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The Effects of Partially Sterilising Agricultural Soils with Formalin, and of Applying Nitrogen Fertilisers, on the Yields and N Contents of Spring and Winter Wheat, of Barley and of Grass

F. V. WIDDOWSON and A. PENNY

Partial sterilization with steam or with formalin solutions has for long been used in horticulture to maintain yields in glasshouses where the same crops have been grown frequently. Russell (1961), quoting from work done in the early 1900s, stated that the larger yields after partial sterilization resulted not only from killing soil-borne pathogens, but also from an increase in mineralisable soil nitrogen, but that the full explanation of the better yields was lacking.

Benzian (1965) showed that in forest nurseries formalin and other soil sterilants greatly increased the height and vigour of conifer seedlings which otherwise were stunted. All other treatments, which included fungicides, soil conditioners, composts and inorganic fertilisers were ineffective unless the soil was drenched with formalin not less than 3 weeks before the seeds were sown. The fact that fungicides did not improve growth, whereas the formalin drench did, showed that more than killing soil fungi was involved and tests showed that the sterilised soils contained more ammonia and the trees grown on them more manganese. These experiments also showed that the increase from formalin was larger where it was given for the first time than where it had been given the year before, so that the benefits of successive treatments were not cumulative.

Cooke (1963) considered problems of growing cereals on some light soils in Hertfordshire and Lincolnshire, where promising crops had failed during dry weather in June, and summarised work then done to try to solve them. Similar problems with cereals had also occurred on light land at Woburn Experimental Station, where, as at the other centres, they were associated with generous N manuring, with dry weather before ear emergence, and with fungi causing root rots. Because the stunted growth in forest nurseries had been overcome by applying formalin to these soils we decided to test formalin for wheat, and included with it tests of other treatments that might help to overcome the problem. In our first experiment we used (1) a non-phytotoxic fungicide (Nabam) to control *Fusarium* spp. (2) irrigation during dry weather to prevent a moisture deficit and (3) a range of nitrogen dressings to apply stress. It was made in 1964 with spring wheat at Woburn; formalin trebled yields. In 1965 we extended the work to Rothamsted where, on heavier soils, cereals had not been harmed, so far as we knew, and we chose one site that had previously grown cereals for many years and another recently ploughed from grass. In 1967 another experiment with formalin was begun on Chalky Boulder Clay at Saxmundham (Suffolk), because barley in a long-term rotation experiment there had yielded disappointingly; the amount of pathogens in the soil was unknown. Also in 1967 another

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experiment was begun with newly sown meadow fescue and timothy at Rothamsted, to establish whether a crop less likely to be damaged by soil pathogens benefited from drenching the soil with formalin before sowing and, if it did, for how long.

The main purposes of the experiments therefore were:

(1) to measure the effect of formalin on the yield of cereals;
(2) to examine the effect of formalin on the nitrogen content of the crops and so the need for fertiliser N;
(3) to examine the effects of formalin and fertiliser nitrogen on the take-all fungus (*Ophiobolus graminis*) and other soil-borne pathogens (D. B. Slope and G. A. Salt), and hence the amount of N needed by uninfected and infected crops.

Also, because D. B. Slope's root samples showed that cereal cyst eelworm (*Heterodera avenae*) was abundant on Butt Close, Williams (1969) measured the effects of the treatments on its incidence.

Experimental methods and treatments

Butt Close, Woburn, 1964–65. This field previously had grown many arable crops; the soil is a light sandy loam over Lower Greensand, holding less than 1 in. of water per foot of soil. In 1963 winter wheat following beans became stunted during dry weather in late May and June, especially on plots given much N; on these plots many ears failed to emerge normally and at harvest yields were small.

In 1964 spring wheat tested these four factors in all combinations:

(1) 38% formaldehyde (at 250 cc/sq yd) applied in water as a drench.
(2) Nabam (a fungicide) sprayed over the seedbed and over the crop.
(3) Water applied to give, with rain, 1 in. of water per week.
(4) Nitrogen fertiliser ('Nitro-Chalk') to give 0·6, 1·2 or 1·8 cwt N/acre.

These 24 treatments were arranged in two blocks of 12 plots; there were two replicates; individual plots were 7 ft wide and 20 ft long (0·0032 acre).

The formalin was applied by watering-can in December 1963 and repeated in February 1964 because too little rain fell after the first drench to wash it in. Then, in March, basal PK fertiliser (0-20-20 at 2½ cwt/acre) and half of each N dressing were broadcast by hand, Nabam (at 10 lb/acre) was sprayed over appropriate plots and then the wheat (Jufy I) was sown with a hand-drill in rows 6 in. apart. The seedbed was made with hand-rakes to limit the movement of sterilised and unsterilised soil from plot to plot. Nabam (at 5 lb/acre) was sprayed over the wheat at the 3-leaf stage and again when it covered the ground completely; the other half of the N was applied in early May. From 18 May to 27 July water was applied weekly by hand-hose to give, with the rain that fell, 1 in. of water per week (4·7 in. of water was applied). At harvest the centre 13 rows of wheat on each plot were cut by hand and threshed, and the grain and straw were weighed. Samples of grain and straw were taken to measure dry matter and % N.

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In 1965 formalin was applied again (in December 1964) in all combinations with the 1964 treatments giving a single replicate of each combination. Nabam was not tested again, calcium nitrate replaced Nitro-Chalk (to eliminate any effect formalin might have on nitrification) and Opal wheat replaced Jufy I. The 1965 summer was wet and water was applied for the wheat only from 25 May to 16 June (1·2 in. of water was added), because after that ample rain fell each week. Other treatments and methods were the same.

Little Knott and Pastures, Rothamsted, 1965–68. The Little Knott experiment was made on a field that had been ploughed from grass in 1943 and then had grown cereals in 19 of the next 21 years; the Pastures experiment was made on a field that had grown grass for 10 years and then was ploughed for spring wheat in 1964. In 1965 the effect of a formalin drench (250 cc of 38% formaldehyde per sq yd) was tested on spring wheat without N and with 0·5, 1·0 or 1·5 cwt N/acre (as calcium nitrate). The eight treatments were arranged in a randomised block; there were four blocks on Little Knott and two on Pastures. Individual plots were 7 ft wide and 20 ft long (0·0032 acre).

The formalin drench was applied by watering-can and basal PK by hand over spring-tined land in February. The first half of the N was applied during March and then Opal wheat was sown by hand-drill in rows 6 in. apart. The remaining N was applied in May. At harvest the wheat was cut by sickle and threshed.

In 1966 the same amount of formalin was tested again in all combinations with the 1965 drench, on whole plots on Little Knott and on half plots on Pastures. The same amounts of N were given to the same plots and at the same times to Kloka spring wheat. The wheat was cut by sickle and threshed.

In September 1966 formalin was applied again (in all combinations with the 1965 and 1966 drenches) either to the stubble, or shortly after ploughing; the N dressings again were cumulative. Basal PK was given and winter wheat (Cappelle) was sown by hand drill in late October. In spring, N (at 0·5, 1·0 or 1·5 cwt/acre) was re-applied to appropriate plots, half of each dressing in March and half in May. On Little Knott the wheat was combine-harvested, but on Pastures it was cut by sickle and threshed.

In September 1967, after ploughing, formalin was again applied in all combinations with the three previous drenches. In October, Cappelle wheat was sown and in spring N was applied to appropriate plots. Both experiments were combine-harvested. Each year the grain and straw were weighed and sampled for dry matter and % N.

Grove Plot, Saxmundham, 1967–68. The experiment was made to test factors that may limit yield on this sandy clay soil with a poor structure. Formalin, lime and two amounts of nitrogen (applied in either March or May) were tested in all combinations on two barley varieties (Maris Badger and Deba Abed). The 32 treatments were arranged in two blocks of 16 plots; individual plots were 7 ft wide and 14 ft long (0·0022 acre).

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In February 1967 a formalin drench (500 cc of 38% formaldehyde per sq yd) and lime where appropriate and basal PK were applied over the ploughed land. In March the soils were sampled and then the barley was sown by hand-drill in rows 7 in. apart; N at 0·6 or 1·2 cwt/acre (as calcium nitrate) was broadcast by hand either on the seedbed or in May over appropriate plots. At harvest the barley was cut by sickle, threshed, and the grain and straw weighed and sampled for dry matter and % N.

In 1968 formalin was tested again in all combinations with the 1967 drench. All the other treatments were repeated on the same plots to give a half replicate of 32 plots. In March the soils were sampled again for mineralisable N. The results given here are averaged over varieties, lime and times of applying N.

Fosters, Rothamsted, 1967–68. This experiment was made on a field that had grown many arable crops. It measured the effects of a February soil drench of formalin (at 500 cc/sq yd) without nitrogen and with 0·3, 0·6 or 0·9 cwt N/acre/cut (as calcium nitrate) on the yield of a March-sown timothy (Scots) and meadow fescue (S.53) ley. The eight treatments were arranged in a randomised block; there were four blocks. Individual plots were 6 ft wide and 12 ft long (0·0016 acre). In 1967 the grass was cut three times (in July, September and November) and in 1968 twice (in May and July); N was re-applied for each cut. The grass was weighed and sampled for dry matter and % N.

Observations

Butt Close, Woburn, 1964–65. On 6 May 1964, wheat growing on soil drenched with formalin was taller and more vigorous than wheat on untreated soil and also was almost weed-free, whereas the other wheat was infested with many weed seedlings (mainly *Matricaria* and *Polygonum* sp.). It was all sprayed to kill the weeds. On 9 June irrigated wheat had larger broader leaves than unirrigated, even though 1·5 in. of rain had fallen the week before, but with so much rain in June none of the wheat failed, and the expected symptoms of scorching did not occur, even though July was dry and sunny.

On 22 April 1965 we observed that wheat growing on soil drenched with formalin in 1964 was inferior to wheat growing on untreated soil; much of it was stunted and had yellow leaves. Also, the large benefits from the new formalin drench were diminished by the residues of the 1964 drench, so that the formalin was most beneficial where it had not been used the year before; these differences persisted until harvest.

Little Knott and Pastures, Rothamsted, 1965–68. On 3 May 1965 wheat on Little Knott growing on soil drenched with formalin was much superior to wheat growing on untreated soil, but on Pastures the wheat showed no benefit, presumably because this soil contained few pathogens, and was rich in N.

In 1966, freshly applied formalin improved growth greatly on Little

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Knott, but only slightly on Pastures. There was no visible benefit or harm, on either field, from the residues of the formalin given in 1965.

In 1967, formalin applied the previous autumn did not visibly benefit the wheat on Little Knott until mid-June, but did after then. By contrast, formalin given the year before was harmful, for in July the wheat growing on nine plots was stunted, had bluish stems and leaves, and the leaves were erect and rolled inwards from the margins; all had been given formalin in February 1966. On Pastures new formalin improved growth during March, but the drench applied over the stubble improved growth less than the drench given after ploughing. The benefits from the formalin persisted until severe lodging occurred well before harvest; the most vigorous wheat lodged most.

In 1968, freshly applied formalin benefited the wheat greatly on Pastures, but had little effect on growth on Little Knott (by contrast to the first two years), but losses from giving formalin the year before were not evident. The wheat responded greatly to N on Little Knott, but there was less visual response on Pastures. At harvest there was little lodging on Little Knott, but on Pastures all the wheat given N was flat.

Grove Plot, Saxmundham, 1967–68. In 1967, formalin improved growth only a little and in 1968 little more; its benefits were evident only with 0·6 cwt N/acre and not when 1·2 cwt N/acre was given. By contrast, N greatly increased growth each year and so the visual effects were mainly from rates and times of N.

Foster's, Rothamsted, 1967–68. The grasses established only slowly during wet weather in May and so, in June, they were topped and a second dressing of N given. Then they grew quickly and growth was better with formalin than without. In 1968 there was little visible benefit from the formalin.

Results

Butt Close, Woburn, 1964–65. Appendix Table 1 shows that in 1964 grain yields (averaged over Nabam) ranged from 9·1 (with 0·6 cwt N/acre) to 37·2 cwt/acre (with 1·2 cwt N/acre, formalin and water). Trebling the amount of nitrogen (to 1·8 cwt N/acre) increased grain yields by 5·7 cwt/acre without irrigation or formalin, by 11·8 cwt/acre with irrigation alone, by only 0·2 cwt/acre with formalin alone, but 5·9 cwt/acre when both formalin and water were given, so that water increased and formalin decreased the need for nitrogen. Appendix Table 1 also shows that in 1964 straw yields ranged from 14·3 (with 0·6 cwt N/acre) to 53·0 cwt/acre (with 1·8 cwt N/acre, water and formalin), so that the straw benefited from one more increment of N than the grain. However, the gains from formalin and from water were proportionally as large for straw as for grain. The table also shows that applying formalin did not consistently change the percentage of N in the wheat grain, but, because it increased yields so much, it more than doubled the amount of N removed by wheat given 0·6 cwt N/acre, and increased by a half the amount of N removed by wheat given 1·8 cwt N/acre. Applying water decreased % N in the grain in five of six

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comparisons, presumably because it increased yields without increasing the amount of mineralisable N in the soil, whereas formalin probably increased it. However, watered wheat removed approximately one fifth more N than unwatered, so that water increased its ability to use N. Nabam increased yields little and so its results are not shown.

Appendix Table 1 shows that in 1965 grain yields ranged from 6·0 (with 0·6 cwt N/acre alone) to 37·4 cwt/acre (with 1·2 cwt N/acre, formalin in 1965 and water), so that although the range was greater in 1965 than in 1964 maximum yields were almost the same in the two years. The Table also shows that formalin was most effective where none had been applied the year before, so that there was a negative interaction between the fresh application and the residues of that given the year before.

The table also shows that giving the wheat 1·8 rather than 1·2 cwt N/acre decreased yields where formalin had been given that year, but that it increased them a little where it had not, showing again the interaction between nitrogen and formalin. Also, the benefits from giving extra N were made larger by giving water, providing that formalin also had been given, but not where it had not. Evidently the residual effects of water were harmful on this sandy soil, because in 1965 water increased grain and straw yields (in 9 or 12 comparisons) where formalin was also newly given and decreased yields (in 9 or 12 comparisons) where it was not. Presumably the water given in 1964 allowed cereal cyst eelworm to multiply faster and so decrease yields in 1965, unless formalin was newly given (Williams, 1969). Appendix Table 2 also shows that straw yields ranged from 11·8 (with 0·6 cwt N/acre and water) to 44·8 cwt/acre (with 1·2 cwt N/acre, water and formalin only in 1965). There was no obvious relationship between the increases from the largest amount of N and formalin.

Formalin tended to diminish % N in the grain, presumably because yields with it were larger, and water also tended to do so, whether or not it increased yields. Formalin greatly increased the amount of N removed by the wheat; it more than trebled the amount by wheat given 0·6 cwt N/acre and almost doubled the amount by wheat given 1·8 cwt N/acre; water increased the amount only where it also increased yields.

Table 1 shows that, in 1964, mean grain and straw yields were almost doubled by formalin, but that the residues of this drench decreased the yields of the wheat that followed in 1965. By contrast the formalin given in 1965 more than doubled grain and straw yields, but, even so, mean yields were smaller than in 1964 (maximum yields were not (Appendix Table 1)). Table 1 also shows that the second increment of 0·6 cwt N/acre increased grain and straw yields in both years, but the third increased only straw yields. Water significantly increased yields during dry weather in 1964, but had little effect in 1965.

Table 2 shows that giving formalin in 1964 increased yields slightly in 1965, but the plots drenched in both 1964 and 1965 yielded less than those drenched in 1965 only, i.e., drenches in two successive years had less effect than one drench immediately before the wheat crop. On this soil, formalin was more effective than N in increasing yield but, even with formalin newly applied, maximum yield needed 1·2 cwt N/acre, which is usually regarded as a large dressing.

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TABLE 1

Mean yields (cwt/acre) of spring wheat (at 15% moisture content) without and with formalin, with three amounts of nitrogen, and without and with irrigation on Butt Close, Woburn, 1964 and 1965

	Formalin in 1964			Formalin in 1965			Nitrogen (cwt/acre/year)				Water		
	Without	With	S.E.	Without	With	S.E.	0·6	1·2	1·8	S.E.	Without	With	S.E.
Yields in 1964													
Grain	15·4	30·8	±0·54	—	—	—	19·2	24·9	25·1	±0·66	20·1	26·0	±0·54
Straw	25·3	44·8	±0·70	—	—	—	27·9	36·6	40·7	±0·86	32·0	38·1	±0·70
Yields in 1965													
Grain	21·4	19·1	±0·36	12·2	28·3	±0·36	16·0	22·4	22·3	±0·44	20·3	20·1	±0·36
Straw	29·4	26·0	±0·68	19·4	36·1	±0·68	22·9	29·3	31·0	±0·83	27·5	28·0	±0·68

TABLE 2

The residual and the direct effects of formalin on the yields (cwt/acre) of spring wheat (at 15% moisture content) given three amounts of nitrogen, on Butt Close, Woburn, 1965

	Formalin in 1964					
	Without			With		
	N cwt/acre/year					
Formalin in 1965	0·6	1·2	1·8	0·6	1·2	1·8
Grain						
Without	6·6	10·5	13·8	8·8	16·5	16·9
With	29·1	35·8	32·6	19·6	26·7	25·8
Straw						
Without	11·9	17·7	22·5	17·8	23·0	23·4
With	37·4	43·5	43·4	24·3	33·2	34·5

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Little Knott, Rothamsted, 1965–68. Appendix Table 2 shows that, in 1965, grain yields ranged from 17·0 (without N or formalin) to 35·4 cwt/acre (with 1·0 cwt N/acre and formalin), and that formalin increased yields with each amount of N. Although 0·5 cwt N/acre increased yield of grain by approximately 11 cwt/acre and straw by even more, there was little or no advantage from giving the wheat more N, whether or not formalin also was given. % N in the grain was increased by each increment of N; wheat given 1·5 cwt N/acre contained approximately 50% more N than wheat given none. By contrast, formalin did not consistently change % N in the grain, but, because it increased yields so much, it increased the amount of N removed (in the grain plus straw) by approximately a quarter, at each rate of N tested. Wheat given 0·5 cwt N/acre and formalin together recovered as much N as wheat given 1·5 cwt N/acre alone, so that the effect of formalin then was approximately equivalent to giving the wheat 1·0 cwt more N/acre.

Appendix Table 2 shows that, in 1966, the residual effects of formalin applied in 1965 greatly decreased yields and that, although these losses were diminished by applying N, they were not eliminated by the largest amount given (1·5 cwt N/acre). The table also shows that these harmful residual effects were diminished by a formalin drench in 1966, which gave larger yields than on plots not drenched in either year. However, the largest yields of grain and straw were obtained by formalin applied for the first time in 1966. The table also shows that this treatment tended to increase % N in the grain; as in 1965, it consistently increased the amount of N recovered by the wheat, and again its effect was approximately equivalent to giving the wheat 1·0 cwt more N/acre.

Appendix Table 2 shows that in 1967 winter wheat on soil not given formalin either in 1966 or in 1967 yielded the most grain, and that it gave approximately the same yield as the spring wheat grown before it. The residual effects of the formalin given in 1966 greatly diminished yields of grain and of straw and the wheat not given N almost failed. A formalin drench repeated in 1967 only partly overcame the harmful residual effects, for even with formalin in both years, both grain and straw yields were smaller than from untreated soil. However, straw yields were increased by formalin applied in 1967 only, and this also increased grain % N, but it did not consistently increase the amount of N recovered by the wheat.

Appendix Table 2 shows that, again in 1968, grain yields tended to be larger without than with newly applied formalin, so that the effectiveness of formalin seemed to be diminishing on this site. Also, by contrast to results in 1967, straw yields were not increased by newly applied formalin. The residual effects of formalin again decreased yields, but much less than in 1967, and their harmful effects were diminished by applying formalin again for the 1968 wheat. The newly applied formalin consistently increased grain % N, but it did not consistently increase the amount of N recovered by the wheat. However, by 1968, only two of the 32 plots in the experiment had not been given any formalin during the four years, which suggests that subsequent applications given to some plots in 1967 and in 1968 were less beneficial than the initial ones.

Table 3 shows that although formalin increased yields each year on

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TABLE 3

Mean yields (cwt/acre) of wheat (at 15% moisture content) without and with formalin on Little Knott Field, Rothamsted, 1965–68

		Formalin given in								
		1965		1966		1967		1968		
Yield in		Without	With	Without	With	Without	With	Without	With	S.E.
1965	Grain	24·5	31·7	—	—	—	—	—	—	±0·61
	Straw	41·8	49·7	—	—	—	—	—	—	±0·77
1966	Grain	33·2	29·9	26·7	36·5	—	—	—	—	±0·64
	Straw	44·8	40·8	34·1	51·5	—	—	—	—	±0·83
1967	Grain	23·6	24·2	30·0	17·7	23·1	24·6	—	—	±1·10
	Straw	35·7	38·4	41·5	32·6	34·0	40·1	—	—	±0·94
1968	Grain	31·0	32·5	30·1	33·4	32·2	31·3	31·1	32·4	±1·15
	Straw	34·2	34·3	32·6	35·9	36·6	31·9	32·9	35·6	±1·55

TABLE 4

Mean yields (cwt/acre) of wheat (at 15% moisture content) without and with formalin on Pastures Field, Rothamsted, 1965–68

		Formalin given in								
		1965		1966		1967		1968		
Yield in		Without	With	Without	With	Without	With	Without	With	S.E.
1965	Grain	27·2	27·8	—	—	—	—	—	—	±0·83
	Straw	55·1	58·3	—	—	—	—	—	—	±1·02
1966	Grain	36·3	36·6	35·7	37·2	—	—	—	—	±0·82[1] ±0·86[2]
	Straw	56·2	57·1	50·8	62·5	—	—	—	—	±0·89[1] ±0·62[2]
1967	Grain	30·4	29·6	31·6	28·4	29·1	30·9	—	—	±0·87[3]
	Straw	62·6	62·4	66·2	58·8	57·8	67·2	—	—	±1·28[3]
1968	Grain	24·6	25·0	24·8	24·8	24·7	25·0	27·1	22·5	±0·73[4] ±0·62[5]
	Straw	37·1	38·7	37·6	38·2	39·2	36·6	38·1	37·7	±1·07[4] ±0·86[5]

[1] Applies to yields from 1965 formalin.
[2] Applies to yields from 1966 formalin.
[3] Does not apply to yields from 1965 formalin.
[4] Applies to yields from 1965 formalin.
[5] Applies to other yields in 1968.

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Little Knott, it increased them more in 1965 and 1966 (when applied in February for spring wheat) than in 1967 and 1968 (when applied in September for winter wheat). However, the losses from the residues of formalin given the year before were as large, or larger, with winter wheat than with spring wheat, so that, in contrast to its direct effects, its residual effects were the same for both spring and winter wheat. In 1967 and 1968 the experiments also measured the effects of giving formalin two years earlier, and Table 3 shows that grain yields were a little larger with than without these formalin treatments. In 1968 the wheat also measured the residual effects of formalin given three years earlier; these also slightly increased yields.

Pastures, Rothamsted, 1965–68. Appendix Table 3 shows what happens when wheat is grown on a nitrogen-rich soil and given too much N. In 1965 N consistently decreased yields of grain, which with 1·5 cwt N/acre were almost halved. By contrast, 0·5 cwt N/acre increased straw yields by more than 10 cwt/acre, but giving more N than this decreased them. Formalin increased grain yields provided that N was not given, but had no consistent effect when it was, although formalin consistently increased the yields of straw. The large amount of N in the soil was confirmed by the large % N in the grain and by the fact that unmanured wheat recovered twice as much N here as on Little Knott (Appendix Table 2) in the same year.

Appendix Table 3 also shows that, in 1966, yields were not diminished by residual effects of the formalin given in 1965 (in contrast to Little Knott). Grain yields were sizeably increased by the new formalin drench only when N was not given, but straw yields were increased independently of N. Yields without N fertilisers were smaller than in 1965 and grain yields were greatly increased by giving 0·5 cwt N/acre (except where formalin also had been given in 1965 and 1966), but not further by giving more. Straw yields also were greatly increased by 0·5 cwt N/acre (whether or not formalin was given), but little more with more N.

The fact that yields of straw, but not of grain, were larger when formalin and nitrogen were given together, suggests that potential grain yield was lost through lodging. Hence, effects were better judged by straw than by grain. The table also shows that newly applied formalin did not consistently increase % N in the grain, but that it did increase the total amount of N removed by the grain and straw in seven of eight comparisons.

Appendix Table 3 shows that, in 1967, wheat yields were diminished by formalin given in 1966, but that most of this loss was prevented either by drenching with formalin again in 1967 or by giving the wheat more than 0·5 cwt N/acre. A new drench greatly increased the yields of grain where the wheat was not given N, and slightly increased them when only 0·5 cwt N/acre was given, but, with more N than this, formalin decreased grain yields. It consistently increased straw yields. The largest yields of grain and of straw were obtained by giving formalin to soil that had been given none the year before, but the best amount of N for each was different. New formalin increased % N in the grain in 7 of 8 comparisons and it also increased the total amount of N removed by the grain and straw, except when 1·5 cwt N/acre was also given. The effect of this new drench on the

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amount of N removed by the wheat was less than that of giving the wheat 0·5 cwt N/acre.

Appendix Table 3 shows that the formalin given for the 1968 wheat consistently decreased grain yields and slightly decreased those of straw, presumably because it made lodging worse in this wet summer. By contrast, the residual effects from the 1967 drench increased grain yields, presumably because this wheat was poorer, lodged less and so yielded more. Nitrogen increased yields a little providing that only 0·5 cwt N/acre was given. With more N, grain yields were consistently diminished and straw yields were irregular. Newly applied formalin usually increased grain % N, but because it decreased yields it usually decreased the total amount of N recovered by the wheat, although fertiliser N consistently increased it.

Table 4 shows that newly applied formalin (averaged over N) increased grain and straw yields only a little each year from 1965 to 1967, and that it greatly decreased yields of grain and slightly decreased yields of straw in 1968.

The residual harmful effects of formalin the year after it was given were far less than on Little Knott; they appreciably diminished yields of grain only in 1967 and of straw in 1967 and in 1968. Formalin given two or three years previously had only small effects on yields, but they were positive in four of six comparisons.

Grove Plot, Saxmundham, 1967–68. The 1967 barley followed a summer fallow. Appendix Table 4 shows that, without formalin, 0·6 cwt N/acre increased grain yields by 14·1 cwt/acre, but with it, by 17·9 cwt/acre. Applying 1·2 cwt N/acre rather than 0·6 increased grain yields further (by 4·9 cwt/acre), but then formalin slightly diminished yields. Formalin also increased straw yields, but more with the single than with the double amount of N, and it also increased % N in the grain, however much N was given. Thus, more total N was always removed by the barley with than without formalin.

Appendix Table 4 shows that, in 1968, yields without N were smaller than in 1967, but that the response to N was larger, so that maximum yields were nearly the same in the two years. As in 1967, newly applied formalin increased yields a little, but more with 0·6 than with 1·2 cwt N/acre. The residual effects from the formalin given in 1967 also increased yields, but

TABLE 5

Mean yields (cwt/acre) of spring barley (15% moisture content) without and with formalin at Saxmundham in 1967 and 1968

	Formalin in 1967			Formalin in 1968		
	Without	With	S.E.	Without	With	S.E.
			Yields in 1967			
Grain	38·5	40·2	±0·68	—	—	—
Straw	40·1	42·7	±0·87	—	—	—
			Yields in 1968			
Grain	37·8	38·8	±0·62	37·6	39·0	±0·62
Straw	42·7	42·8	±0·77	42·5	43·1	±0·77

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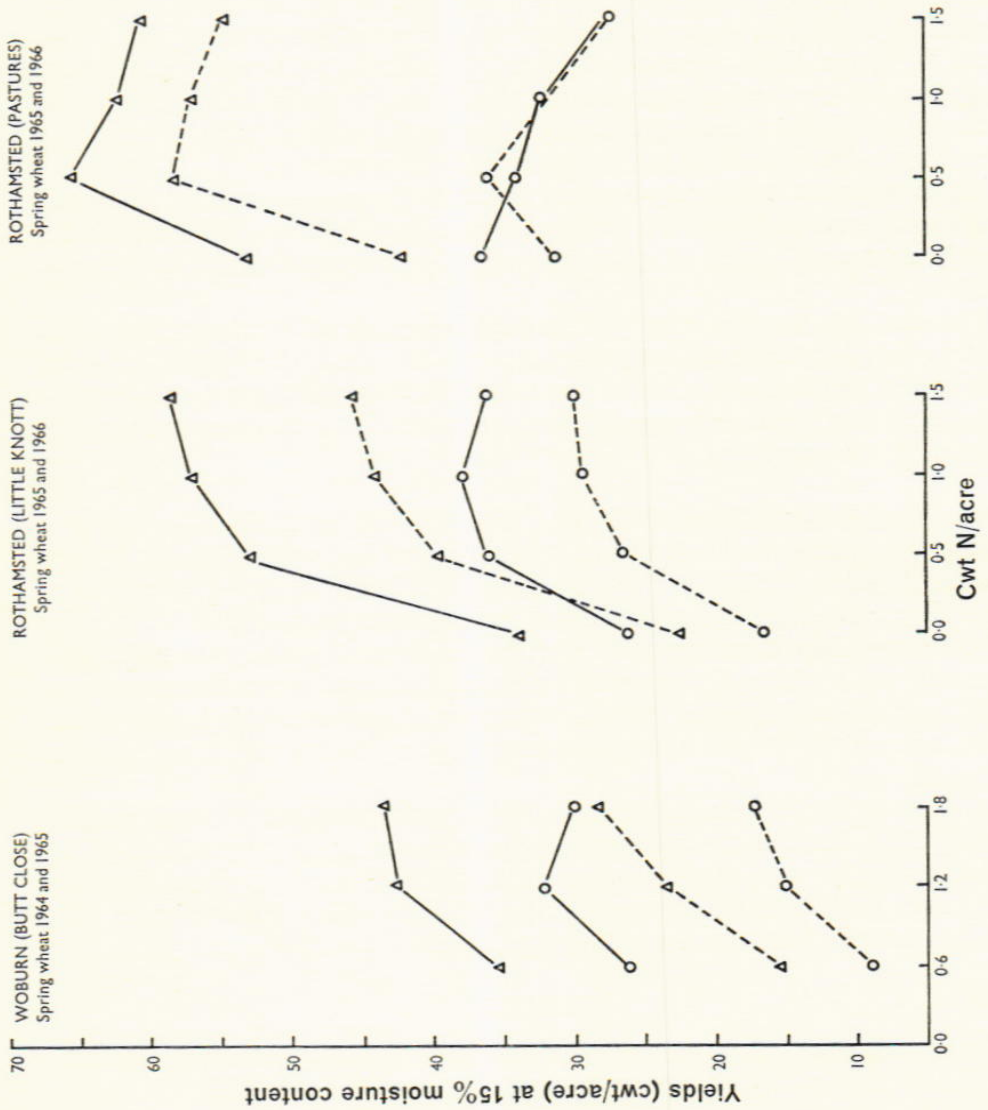

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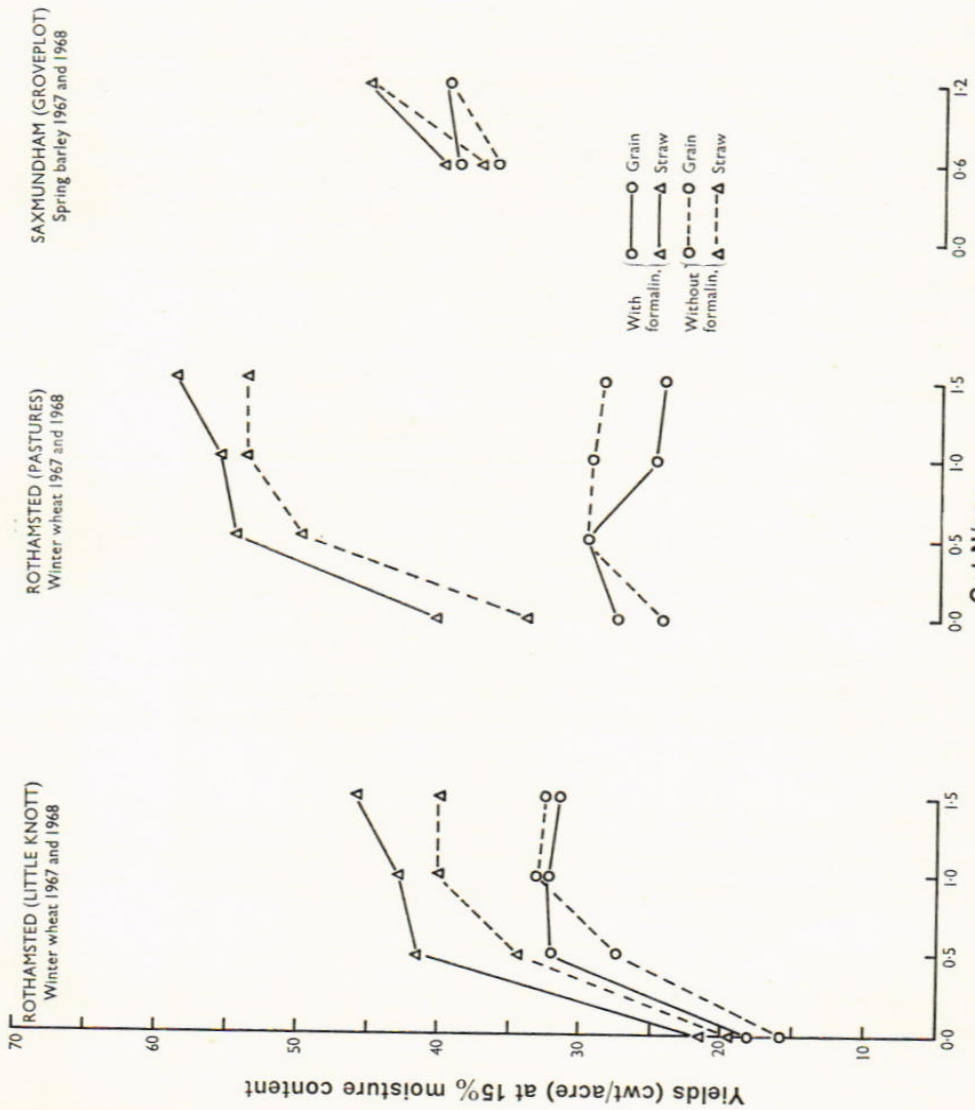

FIG. 1. The mean effects (in pairs of years) of applying formalin and nitrogen separately and together in four cereal experiments, 1964–68.

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usually less than did the new drench. Formalin applied in either year increased % N in the grain, but the combined effect of both drenches was not consistently greater than that of a drench in 1968 only.

Table 5 shows that newly applied formalin increased mean grain and straw yields each year, though by much less than on soils with a long history of arable crops at Woburn (Butt Close) and at Rothamsted (Little Knott). Also, in contrast to the other experiments, the residual effects of formalin were beneficial rather than harmful, which suggests that at Saxmundham the effects of formalin were mainly from an increase in mineral N and not from a decrease in soil pathogens. Table 6 shows the amounts of mineralisable N in soil samples taken just before the barley was sown in March 1968 and then incubated in the laboratory for 24 days at 25°C (by J. K. R. Gasser). These show that the soil contained little mineral N; formalin increased the amount of N mineralised after incubation, either when it had been given in 1967 or in 1968, but giving it in both years increased mineral N most. Judged by yields, this increase in mineral N was

TABLE 6

The total amounts of mineralisable N in Saxmundham soils in March, 1968

	Formalin applied			
	None	1967	1968	1967/68
	ppm N (NO_3+NH_4)			
Mineral N in fresh soil	7·3	6·9	4·5	3·1
Mineral N after incubation	16·6	17·4	19·3	26·4
Increase (Δ mineral N)	9·3	10·5	14·8	23·3

probably equivalent to giving the barley only another 10 lb N/acre; the extra N from giving formalin in 1967 and in 1968, rather than in 1968 alone, was not reflected in larger yields or in larger amounts of N removed by the barley.

Fosters, Rothamsted, 1967–68. Appendix Table 5 shows that, in 1967, formalin greatly increased the yields of grass at the first cutting and slightly increased them at the second and third cuttings. At the first cut, % N was

TABLE 7

Total yields (cwt/acre) of dry grass from five cuts, the mean percentage of N in dry grass and the total amounts (cwt/acre) of N taken up (in five cuts) in an experiment testing nitrogen and formalin for grass, 1967–68

	Total yields		Mean % N in dry grass		Total N taken up	
cwt N/acre/cut	–	F	–	F	–	F
0·0	35·0	46·0	1·81	1·73	0·62	0·77
0·3	90·2	104·8	2·18	2·20	1·76	2·09
0·6	116·6	125·4	2·69	2·67	2·80	3·03
0·9	118·6	127·7	3·05	2·97	3·34	3·49

– = No formalin in 1967.
F = Formalin in 1967.

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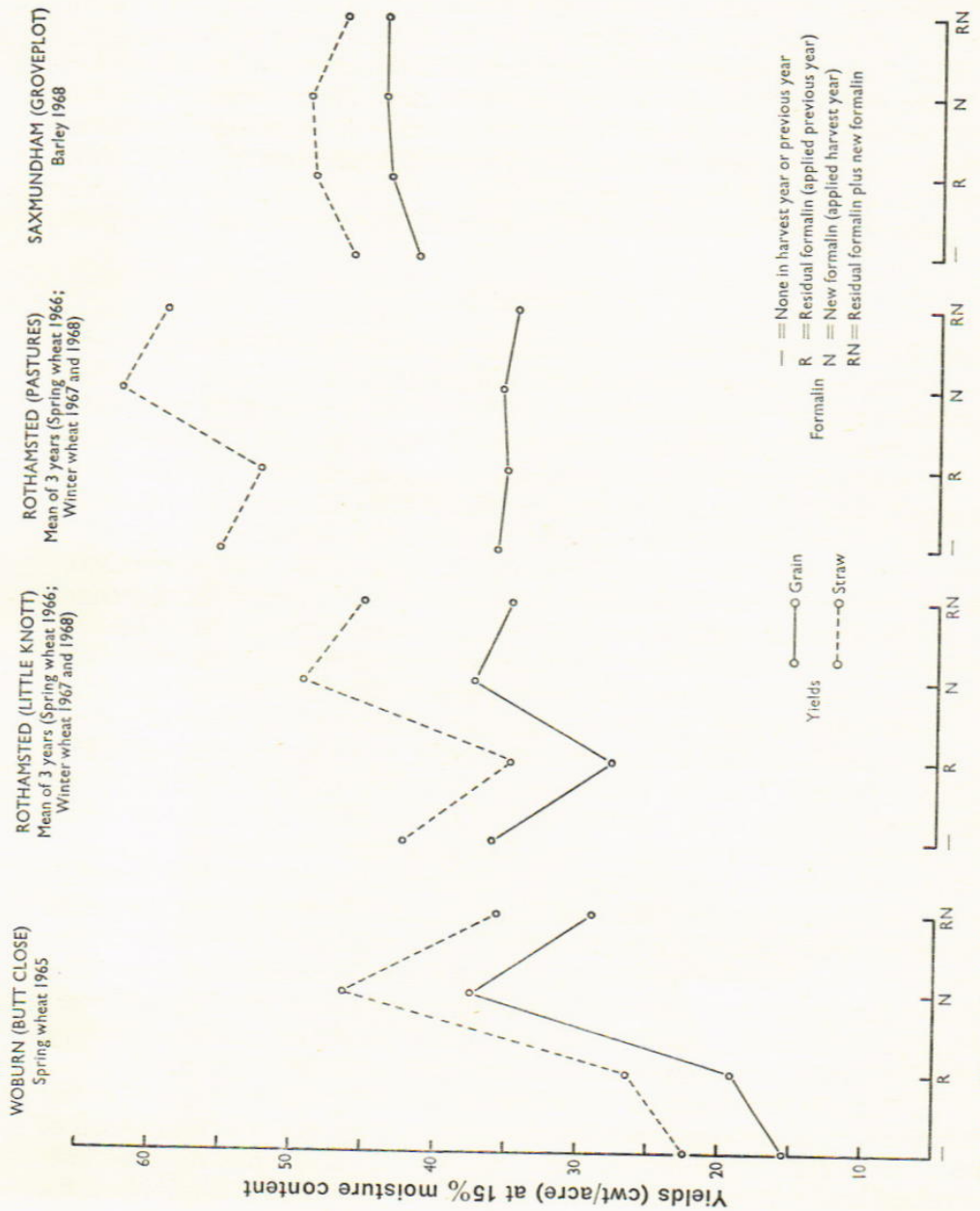

FIG. 2. The residual, direct and cumulative effects of formalin on yields of cereals in four experiments, 1965–68.

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decreased, but total N increased, whereas at the second and third cuttings formalin increased both % N and the total amount removed by the grass.

In 1968 the residual benefits of formalin were small but consistent. They increased yields at the first and the second cuttings (16 months after the formalin had been applied), but they increased % N and the yield of nitrogen only at the first, and of grass not given N at the second cutting.

Table 7 shows that over the two years formalin increased yields by 11·0 cwt/acre without N and by 9·1 cwt/acre with most N, so formalin had proportionally most effect when N was not given. Nitrogen alone increased yields by 83·6 cwt/acre, so that its effect was approximately eight times larger than that of formalin. Formalin did not consistently change % N in the grass, but it did increase the total amount of N recovered by the grass.

Discussion

The results illustrated well the problems involved in making experiments with formalin and other sterilants, for not only did the formalin control soil pathogens and so produce bigger crops, but it also increased the amounts of N recovered by the crops and so presumably the amounts of N mineralised in the soils (Gasser & Peachey, 1964). However, because of these interactions and because we did not measure the effects of formalin on mineralisable soil N (except at Saxmundham) we cannot tell whether the healthier crops grown with formalin (Slope, 1966; Salt, 1966) used the existing reservoir of soil N more efficiently, or whether their larger yields depended partly on the additional N provided by the partial sterilisation of the soil. However, except at Woburn (where cereal cyst nematode was abundant) fertiliser nitrogen and formalin were to some extent interchangeable, when each was tested alone. At Rothamsted the effect of giving formalin alone was comparable to that of giving nitrogen alone, but it never exceeded that of giving 0·5 cwt N/acre. Nevertheless, when formalin and 0·5 cwt N/acre were given together, they interacted, and it was seldom possible to obtain as large a yield from nitrogen alone, however much was given.

Fig. 1 shows mean results for pairs of years in each cereal experiment. It is very evident that the effects of nitrogen and formalin were far better measured by the straw than by the grain, for the yields of straw were always larger with formalin than without, whereas formalin sometimes diminished grain yields, presumably because the larger crop that it gave lodged more severely. Apparently lodging did not diminish straw yields, otherwise formalin would have diminished these as well as those of grain.

Fig. 2 shows mean results (averaged over nitrogen dressings) of giving formalin for the previous crop, for the current crop or for both, in each of the four cereal experiments. Residual effects of formalin sometimes increased and sometimes decreased yields, but they always diminished the benefit from freshly applied formalin, which consistently increased yields. Formalin had similar effects on grain and on straw yields, except on the Pastures experiment, where lodging spoilt the comparison for grain. So again the effects of formalin were best measured by yields of straw.

This paper is intended to give the yields obtained from the experiments in full, and to show and discuss the interactions between nitrogen fertiliser and

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formalin. It also shows the amounts of N recovered by the crops and that formalin increased this whether or not soil pathogens were abundant. It does not discuss the effects of formalin on cereal cyst nematode (*Heterodera avenae*) in the Butt Close experiment, because these have already been published (Williams, 1969); nor effects on take-all (*Ophiobolus graminis*) and other soil fungi, because D. B. Slope and G. A. Salt will give their results in other papers.

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References

Benzian, B. (1965) Experiments on nutrition problems in forest nurseries. *Bull. For. Commn, Lond.* No. 37, Vol. I, p. 134. London: H.M.S.O.

Cooke, G. W. (1963) *Rep. Rothamsted exp. Stn for 1962*, 55.

Gasser, J. K. R. & Peachey, J. E. (1964) A note on the effects of some soil sterilants on the mineralisation and nitrification of soil-nitrogen. *J. Sci. Fd Agric.* **15**, 142.

Russell, E. W. (1961) *Soil conditions and plant growth.* 9th ed., p. 220. London: Longmans, Green and Co.

Salt, G. A. (1966) *Rep. Rothamsted exp. Stn for 1965*, 128.

Slope, D. B. (1966) *Rep. Rothamsted exp. Stn for 1965*, 127.

Williams, T. D. (1969) The effects of formalin, nabam, irrigation and nitrogen on *Heterodera avenae* Woll., *Ophiobolus graminis* Sacc. and the growth of spring wheat. *J. Ann. appl. Biol.* **64**, 325–334.

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APPENDIX TABLE 1

Yields of spring wheat grain and straw, the percentage of N in grain, and the amounts of N taken up by grain plus straw on Butt Close field at Woburn, 1964 and 1965

Year	1964		1965			
			Without formalin in 1964 or 1965	With formalin in		
cwt N/acre/year	Without formalin	With formalin		1964	1965	1964 and 1965
Yields (cwt/acre) of grain at 15% moisture content						
Without water						
0·6	9·1	26·3	6·0	11·6	29·0	19·7
1·2	15·1	29·1	10·1	17·7	34·2	23·5
1·8	14·8	26·5	16·2	18·8	34·0	23·0
With water						
0·6	11·6	29·9	7·2	6·0	29·1	19·6
1·2	18·3	37·2	11·0	15·3	37·4	29·8
1·8	23·4	35·8	11·3	15·0	31·4	28·7
S.E.	±1·33			—		
Yields (cwt/acre) of straw at 15% moisture content						
Without water						
0·6	14·3	37·8	12·0	23·8	35·6	23·6
1·2	25·2	43·0	16·4	24·0	42·2	28·9
1·8	28·4	43·0	25·2	26·8	42·0	29·4
With water						
0·6	17·6	41·8	11·8	11·8	39·3	25·0
1·2	28·1	50·0	19·0	22·0	44·8	37·5
1·8	38·1	53·0	19·8	20·1	44·8	39·6
S.E.	±1·72			—		
Percentage of N in grain						
Without water						
0·6	1·96	1·77	2·14	1·84	1·82	1·94
1·2	2·23	2·24	2·40	2·44	2·32	2·19
1·8	2·61	2·58	3·00	2·68	2·64	2·79
With water						
0·6	1·88	1·96	2·08	2·01	1·84	1·70
1·2	2·02	2·12	2·51	2·16	2·07	2·24
1·8	2·31	2·31	2·77	2·55	2·52	2·41
N (cwt/acre) in grain plus straw						
Without water						
0·6	0·200	0·487	0·168	0·271	0·590	0·433
1·2	0·377	0·704	0·336	0·451	0·883	0·632
1·8	0·457	0·767	0·576	0·574	1·043	0·772
With water						
0·6	0·240	0·624	0·189	0·160	0·593	0·375
1·2	0·405	0·850	0·304	0·413	0·879	0·733
1·8	0·599	0·911	0·392	0·462	1·015	0·849

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APPENDIX TABLE 2

Yields of wheat[1] grain and straw, the percentage of N in grain, and the amounts of N taken up by grain plus straw on Little Knott field, Rothamsted, 1965–68

Year	1965		1966				1967				1968			
cwt N/ acre/ year	Without formalin	With formalin	Without formalin in 1965 or 1966	With formalin in 1965	1966	1965 & 1966	Without formalin in 1966 or 1967	With formalin in 1966	1967	1966 & 1967	Without formalin in 1967 or 1968	With formalin in 1967	1968	1967 & 1968
Yields (cwt/acre) of grain at 15% moisture content														
0·0	17·0	23·9	19·4	13·0	29·2	27·6	21·6	4·4	24·1	9·4	20·3	17·5	21·4	18·2
0·5	28·3	34·9	27·1	21·9	36·2	38·4	28·6	14·7	31·9	22·8	37·0	29·0	32·6	41·0
1·0	26·6	35·4	36·3	28·2	42·5	38·1	39·6	20·8	25·0	26·8	39·6	31·4	37·6	39·2
1·5	26·2	32·5	34·6	32·7	40·1	39·3	33·6	22·0	36·0	21·1	36·3	37·8	32·6	36·5
S.E.	±1·21			±1·81				—				—		
Yields (cwt/acre) of straw at 15% moisture content														
0·0	27·0	34·1	20·6	16·0	34·8	32·7	24·6	11·2	25·0	22·0	24·7	17·0	22·0	16·8
0·5	46·8	52·5	37·0	28·0	53·6	53·3	38·0	32·8	50·0	36·4	39·5	27·6	36·6	42·6
1·0	45·9	56·8	45·2	39·1	59·0	55·2	46·0	40·0	45·0	37·2	44·0	29·8	46·8	42·1
1·5	47·7	55·4	44·0	43·2	64·0	59·2	46·2	33·2	57·2	48·0	39·6	41·1	39·6	38·4
S.E.	±1·53			±2·34				—				—		
Percentage of N in grain														
0·0	1·87	1·93	1·73	1·71	1·83	1·85	1·70	2·02	1·62	1·74	1·69	1·65	1·84	1·74
0·5	2·09	2·14	1·71	1·83	1·81	1·94	1·79	1·96	1·88	1·82	1·83	1·84	1·96	1·85
1·0	2·36	2·27	1·89	1·89	2·14	1·92	2·05	2·27	2·14	2·20	2·29	2·25	2·37	2·31
1·5	2·81	2·70	2·03	2·18	2·03	1·95	2·42	2·54	2·61	2·70	2·61	2·51	2·62	2·51
S.E.	±0·069			—				—				—		
N (cwt/acre) in grain plus straw														
0·0	0·386	0·528	0·367	0·224	0·551	0·545	0·378	0·152	0·400	0·252	0·404	0·312	0·446	0·333
0·5	0·755	0·918	0·495	0·438	0·684	0·697	0·569	0·422	0·634	0·480	0·734	0·569	0·723	0·795
1·0	0·794	1·072	0·706	0·547	0·925	0·733	0·839	0·564	0·620	0·649	1·039	0·739	1·049	0·998
1·5	0·933	1·123	0·694	0·686	0·916	0·943	0·916	0·670	1·082	0·770	1·055	1·068	1·039	1·042
S.E.	±0·0449			—				—				—		

[1] Spring wheat in 1965 and 1966, winter wheat in 1967 and 1968.

APPENDIX TABLE 3

Yields of wheat[1] grain and straw, the percentage of N in grain, and the amounts of N taken up by grain plus straw, on Pastures field, Rothamsted, 1965–68

Year	1965		1966				1967				1968			
			Without formalin	With formalin in			Without formalin	With formalin in			Without formalin	With formalin in		
cwt N/acre/year	Without formalin	With formalin	in 1965 or 1966	1965	1966	1965 & 1966	in 1966 or 1967	1966	1967	1966 & 1967	in 1967 or 1968	1967	1968	1967 & 1968
						Yields (cwt/acre) of grain at 15% moisture content								
0·0	33·6	35·9	24·6	32·2	34·5	39·3	21·4	19·4	33·1	30·6	25·2	31·6	23·4	23·3
0·5	32·7	28·5	39·4	39·0	39·7	39·3	35·4	21·6	37·8	32·6	30·4	31·6	24·6	24·0
1·0	24·1	25·1	39·7	38·8	39·0	39·0	32·8	35·0	26·9	28·9	23·6	26·6	22·8	21·5
1·5	18·5	21·7	39·2	32·9	34·2	32·7	34·2	33·0	31·0	26·0	26·2	21·4	21·2	19·6
S.E.	±1·65			±2·37[2] ±2·43[3]				—			—			
						Yields (cwt/acre) of straw at 15% moisture content								
0·0	50·0	54·1	31·3	36·6	50·7	53·1	38·4	32·7	55·2	47·3	34·6	29·8	33·3	25·4
0·5	61·2	64·3	54·6	55·6	64·3	69·7	66·5	48·2	71·4	64·6	44·6	40·4	43·4	39·0
1·0	56·6	59·0	57·8	57·0	64·8	66·4	65·2	68·6	72·4	66·7	41·2	41·1	45·0	39·2
1·5	52·8	56·0	59·6	54·0	66·5	64·3	72·8	70·2	87·4	72·2	37·5	35·4	34·4	42·2
S.E.	±2·05			±2·18[2] ±1·77[3]				—			—			
							Percentage of N in grain							
0·0	2·15	2·13	1·86	1·83	1·79	1·70	1·70	1·66	1·77	1·59	1·83	1·92	1·91	2·07
0·5	2·35	2·30	1·80	1·82	2·00	2·04	1·88	1·82	1·94	1·96	2·20	1·92	2·23	2·17
1·0	2·34	2·51	2·14	1·90	2·16	2·22	2·25	2·08	2·44	2·31	2·40	2·43	2·54	2·50
1·5	2·46	2·49	2·24	2·19	2·18	2·14	2·50	2·58	2·71	2·68	2·74	2·54	2·56	2·66
S.E.	±0·036			—				—			—			
							N (cwt/acre) in grain plus straw							
0·0	0·844	0·969	0·511	0·641	0·699	0·764	0·395	0·348	0·616	0·512	0·536	0·660	0·544	0·516
0·5	1·054	1·015	0·812	0·811	0·932	0·986	0·764	0·468	0·810	0·795	0·766	0·710	0·690	0·638
1·0	1·065	1·123	1·041	0·915	1·068	1·128	0·826	0·913	0·890	0·766	0·748	0·826	0·791	0·726
1·5	0·958	1·014	1·077	0·992	1·064	1·047	1·113	1·016	1·111	1·098	0·922	0·742	0·772	0·770
S.E.	±0·0520			—				—			—			

[1] Spring wheat in 1965 and 1966, winter wheat in 1967 and 1968.
[2] For use in comparing columns 1 with 2 or 4, 2 with 3, and 3 with 4 in 1966.
[3] For use in comparing columns 1 with 3 or 2 with 4 in 1966.

APPENDIX TABLE 4

Yields of barley grain and straw, the percentage of N in grain, and the N taken up by grain plus straw at Saxmundham (Suffolk), 1967 and 1968

Year	1967		1968			
			Without formalin	With formalin in		
cwt N/acre/year	Without formalin	With formalin	in 1967 or 1968	1967	1968	1967 and 1968
Yields (cwt/acre) of grain at 15% moisture content						
0·0	21·9 (±1·36)	—	11·8	—	—	—
0·6	36·0	39·8	35·6	37·8	39·6	37·5
1·2	40·9	40·5	37·7	39·5	38·4	40·3
S.E.	±0·96			±1·24		
Yields (cwt/acre) of straw at 15% moisture content						
0·0	21·0 (±1·74)	—	10·8	—	—	—
0·6	35·9	40·4	36·2	41·3	41·4	37·4
1·2	44·3	45·0	46·2	46·4	47·2	46·2
S.E.	±1·23			±1·53		
Percentage of N in grain						
0·0	1·44 (±0·084)	—	1·70	—	—	—
0·6	1·38	1·58	1·67	1·78	1·86	1·84
1·2	1·70	1·79	2·25	2·26	2·26	2·30
S.E.	±0·060			±0·052		
N (cwt/acre) in grain plus straw						
0·0	0·342 (±0·0504)	—	0·214	—	—	—
0·6	0·535	0·682	0·668	0·784	0·843	0·747
1·2	0·794	0·829	1·068	1·156	1·099	1·150
S.E.	±0·0357			±0·0346		

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APPENDIX TABLE 5

Yields of, and the percentages and amounts of N in dry grass from a timothy/meadow fescue ley at Rothamsted in 1967 and 1968

Year	1967						1968			
cwt N/ acre/cut	1st cut	2nd cut Without formalin	3rd cut	1st cut	2nd cut With formalin	3rd cut	1st cut Without formalin	2nd cut	1st cut With formalin	2nd cut
					Yields (cwt/acre) of dry grass					
0·0	5·0	17·5	0·7	12·9	18·4	1·2	5·0	6·8	6·0	7·6
0·3	12·2	29·7	6·2	20·1	29·0	6·6	22·7	19·4	27·6	21·5
0·6	16·5	32·4	7·9	23·6	32·9	7·8	36·6	23·3	37·2	23·9
0·9	18·3	32·1	6·4	23·1	32·9	7·2	40·9	20·8	43·2	21·2
S.E.	±1·05	±0·99	±0·40	±1·05	±0·99	±0·40	±0·63	±0·63	±0·63	±0·63
					Percentage of N in dry grass					
0·0	2·40	1·81	1·97	1·77	1·79	2·21	1·62	1·25	1·64	1·26
0·3	2·90	1·90	2·98	2·47	2·07	3·34	1·76	1·36	1·75	1·37
0·6	3·19	2·34	3·88	2·76	2·54	4·12	2·09	1·96	2·14	1·79
0·9	3·27	2·89	4·05	2·92	2·69	4·21	2·51	2·54	2·56	2·46
S.E.	±0·070	±0·058	±0·060	±0·070	±0·058	±0·060	±0·042	±0·077	±0·042	±0·077
					N (cwt/acre) in dry grass					
0·0	0·116	0·319	0·015	0·226	0·328	0·026	0·081	0·086	0·099	0·095
0·3	0·347	0·562	0·185	0·491	0·600	0·219	0·401	0·264	0·484	0·293
0·6	0·521	0·757	0·307	0·647	0·835	0·321	0·764	0·456	0·796	0·428
0·9	0·593	0·927	0·258	0·672	0·882	0·304	1·030	0·527	1·105	0·523
S.E.	±0·0326	±0·0219	±0·0149	±0·0326	±0·0219	±0·0149	±0·0216	±0·0195	±0·0216	±0·0195

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