. In the first year the R treatment for spring wheat, spring barley and spring beans, was one rotary cultivation: the P and T plots were disc harrowed. Since then, all cultivations for winter-sown crops were done shortly before drilling. For spring-sown crops treatment P was always done in autumn, and R and T were done some in autumn and some in spring. T treatments usually consisted of two or three passes with a heavy cultivator, each at a different angle. The P treatment was about 8 in. deep, the T 6–7 in. deep and the R treatment produced 8–10 in. of tilth for potatoes and 5–6 in. for cereals and beans. The R cultivations done in autumn with a three-bladed rotary cultivator usually left too fine a tilth for over-wintering, so in 1967 and after, a two-bladed machine was used for autumn operations for all crops other than winter wheat; a three-bladed machine was used for all spring operations.

Each year weeds on sample areas of the potato and bean plots were identified and counted, and general observations were made on the weediness of the cereal blocks.

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Couch grass (*Agropyron repens*) was present from the start of the experiment and in all years from 1965, except 1969 and 1970, the ground after potatoes for barley was sprayed with TCA at 20 lb/acre in an attempt to control it. In 1966 the bean stubble was sprayed with aminotriazole at 2 gal/acre in 40 gal.

A report for the years 1961–65 appeared in the *Rothamsted Report for 1965*, 221–232. This report covers the years 1961–72 but omits reference to treatments which were discontinued by 1965. After 1972 the experiment was considerably modified. Full agricultural details are given in (*Numerical*) *Results of Field Experiments* or *Yields of the Field Experiments*, both published by Rothamsted.

Crops

Beans. All primary cultivations were done in the autumn except when the weather was unsuitable. Only one ploughing was done and one rotary cultivation except in 1966 and 1969 when there were two. From 1968 onwards a two-bladed machine was used. T plots were normally cultivated twice (three times in 1966). Seedbeds after the P and T treatments were prepared by a spring-tined cultivator (plus disc harrows in 1966) until 1968 and thereafter by a power harrow.

In all years simazine was applied at 1 lb/acre in 20–40 gal.

In 1963 and 1965 winter beans were grown and the mean yields were:

TABLE 1

Winter beans, 1963 and 1965

Grain—cwt/acre at 85% DM

		P	R	T	Mean
Mean 1963 and 1965	M	33·8	28·4	28·1	30·1
	Sx	28·6	28·1	27·0	27·9
	Sy	27·2	27·4	31·7	28·8
	Mean	29·8	28·0	28·9	28·9
Non-gramineous weed numbers/yd²					
Mean 1963 and 1965		60 (175)	66 (129)	89 (163)	72 (155·8)

M = no spray—mechanical cultivations
Sx = simazine in autumn
Sy = simazine, half in autumn, half in spring
( ) = weeds in rows

The better mean yield from the PM plots is due to a very big yield (39·1 cwt/acre) in 1963.

In 1961, 1962 and 1964 spring beans were grown and the mean yields were:

TABLE 2

Spring beans, 1961, 1962 and 1964

Grain—cwt/acre at 85% DM

		P	R	T	Mean
Mean 1961, 1962 and 1964	M	24·9	26·3	25·2	25·5
	S	25·1	25·1	24·1	24·8
	Mean	25·0	25·5	24·5	25·0
Non-graminous weed numbers/yd²					
Mean 1961, 1962 and 1964		9 (20)	15 (40)	19 (51)	14 (37·6)

M = no spray—mechanical cultivations
S = simazine (Sx and Sy treated similarly)
( ) = weeds in rows

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Spring beans were grown each year after 1965:

1966	Pedigree Tick
1967	Tarvin
1968–72	Maris Bead

TABLE 3

Spring beans, 1966–72

Grain—cwt/acre at 85% DM

		P	R	T	Mean
Mean 1966–72	M	24·4	21·3	22·0	22·6
	S	22·8	20·8	20·6	21·4
	Mean	23·3	21·0	21·1	21·8
		Non-gramineous weed numbers/yd²			
Mean 1966–72	M	16 (74)	24 (112)	42 (125)	29 (99)
	S	20	45	44	36
	Mean	18	34	43	33

M = no spray—mechanical cultivations
S = simazine (Sx and Sy treated similarly)
( ) = weeds in rows

TABLE 4

Spring beans, 1971–72

Grain—cwt/acre at 85% DM

		P	R	T	Mean
1971	M	19·0	16·9	15·0	17·0
	Sx	17·7	14·7	14·7	15·7
	Sy	15·3	15·3	15·5	15·4
	Mean	17·4	15·7	15·1	16·1
1972	M	28·9	23·6	26·8	26·5
	Sx	24·6	23·5	21·0	23·1
	Sy	29·3	24·3	26·6	26·7
	Mean	27·6	23·8	24·8	25·4
Mean 1971, 1972	M	24·0	20·3	20·9	21·7
	Sx	21·2	19·1	17·9	19·4
	Sy	22·3	19·8	21·1	21·1
	Mean	22·5	19·7	19·9	20·7
		Non-gramineous weed numbers/yd²			
1971	M	26 (60)	31 (92)	46 (135)	35 (96)
	Sx	38	22	34	31
	Sy	65	85	102	84
	Mean	43	46	61	50
1972	M	23 (134)	24 (219)	80 (192)	43 (182)
	Sx	32	88	64	61
	Sy	34	131	85	83
	Mean	30	81	76	62
Mean 1971, 1972	M	24 (97)	27 (155)	63 (165)	39 (139)
	Sx	35	55	49	46
	Sy	49	108	93	83
	Mean	36	63	68	56

M = no spray—mechanical cultivations
Sx = simazine
Sy = dinoseb acetate
( ) = weeds in rows

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A granular fertiliser (0 : 14 : 28) was applied at 3·25 cwt/acre each year in a band by the side of the seed. A Smythe drill was used in order to place the seed deep enough to avoid damage from simazine.

The M cultivations consisted of two or three tractor hoeings. The yield of beans fluctuated according to the season and in 1970 was very small. The P plots consistently gave a better yield than the R and T plots but there was little difference between these two treatments. In most years simazine caused some slight loss of yield. Except for the two exceptional years 1970 and 1971 yields remained satisfactory (Table 3).

There were consistently less weeds both in and between rows on the P plots than the R and T plots, and in most years simazine was rather less effective than mechanical cultivations in controlling them. The success of the mechanical cultivations can be gauged from the number of weeds in the rows, which later in the season spread between the rows. Simazine gave reasonable control of weeds both in and between rows, and though in many cases there were more weeds between the rows of the S treatments, the plots appeared less weedy (Table 4).

In 1971 and 1972 dinoseb acetate applied as 'Ivosit' at 6 lb/acre in 38 gal was compared with simazine and mechanical control. It was less successful in controlling weeds, and in 1971, a year when yields were generally poor, caused the plants to darken and the leaves to wilt, an effect attributed to the material being absorbed through the wax on the skin being made thin by wind damage. In 1972 when yields were normal there was no apparent damage and no loss of yield.

Wheat. In all years there was only one ploughing and rotary cultivation (except for two rotary cultivations in 1966). In all years a three-bladed machine was used for winter-sown crops as the tilth produced by a two-bladed machine on the bean stubble was too coarse. Tine treatments were done two or three times according to the state of the ground. Until 1968 seedbeds on the P and T plots were prepared by a spring-tined cultivator but in 1969 and after usually by a power harrow in order to lessen the number of passes over the plots.

Kloka or Kolibri spring wheat was sown in 1966, 1967 and 1971, but Cappelle winter wheat was sown in all other years. In 1966 autumn cultivations were done on P and T treatments but the ground was too wet to rotary cultivate or drill; in 1966 an application of aminotriazole in autumn to control couch grass, followed by bad weather, forced drilling to be delayed until spring 1967, though cultivations were done in autumn, while in 1970 the cleaning of the weedy bean stubble delayed drilling until spring 1971.

A compound fertiliser was combine-drilled each year and the winter wheat received a top dressing of nitrogen.

Winter wheat	
1968 and 1969	280 lb/acre 6 : 15 : 15 plus 3 cwt/acre 'Nitro-Chalk 21'
1970	210 lb/acre 8 : 20 : 16 plus 3 cwt/acre 'Nitro-Chalk 21'
1972	224 lb/acre 10 : 24 : 24 plus 3 cwt/acre 'Nitro-Chalk 21'
Spring wheat	
1966	392 lb/acre 20 : 10 : 10
1967 and 1971	336 lb/acre 25 : 10 : 10

The herbicides used at the manufacturer's recommended rate and stage of growth were:

1966–70	mecoprop/2,4-D
1971 and 1972	ioxynil/mecoprop

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The wheat crops looked very uniform each year but the hormone-sprayed plots had fewer weeds. The effect on yield of the primary cultivation treatments varied from year to year but the means over the whole period of the experiment remained very constant.

On the P plots the residual effects of simazine applied to the preceding bean crop were variable but generally small in both winter and spring wheat. The R plots showed a slight benefit in most years and the T plots a slight lessening of yield in most years, presumably due to the simazine remaining near the surface.

TABLE 5

Residual effects of treatments to beans 1961–72

Wheat—grain cwt/acre at 85% DM

		P	R	T	Mean
Winter wheat 1964, 1965, 1968–70, 1972, 1973	M	47·2	47·3	48·1	47·5
	S	46·9	47·9	46·5	47·1
	Mean	47·0	47·7	47·0	47·3
Spring wheat 1962, 1963, 1966, 1967, 1971	M	35·2	34·9	35·2	35·1
	S	35·1	36·2	34·6	35·3
	Mean	35·1	35·8	34·8	35·2

M = no spray—mechanical cultivations S = simazine

In the years 1961–65 hormone weedkillers generally lessened the yields of winter and spring wheat, but in 1966–72 the R and T treatments showed some overall benefit. In 1966 there was a benefit on the R and T plots but a decrease on P plots; in 1970 there was a marked benefit on the R and T treatments and a striking improvement on the T treatments in 1972.

TABLE 6

Mean response to herbicides. Hormone—no spray

Wheat—grain cwt/acre at 85% DM

	P	R	T	Mean
Mean 1961–65	−2·8	−1·2	−1·7	−1·9
Spring wheat 1966	−2·4	+3·0	+1·6	+0·7
Spring wheat 1967	No treatments—whole plot sprayed owing to excessive weeds			
Spring wheat 1971	−0·5	+1·0	+1·0	+0·5
Winter wheat 1968	+0·7	−0·9	−1·8	−0·6
Winter wheat 1969	−1·7	−1·3	+0·1	−0·9
Winter wheat 1970	+0·0	+3·5	+4·2	+2·6
Winter wheat 1972	+1·9	−0·2	+5·8	+2·5
Mean 1966–72 (excluding 1967)	−0·3	+0·8	+1·8	+0·8

TABLE 7

Residual effects of treatments to beans 1971 and 1972

Wheat—grain cwt/acre at 85% DM

		P	R	T	Mean
1972	M	55·6	51·8	52·4	53·2
	Sx	56·3	56·2	52·0	54·8
	Sy	57·1	48·7	48·5	51·4
	Mean	56·3	52·2	51·0	53·2
1973	M	47·1	51·6	49·6	49·4
	Sx	44·7	48·0	45·4	46·0
	Sy	39·2	51·8	50·8	47·2
	Mean	43·7	50·5	48·6	47·6

M = no spray—mechanical cultivations
Sx = simazine Sy = dinoseb acetate

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In 1972 and 1973 the residues of simazine and dinoseb acetate were compared; in 1972, the year following damage to the bean crop, there was a significant loss of yield from the dinoseb acetate on the R and T plots but on the P plots the residues of both sprays increased the yield. In 1973 all these effects were reversed.

Potatoes. Ploughing was always done in autumn; in all years the rotary hoeing was done twice—usually once in autumn by a two-bladed machine and once in spring with a three-bladed machine. Two tine operations were done each autumn and in the three years 1966–68 a third operation was done in spring. Seedbed preparatory treatments were done by either a spring-tined harrow or a power harrow. The cleaning operations given to the M plots usually consisted of a chain harrowing, two or three inter-row cultivations and a final ridging.

The varieties grown and fertilisers used were:

1961–65	Majestic with 12 cwt/acre 10 : 10 : 18 fertiliser
1966	Pentland Dell with 12 cwt/acre 10 : 10 : 18 fertiliser
1967–70	Pentland Dell with 10 cwt/acre 13 : 13 : 20 (SP) fertiliser
1971 and 1972	Pentland Crown with 10 cwt/acre 13 : 13 : 20 (SP) fertiliser

(SP) = sulphate of potash

The herbicides used were:

1964–65	linuron (2 lb/acre) plus paraquat (0·75 lb/acre)
1966–68	linuron (1 lb/acre) plus paraquat (0·37 lb/acre)
1969–72	linuron (1 lb/acre) plus paraquat (0·75 lb/acre)

In the two years 1964–65 there was a benefit in yield from the spray on the T plots but none on the P and R plots. Weeds were adequately controlled by both M and S treatments.

In the seven years 1966–72 the yield of total produce varied considerably according to season but the mean yield remained very similar to that of the years 1963–65. In most years the P plots yielded best; the mean yield was about 2·5 tons/acre more than the R plots, and about 1·75 tons/acre more than the T plots. The PM plots yielded more than the PS or PSy plots but sprays increased the yield on the R and T plots.

TABLE 8

Potatoes, 1966–72

Total tubers—tons/acre

		P	R	T	Mean
Mean 1966–72	M	17·71	13·07	13·17	14·65
	S	15·29	13·96	15·15	14·80
	Sy	15·87	14·53	15·09	15·16
	Mean	16·29	13·85	14·47	14·87

Non-gramineous weed numbers/yd²

		P	R	T	Mean
Mean 1966–72	M	22	44	51	39
	S	10	36	22	23
	Sy	10	17	22	16
	Mean	14	32	32	26

M = no spray—mechanical cultivations
S = linuron and paraquat
Sy = as S plus rotoridging
1966–68—weed count after rotoridging
1969—weed count before rotoridging
1970–72—weed count after rotoridging

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Weeds were more numerous in the last seven years particularly in 1966 and 1967, though yields in these years were satisfactory. In all years weeds were less on the ploughed plots with both mechanical and spray treatments, and this may partly account for the greater yield from these plots. In most years the spray was more effective than mechanical operations in controlling weeds. The effect of rotoridging on weed numbers was small except on the R plots. Rotoridging slightly increased the yield on the P and R plots but not on the T plots.

The percentage of tubers passing over a 1½-in. riddle (which included damaged tubers of ware size) remained practically constant at 97% on all treatments. In 1966 a sample from each plot was inspected for 'greening' but there was practically none.

TABLE 9

Potatoes, 1966–72; Mean difference Sy–S

Total tubers—tons/acre

	P	R	T	Mean
Mean 1966–72	+0·58	+0·57	−0·06	+0·37

Sy = rotoridged
S = not rotoridged

Barley. The P plots were usually ploughed once in the autumn and then worked to a seedbed by a spring-tined cultivator until 1968 but in subsequent years by a power harrow. The wet autumn of 1966 delayed all treatments until early spring 1967. R plots were usually rotary cultivated with a two-bladed machine in the autumn (in 1966 and 1967 they were done in spring by a three-bladed machine) followed in spring by treatments similar to those given to the P plots. In 1969 the autumn rotary cultivation was followed by one in spring with a three-bladed machine. The T plots were cultivated twice in the autumn except in 1966 and 1967 when the operations were done in spring. Seedbeds were prepared as for the P plots.

Proctor was the variety grown in 1961–63, Maris Badger in 1964–69 and Julia in 1970–72.

Granular fertilisers were combined drilled each year:

1961 and 1962	20 : 10 : 10 at 3 cwt/acre
1963–66	20 : 10 : 10 at 2·5 cwt/acre
1967–72	25 : 10 : 10 at 3 cwt/acre

The herbicides used (at recommended rates and stage of growth) were:

1966–70	mecoprop/2,4-D (all plots sprayed in 1967)
1971–72	ioxynil/mecoprop

TABLE 10

Residual effects of treatments to potatoes

Barley—grain cwt/acre at 85% DM

		P	R	T	Mean
Mean 1962–65	M	43·0	42·6	42·7	42·7
	S	44·2	42·4	42·3	42·9
	Mean	43·8	42·5	42·4	42·8
Mean 1966–72	M	44·3	43·7	44·1	44·0
	S	44·4	43·8	43·9	44·0
	Mean	44·4	43·8	44·0	44·0
Mean 1962–65	M–S	−1·2	+0·2	+0·4	−0·2
Mean 1966–72	M–S	−0·1	−0·1	+0·2	+0·0

M = no spray—mechanical cultivations
S = linuron/paraquat spray

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The yield from the primary cultivation treatments varied a little from year to year, but the mean of the seven years 1966–72 showed that as in the first five years there was little difference between them. The yields were remarkably consistent throughout the whole period of the experiment. The slightly higher mean yield in the last seven-year period is probably due to the extra nitrogen given in six of the seven years and the better variety.

In the years 1962–65 the beneficial effect of the herbicides to the preceding potatoes was small but positive each year on the P plots. In the seven years 1966–72 there was no indication of any residual effects on any treatment.

The hormone sprays decreased the mean yield in the first five years except on the T plots where the mean yield was increased. In the six years 1966–72 hormone sprays increased the mean yield on all cultivation treatments, with best increases from the R and T plots, presumably due to the larger number of weeds on these treatments.

TABLE 11

Mean response to herbicides. Hormone (H)—no spray (O)

Barley—grain cwt/acre at 85% DM

	P	R	T	Mean
Mean 1961–65	−0·5	−1·1	+1·4	−0·1
Mean 1966–72	+0·6	+1·4	+1·4	+1·1

Other treatments

Effects of treatments A, B and C. The effect of delaying cultivations until spring, for spring-sown crops (A), was rather variable from year to year. The bean plots were all sprayed with simazine but the cereal plots were split for H *v.* O; potatoes were rotoridged from 1967 onwards. The beans on the A plots yielded slightly less than the P plots but rather more than the R and T; potatoes yielded less than the P and T plots but about the same as the R plots. There was no effect on the yield of spring barley.

In tables 12, 13 and 14 the A, B and C figures are the mean of all split plots, and the P, R and T figures are the mean of the S plots.

TABLE 12

Effect of treatment A

Potatoes—tons/acre—total produce
Grain—cwt/acre at 85% DM

		A	P	R	T
Mean 1966–72	Spring beans	21·6	22·8	20·8	20·6
Mean 1964–72	Potatoes	14·24	15·22	14·11	15·16
Mean 1964–72	Barley	44·3	44·3	44·4	44·0

The minimum cultivation treatments (B) which started in 1965/66 were unsatisfactory. The number and type of cultivations given varied greatly according to the condition of the land, but on no occasion was the land ploughed. The main operations were tine

TABLE 13

Effect of treatment B

Potatoes—tons/acre—total produce
Grain—cwt/acre at 85% DM

		B	P	R	T
Mean 1966–72	Spring beans	21·6	22·8	20·8	20·6
	Wheat	42·8	42·8	43·5	41·5
	Potatoes	14·26	15·29	13·96	15·15
	Barley	43·9	43·9	44·1	43·8

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cultivating, disc harrowing and spring-tine harrowing or power harrowing. The ground for potatoes was rotary cultivated once or twice.

The treatments had less effect on yield than was expected.

From 1969 onwards a series of plots (C) was allocated treatments that are usual farm practice for each crop. The primary cultivations consisted of autumn ploughing for beans, ploughing or tine cultivating for wheat, autumn ploughing followed by a spring rotary cultivation for potatoes and tine cultivating in autumn for barley after potatoes. The whole of each plot was sprayed each year and the potatoes were rotoridged as they had been from 1967 onwards.

The yield of spring beans from the C plots was slightly better than the P plots and outyielded the R and T. The low mean yield is due to the very low yield of the plots in 1970. The wheat and potato plots gave a yield similar to the other treatments. Barley yielded as well as the P plots which outyielded the R and T.

TABLE 14

Effect of treatment C

Potatoes—tons/acre—total produce
Grain—cwt/acre at 85% DM

		C	P	R	T
Mean 1969–72	Spring beans	18·88	18·63	16·73	15·83
	Wheat	47·6	47·7	47·3	46·6
	Potatoes	14·26	14·21	13·12	14·30
	Barley	46·9	46·9	45·4	44·5

The effect of paraquat. Paraquat was introduced on split plots in 1967 to see whether killing weeds in the autumn had any effect on the cultivation treatments, or the yield and the weed numbers in the following year. The treatments killed the weeds in the stubble very effectively. In almost every following crop each year there was a small but positive gain from the use of paraquat, but though the stubbles were much cleaner this had little effect on the weed population in the following year.

TABLE 15

Effect of paraquat—no spray

Beans and wheat—cwt/acre
Potatoes—tons/acre

		P	R	T	Mean
Mean 1968–72	Beans	+0·1	+0·7	+0·9	+0·6
Mean 1968, 1969 1970, 1972	*Wheat	+0·2	+1·3	+1·4	+1·0
Mean 1968–72	Potatoes	+1·07	+0·15	+0·62	+0·60

1968–70 paraquat applied at 0·75 lb/acre
1972 paraquat applied at 0·5 lb/acre
*1971 paraquat applied to whole plots at 1·5 lb/acre

Other observations

Penetrometer assessment. During the autumn of 1970 an attempt was made to find out if there were differences in soil compaction resulting from the cumulative effect of nine years of the primary cultivation treatments.

A constant-rate, self-recording penetrometer, loaned by the National Institute of Agricultural Engineering, Silsoe, was used. The probe had a 1·5-in. long core with an apex angle of 30°.

The assessment was made by six recordings on each of the primary cultivation treat-

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ments (P, R and T) and also on the plots receiving the minimum cultivation treatment (B), on winter wheat and barley stubble. Sub-plots for measurements were selected to include unsprayed and hormone-sprayed areas, and stubble treated with paraquat.

Flints made it very difficult to obtain valid results but with considerable difficulty one set of six records was obtained from each of the selected plots on the wheat stubble.

The results showed that resistance to penetration was greatest on the minimum cultivated plots and then decreased in the order ploughed, rotary cultivated, deep-tine cultivated. The plots receiving minimum cultivations offered greatest resistance to penetration in the top 2 in. of the profile; resistance decreased below about 6 in. on the ploughed treatment. One plot on the tine treatment showed a marked decrease in resistance at depths greater than 7 in.

Water infiltration. In winter 1968/69 an attempt was made to detect differences between P, R and T plots in the rate at which water infiltrated into the subsoil. This was done on 1 yd square sample areas enclosed by barriers pushed down into the soil. Infiltration rates differed greatly but differences were associated with differences in soil texture and no effect of cultivation treatments could be detected.

Simazine degradation. During 1964/65 topsoil samples were taken from one unsprayed plot, one plot which received 1 lb simazine in autumn and one plot which received the same amount but divided half in autumn and half in spring. These were examined for possible simazine-degrading micro-organisms; many enrichment cultures were made but no organisms could be isolated able to degrade simazine when it was the sole source of both nitrogen and carbon. A bio-assay was developed using *Chlorella* as the test organism but this was only sensitive to simazine concentrations greater than about 1 ppm, and the concentrations in the samples did not reach this level.

Soil analysis

Rothamsted results. Samples of topsoil (0–8 in. or 0–9 in.) were taken from all plots of treatments P, R and T (and some others) in 1965, 1970 and 1972. Organic carbon was determined for all samples by the Walkley–Black method (Walkley, 1947) using the factor 1·3. Soluble phosphorus and potassium were determined on the 1972 samples; phosphorus by Olsen's (1954) method, potassium was the amount exchangeable to neutral 1N-ammonium acetate. The results are shown in Table 16; differences between years may be attributed to slight differences in depth of sampling.

Consistently more carbon was found in R plots than in P plots and still more in T plots. The extra organic matter in the R and T plots was largest in 1970. However, the sampling in 1970 was probably least reliable because the soil was very dry and it was difficult to sample all treatments to the same depth. The results for 1965 and 1972 were more consistent; the extra carbon in the soil was:

	%C in air-dry soil	
	T minus P	R minus P
1965	+0·12	+0·07
1972	+0·10	+0·07

Table 16 also shows that soluble phosphorus and potassium were both larger on R and T plots (which differed little) than on P plots in 1972. Table 16 shows the percentage carbon and soluble phosphorus and potassium in the soils of the A, B and C plots in 1972. The A plots (rotary cultivated in spring for spring crops) were about equal to the

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R plots; the B plots (minimum cultivation) were roughly the same as the T plots and the C plots (as might be expected) were similar to P plots.

TABLE 16

Results of soil analyses 1960, 1965 and 1972: Effect of primary cultivations

		P	R	T	A	B	C
Carbon (%)[a]	1965	1·46	1·53	1·58	—	—	—
	1970	1·46	1·58	1·66	1·49	1·61	—
	1972	1·38	1·45	1·48	1·46	1·44	1·38
Phosphorus (ppm)[b]	1972	48	55	56	49	57	50
Potassium (ppm)[c]	1972	150	166	172	156	190	155

In the 1965 and 1970 samplings, replicates were bulked before analyses.
(a) Organic carbon (Walkley–Black values, corrected using factor 1·3)
(b) Phosphorus soluble in 0·5M-$NaHCO_3$ mg/kg
(c) Potassium exchangeable to 1N-ammonium acetate

I.C.I. results. In spring 1973 five 1·7 cm cores were taken by I.C.I. Plant Protection (D. Riley), from each replicate plot in Series IV (winter wheat in 1973) and bulked together. A second set of samples was then taken to estimate the sampling and analytical errors. The samples were taken at depths 0–1 in., 1–4 in. and 4–6 in. Available nutrients were determined by standard ADAS methods, phosphorus being extracted with 0·5M-$NaHCO_3$ at pH 8·5 and potassium and magnesium with 1M-NH_4NO_3. Values for pH were measured in slurries with a soil : water ratio of 1 : 2·5. Organic carbon was determined by the Walkley–Black method using the factor 1·3. Aggregate stabilities were determined by Low's (1954) method on samples taken with a spade as described by Low.

TABLE 17

Results of soil analyses: 1973 Series IV—by I.C.I. Plant Protection Ltd.

	P			R			T		
Sampling depth (in.)	0–1	1–4	4–6	0–1	1–4	4–6	0–1	1–4	4–6
Carbon (%)	1·6	1·6	1·6	1·9	1·9	1·6	1·6	1·7	1·6
Phosphorus (ppm)	35	37	39	58	44	37	52	48	32
Potassium (ppm)	132	136	141	230	215	126	215	182	102
Magnesium (ppm)	24	25	24	28	27	25	31	28	25
pH	7·4	7·6	7·6	7·1	7·3	7·6	6·8	7·2	7·5
Aggregate stability	6	8	—	7	6	—	6	4	—

Comparison of the Rothamsted and I.C.I. Plant Protection results cannot be made because of the differences in the depth of soil sampled; I.C.I. samples from the 0–6 in. depth were less than the depth of ploughing on the P plots, Rothamsted samples from the 0–9 in. depth were deeper than the depth of cultivation on the R and T plots. However, the results in Table 16 and 17 are not so different as to suggest any large discrepancies in analytical results.

The I.C.I. results are interesting in showing that for the three horizons sampled there is a suggestion of a soluble P and K profile developing on the R and T treatments, the amounts of soluble phosphorus and potassium on the 4–6 in. depth are appreciably less than on the 1–4 in. depth. As would be expected, no such profile has developed on the P plots where ploughing was deeper than 6 in. A similar profile has not developed for magnesium because this nutrient was not applied. On the R and T plots the top inch of this slightly calcareous soil has become more acid than the 4–6 in. depth. Only on the R plots do the results for carbon suggest that more carbon is accumulating in the top 4 in. of soil. Riley (private communication) suggests that these profiles are less well developed

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than those where direct drilling has been practised for a number of years. This would be consistent with the fact that on the R and T treatments there has been more soil mixing than would happen with direct drilling.

Differences associated with post-planting weed control (Table 18) were generally small. The decrease in soil potassium on the Sx plots (which could have occurred by chance alone with a probability of between 0·01 and 0·05) should perhaps be attributed to sampling error since it is hard to explain the difference between Sx and Sy, whose treatments were very similar.

TABLE 18

Results of soil analyses 1965, 1970 and 1972; effect of post-planting weed control

		M	Sx	Sy
Carbon (%)	1965	1·53	1·52	1·52
	1970	1·61	1·54	1·54
	1972	1·45	1·42	1·44
Phosphorus (ppm)	1972	52	52	55
Potassium (ppm)	1972	164	156	167

Analysis of variance of the 1972 results shows significant differences between the four series, and the earlier samplings show that these are differences between the four areas of land and are not associated with the crops of the rotation. There was no evidence of any interaction between treatments and series.

Earthworms. In autumn 1971 the two cereal stubbles (Series III and IV) were sampled, using dilute formalin (Raw, 1959) to determine the populations of earthworms. Four quadrants, each of 4 ft^2 were sampled on each replicate, a total of 16 samples per cultivation treatment.

TABLE 19

Numbers of earthworms per square yard (autumn 1971)

	P	R	T	B
	Lumbricus terrestris			
After wheat	4·0	8·8	10·8	7·6
After barley	0·4	2·2	7·0	5·8
Mean	2·2	5·5	8·9	6·7
	Other species (total)			
After wheat	10·1	3·2	7·9	18·2
After barley	8·6	4·3	13·7	13·0
Mean	9·3	3·7	10·8	15·6

There were four times as many *Lumbricus terrestris* on tined plots as on ploughed plots, with rotary cultivated plots and minimum-cultivation plots intermediate. Other species (whose numbers are amalgamated in the table) gave about equal numbers on tined and ploughed plots but were less than half as numerous on rotary cultivated plots. Minimum-cultivation plots had more worms of these species than tined or ploughed plots. There were more *L. terrestris* after spring wheat than after barley; other species differed little between the crops.

Cereal diseases. The wheat and barley were not regularly examined for diseases, but take-all whiteheads were common in spring wheat in 1963. In early August 17% of the plants had take-all which appeared most prevalent on the P plots.

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Summary of the results

Beans. In the last seven years ploughing usually gave a slightly better yield of spring beans, and in all years weeds were fewer than on the R and T plots. With all cultivation treatments yields were slightly less when simazine was used; mechanical cultivations were rather more effective than simazine in controlling weeds between rows. Dinoseb acetate was less effective than simazine for weed control and under certain weather conditions can damage the crop.

Wheat. There were no differences in yield of winter or spring wheat between the primary cultivation treatments, and there was no decline in yield during the course of the experiment. There was a small positive residual effect on the rotary cultivated plots from the simazine applied to the previous bean crop, but a slight negative effect on the tined plots. The effect of hormone weedkillers varied from year to year and were generally small; the rotary cultivated plots gained most benefit.

Potatoes. In most years the ploughed plots yielded best and the tined plots least; yields showed no sign of diminishing during the course of the experiment. On the ploughed plots the linuron/paraquat spray consistently gave less yield than those mechanically cultivated, but the sprayed plots yielded more than the cultivated ones on land that had been rotary cultivated or tined. In all years weeds were less on the ploughed plots, whether mechanically cultivated or sprayed. Rotoridging after spraying had little effect on either weed numbers or yields.

Barley. There was no significant difference between the primary cultivation treatments; the mean yield in 1966–72 was greater than in 1962–65 probably because more nitrogen was applied and a better variety was introduced. The effect of the hormone weedkillers was small but positive in most of the last seven years, the benefit being greatest on the R and T treatments. There was no residual effect from the weedkiller applied to the preceding potato crop.

Paraquat. This, when used on autumn stubbles, had a slight beneficial effect on yield in most years but had no consistent effect on the weed population the following year.

Penetrometer assessment. This proved very difficult to do because of the many flints in the soil but resistance to penetration was greatest on the minimum cultivated plots and then decreased in the order ploughed, rotary cultivated, tine cultivated.

Water infiltration. An attempt to detect differences between the prime cultivation treatments proved negative.

Simazine degradation. No organism could be isolated able to degrade simazine when it was the sole source of both nitrogen and carbon.

Soil analysis. In the Rothamsted samples consistently less carbon was found in the P plots than in the R and T plots but in the I.C.I. Plant Protection samples (taken to lesser depths) the percentage carbon was the same on the P and T plots but greater on the R plots. Samples taken in 1972 by Rothamsted and in 1973 by I.C.I. Plant Protection Ltd., showed that there was more phosphorus and potassium on the R and T plots than on the P plots. There were no consistent differences between crops or interaction between treatments and crops.

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Earthworm populations. There were considerable differences between the primary cultivation treatments. The biggest population was on the plots receiving least cultivations and the smallest on the P plots.

Cereal diseases. The crops were not examined often enough to form any opinion on the incidence of diseases but in 1963 take-all appeared to be most prevalent on the P plots.

Weeds. There were no marked changes in the species of weeds and none became dominant. In many years control measures were taken against couch grass (*Agropyron repens*).

Discussion

Since the experiment began in 1961 many changes have taken place in British agriculture, brought about by economic conditions and the shortage of labour, and many of these add interest and importance to results obtained. The number of farm workers per 1000 acres of cropped land has decreased sharply (15·6 in 1962, 7·7 in 1972); this has forced farmers to use modern equipment to the fullest extent for autumn cultivations, seedbed preparation, drilling and harvesting, accepting (if necessary) a small loss of yield in consequence. Similarly the recent great increase in the cost of fuel oil has provided a powerful incentive to lessen the number of operations, or combine operations needing fewer passes by tractors, which leads to less soil compaction.

Public concern about the pollution of soils and water by persistent active chemicals (such as herbicides) which may have unforeseen side effects has forced farmers and others to consider the long-term effects of single and especially repeated applications. Finally, the report *Modern Farming and the Soil* (Agricultural Advisory Council, 1970) generated some concern about the conservation of organic matter in soils to save them from dire loss of structure. It is possible that the smaller amount of soil carbon in the ploughed treatment is due to the more thorough mixing and aeration of the soil causing more rapid oxidation of crop residues than occurs with other treatments. It is not unreasonable to suggest that the different amount of weeds on the P, R and T plots may have contributed appreciably to the difference in carbon in the soil, as other experiments (Dyke, 1965) where weed populations have been allowed to overwinter, suggest that weeds can contribute to the soil carbon.

It seems unlikely that differences in soluble phosphorus and potassium between P, R and T treatments arise from differences in offtake of nutrients in the crops since the mean yields differed little. A tentative explanation, offered by A. E. Johnston, is that, with the more thorough mixing of the 0–9 in. layer of soil caused by ploughing, a greater proportion of applied phosphorus and potassium have been fixed in forms not soluble in the reagents used. Although total phosphorus and total potassium have not been determined, they are probably the same on all treatments. The additional soluble phosphorus and potassium in the R and T plots (if this argument is correct) is near the surface and their availability to crops will depend on the growing season and the rooting pattern of the crop.

This is an example of an experiment in which we may welcome a mainly 'negative' result: that is, the absence of appreciable differences in yield between some or all of the treatments, and in the event this has proved to be true of many of the comparisons made. No direct measurements have been made of rates of work of different implements, or of their power requirements, because this would have been impracticable on such small plots. But work by Patterson, Chamen and Richardson (1974), provides figures which could be used in conjunction with our results.

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On the whole the results seem to justify farmers' common sense; any system of cultivation that produces a physically adequate seedbed into which seed can be drilled or planted to the correct depth can give yields within a few per cent of the best obtainable by more thorough, expensive and time-consuming methods. Any system of controlling weeds after planting, whether by inter-row cultivation, herbicides (selective or soil-acting), or a combination of both, gives full, or very nearly full, yields of the crops included in our experiment. Any combination of primary cultivation and later weed control that fails to keep weeds (especially perennial weeds) under reasonable control leads, in the short or long term, to unacceptable loss of yield. Abandoning the mouldboard plough in favour of non-inverting methods of cultivation conserves soil organic matter and nutrients, and though the differences have not obviously affected crop yields on our soil they might do so elsewhere. Other possible effects are to slightly increase the total number of earthworms though not of all species and decrease slightly the soil-borne disease of cereals. Again, neither effect seems likely to be of great practical importance at any rate on our soil.

Finally, in spite of careful observation, we have no evidence of harmful accumulation of persistent herbicides in soil and no evidence that, after repeated application, these materials become less effective because of more rapid breakdown by microbes, and there has been no sign of a serious increase of any menacing 'new' weed under any of the systems tested.

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