Widdowson, F. V., Penny, A., Williams , R. J. B. and Cooke, G. W. 1960. The value of calcium nitrate and urea for main-crop potatoes and kale. *The Journal of Agricultural Science.* 55 (1), pp. 1-10.

J. Agric. Sci. (1960), 55, 1
Printed in Great Britain

The value of calcium nitrate and urea for main-crop potatoes and kale

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(*Received* 18 *June* 1959)

Calcium nitrate is an important fertilizer in some countries of North-Western Europe, for instance it supplied 85% of the total amount of nitrogen used in Denmark in 1956 (O.E.E.C. 1958). No calcium nitrate is used in Britain. Two-thirds of the total nitrogen used here is in the form of ammonium sulphate and this material supplies the bulk of the nitrogen in current compound fertilizers. Ammonium nitrate supplies about one-quarter of our nitrogen requirements but nearly all is applied (as mixtures with calcium carbonate) for top-dressing and very little is incorporated in compound fertilizers at present.

The trend in modern fertilizer production is towards more concentrated materials which reduce costs per unit of plant nutrient by lowering the cost of handling in the works, bagging and transport. Ammonium sulphate restricts the maximum nitrogen content of compound fertilizers; in the United States manufacturers use 'nitrogen solutions' (solutions of ammonium nitrate, urea and ammonia) both to obtain higher concentration and also because they are cheap. Similar compound fertilizers are likely to be produced in this country. Urea (containing 46% of nitrogen) is the most concentrated solid nitrogen source available to fertilizer manufacturers. Its ready solubility in water and its high concentration make it especially suitable for using in liquid fertilizers and particularly in foliar sprays. It has obvious advantages for the production of highly concentrated compound fertilizers rich in nitrogen.

The experiments described here were done to assess the value of seedbed dressings of calcium nitrate and urea for potatoes and kale with ammonium sulphate as a standard. The value of calcium nitrate for spring wheat and barley has been examined in parallel experiments described by Widdowson, Penny, Williams & Cooke (1959). Nicholson & Hooper (1957) compared calcium nitrate with other nitrogen fertilizers as a top-dressing for winter wheat and for spring cabbage.

NATURE OF THE EXPERIMENTS

The experiments described here were made on commercial farms in the East Midlands and Eastern Counties from 1955 to 1958. There were twenty-two experiments with main-crop potatoes and seven with kale.

Experiments on potatoes

There were seven experiments in 1955, eight in 1956 and seven in 1957. Each compared seedbed dressings of calcium nitrate and ammonium sulphate at rates supplying 0·5, 1·0 and 1·5 cwt. N/acre. The 1955 experiments included tests of mid-season top-dressings of nitrogen that have already been described (Cooke, Widdowson & Wilcox, 1957); at each centre there were three randomized blocks, each of twelve plots. In 1956 and 1957 tests of top-dressings were discontinued and urea was included in the experiments. Each fertilizer was tested at the three rates listed above. The nine fertilizer treatments plus one plot receiving no nitrogen were arranged in a randomized block. There were four blocks at each centre. A phosphate-potash compound fertilizer was applied to each plot at rates suited to local conditions (usually it supplied 0·75 cwt. P_2O_5 and 1·5 cwt. K_2O/acre).

Experiments on kale

There were two experiments in 1955, 1956, and 1957, and one in 1958. In 1955, seedbed dressings of calcium nitrate and ammonium sulphate were compared at rates supplying 0·6, 1·2 and 1·8 cwt. N/acre. Duplicate plots at the two lower levels of manuring received a mid-season top-dressing of 0·6 cwt. N/acre (as 'Nitro-Chalk') to compare divided and single dressings. There were three blocks, each of twelve plots, at each centre. In 1956 and 1957 urea was included in the experiments and each fertilizer was tested at 1·0 and 2·0 cwt. N/acre. Tests were also made of divided dressings, duplicate plots having each fertilizer at the lower level of manuring received a mid-season top-dressing of 1·0 cwt. N/acre (as 'Nitro-Chalk'). The nine fertilizer treatments plus one plot without nitrogen were arranged in a randomized block; each experiment had four blocks. The 1958 experiment also tested potash and there were three blocks each of sixteen plots. (The results of the potash test are not discussed here.) The levels and forms of nitrogen used in 1958 were identical with those tested in 1956 and

1957. Basal dressings of phosphate-potash compound fertilizer were applied to all plots of each experiment in each year; normally 0·75 cwt. P_2O_5 and 1·5 cwt. K_2O/acre was supplied.

Fertilizers tested

Ordinary calcium nitrate is a very hygroscopic salt which cannot be granulated easily. By adding a small proportion of ammonium nitrate a double salt ($5Ca(NO_3)_2$, NH_4NO_3, $10H_2O$) can be produced in a granular form that is less hygroscopic; it contains 15·5 % of nitrogen. Batches of this fertilizer were imported from Holland for all these experiments.

The urea tested in 1956 was a granulated product; it was purchased from importing agents and is believed to have been manufactured in Italy. This fertilizer contained 43·5 % of nitrogen and also 4·5 % of biuret, an impurity that is often toxic to plants. This batch of urea affected emergence and reduced plant establishment seriously. A purer batch of urea, made in England and containing 46·6 % of nitrogen, was obtained for the 1957 experiments: this was a crystalline material containing less than 1 % of biuret; it caused much less damage to germination. The urea used in 1958 was a prilled product imported from Holland which stored and handled well; it contained 46·5 % of nitrogen and 1·3 % of biuret.

Commercial batches of ammonium sulphate were used as the standard nitrogen fertilizer in all these experiments.

Methods of laying down the experiments

Experiments on potatoes

Each centre was visited in early spring and a site selected for the experiment parallel to the planting line to be used by the farmer. A second visit to the site was made immediately before planting and the fertilizers were applied either over the ridges (at eight centres) or on the flat (at fourteen centres), depending upon the method of planting to be used. Individual plots were normally 11 yards long and contained eight rows spaced 28 in. apart. At harvest the centre four rows of each plot were dug by hand, discarding a short length at each end of each row. The tubers were picked, cleaned and weighed.

Experiments on kale

Sites for these experiments were again selected according to the sowing line to be used by the farmer. Fertilizers were broadcast on the flat at every centre. At Harpenden and Hitchin in 1955, and at Sandridge in 1956 and 1957, the field was ridged after the manures had been spread and the kale was sown on the ridges after rolling. At Stagenhoe in 1956 and 1957, and at Leverstock Green in 1958, the kale was sown on the flat in rows 14 in. and 22 in. apart respectively. Afterwards each experiment received the same cultivations as the remainder of the field. Individual plots normally contained eight rows of kale and were 11 yd long. At Stagenhoe the crop was grown in narrow rows and the experiments were laid out at right angles to the direction of drilling as this facilitated harvesting the crop by motor scythe. At the other centres the six central rows of each plot were cut by hand, discarding a short length at each end of each row, and the weight of the produce was recorded. The numbers of plants harvested were counted at Sandridge in 1957 and at Leverstock Green in 1958.

RESULTS OF THE EXPERIMENTS

Potatoes

Yields without nitrogen and the increases given by each level of the fertilizers tested at each centre are shown in Appendix Table 1. The experiments have been divided into two groups. In the first, the fertilizers were broadcast over the furrows before hand-planting, and in the second they were broadcast on the flat before planting by machine. The general response to nitrogen was small and only four of the experiments gave maximum responses of more than 3 tons/acre, three of these (Rearsby, Spalding and Takely) were done in 1955. There was little average gain from applying more than 0·5 cwt. N/acre in either 1956 or 1957. Rather more than half of the total number of responses to nitrogen were significant ($P = 0{\cdot}05$ or less).

In the first group of experiments (Appendix Table 1) ammonium sulphate broadcast over the furrows was slightly inferior to calcium nitrate when dressings of 0·5 cwt. N/acre were used. When 1·0 and 1·5 cwt. N/acre were given, calcium nitrate applied over the furrows checked early growth and gave lower yields than ammonium sulphate. The high rate of calcium nitrate gave a lower average yield than the medium and the low rates. Ammonium sulphate and urea were compared only in 1956 and 1957. The granulated urea used in the 1956 experiments checked early growth severely and reduced plant establishment; dressings of urea supplying 1·0 and 1·5 cwt. N/acre produced lower average yields than were obtained on unmanured land. (It is believed that this effect was caused by the 4·5 % of biuret present in the granulated urea.) The purer crystalline urea, containing less than 1 % of biuret, tested in the 1957 experiments did not damage emergence.

The increases given by the three fertilizers in experiments where they were broadcast on the flat are shown in the lower part of Appendix Table 1. Ammonium sulphate produced slightly higher mean yields than calcium nitrate when the fertilizers supplied 0·5 and 1·0 cwt. N/acre. When the dressings were increased to 1·5 cwt. N/acre calcium nitrate depressed yields and ammonium sulphate was much superior. It is clear that heavy dressings of nitrate fertilizers may produce consistently lower yields of potatoes than ammonium sulphate and that the chances of fertilizer injury with nitrate nitrogen will be increased when dressings are concentrated too close to the 'seed'. Comparisons betweeen urea and ammonium sulphate are complicated by the use in 1956 of granulated urea containing much biuret. Dressings of this fertilizer broadcast over flat seedbeds before planting by machine caused less damage to emergence than similar dressings applied over the furrows before planting; the damage caused, however, was sufficient to reduce yields at the high rate of dressing. In 1957 the purer crystalline urea used had no harmful effects on emergence and it gave yields similar to those given by ammonium sulphate.

Table 1 summarizes the yields given by the three forms of nitrogen at each level of manuring (averaging all centres). The general level of response to nitrogen was poor. Ammonium sulphate produced higher average yields than either calcium nitrate or urea at the higher rates of manuring.

A more detailed examination of the results is made in Table 2 by listing average yields without nitrogen and the additional increases in yield from each increment of each fertilizer; the numbers of positive and significant positive effects in each year are also stated. Gains from the nitrogen dressings were highest in 1955. The 1956 crops were much less responsive, but total yields were greater than those in 1955 as a result of high yields without nitrogen. Average responses in 1957 were very low and there was no justification for applying more than 0·5 cwt. N/acre. The average response to each increment of nitrogen decreased in succeeding years and there was little general benefit from applying more than 1·0 cwt. N/acre. Consistent and significant increases in yield were only obtained from the first increment of nitrogen in each year.

Table 3 summarizes differences between yields given by ammonium sulphate, by calcium nitrate and by urea in each year. Ammonium sulphate and calcium nitrate can be compared over the three years because the same kinds of the two fertilizers were tested each year. Ammonium sulphate produced slightly higher mean yields than calcium nitrate at the two lower rates of application; just under half of the possible comparisons at these rates were in favour of ammonium sulphate, but only three of the differences were significant. At the high rate of dressing, ammonium sulphate produced higher yields than calcium nitrate at eighteen of the twenty-two centres and four of the differences were significant.

Two different types of urea fertilizer were tested in the two years of potato experiments. General comparisons are complicated by the toxic effects of the granulated urea tested in 1956 which gave consistently lower yields than ammonium sulphate, the advantages of the latter fertilizer increasing as the level of manuring was raised. Nineteen of the twenty-four available comparisons in 1956 were in favour of ammonium sulphate and six of these differences were significant. Crystalline urea tested in 1957 was equivalent to ammonium sulphate for practical purposes and none of the differences between yields given by the two materials was significant.

Kale

Yields of kale grown without nitrogen fertilizer and the increases given by the levels and forms of nitrogen tested at each centre are stated in Appendix Table 2. There were large and significant increases from the fertilizer dressings at every centre except Sandridge in 1957; this site had been ploughed out of old grass in 1953 and had then been cropped with winter wheat for three years, and the lack of response to fertilizer was probably traceable to the nitrogen provided by the decomposing turf. All the remaining sites were on old arable fields.

The mean yields of kale given by the three nitrogen fertilizers in each year are shown in Table 4. There were no consistent differences between yields given by ammonium sulphate and by calcium nitrate in 1955 except that ammonium sulphate was slightly superior at both centres at the highest rate of manuring. In 1956, calcium nitrate damaged plant establishment severely at Sandridge and the experiment had to be resown, but at harvest at both centres calcium nitrate was slightly superior to

Table 1. *Average yields of potatoes in tons per acre in experiments carried out from* 1955 *to* 1957

Dressing applied, cwt./acre of N	Averages of 3 years		Averages of 2 years		
	Ammonium sulphate	Calcium nitrate	Ammonium sulphate	Calcium nitrate	Urea
0·0	8·91			9·73	
0·5	9·87	9·80	10·53	10·48	10·53
1·0	10·19	10·05	10·62	10·45	10·19
1·5	10·34	9·62	10·66	10·09	9·82

Table 2. *Mean yields of potatoes without nitrogen fertilizer, the mean increases from each increment of ammonium sulphate, calcium nitrate, and urea and the numbers of positive, and significant positive effects*

(P = 0·05 or less.)

	Yields of total tubers (in tons/acre)					No. of positive effects				No. of significant positive effects			
Year	1955	1956	1957	Mean of 1956, 1957	Mean of all years	1955	1956	1957	Total (all years)	1955	1956	1957	Total (all years)
No. of exp.	7	8	7	15	22								
Yields without nitrogen	7·17	10·44	8·92	9·73	8·91	—	—	—	—	—	—	—	—
Increases from each increment of ammonium sulphate													
First 0·5 cwt. N	1·28	1·06	0·51	0·80	0·95	6	8	3	17	2	2	3	7
Second 0·5 cwt. N	0·82	0·18	−0·01	0·09	0·32	6	5	3	14	1	0	0	1
Third 0·5 cwt. N	0·39	0·04	0·03	0·04	0·15	4	3	3	10	0	0	0	0
Increases from each increment of calcium nitrate													
First 0·5 cwt. N	1·19	1·05	0·41	0·75	0·89	6	7	5	18	3	3	1	7
Second 0·5 cwt. N	0·83	−0·08	0·04	−0·03	0·25	7	4	3	14	0	0	0	0*
Third 0·5 cwt. N	−0·59	−0·51	−0·19	−0·36	−0·43	1	3	3	7	0	1	0	1*
Increases from each increment of urea									(2 years)				(2 years)
First 0·5 cwt. N	—	0·85	0·74	0·80	—	—	8	6	14	—	2	2	4
Second 0·5 cwt. N	—	−0·39	−0·28	−0·34	—	—	3	4	7	—	0	0	0*
Third 0·5 cwt. N	—	−0·84	0·17	−0·37	—	—	2	3	5	—	0	0	0*

* There were two significant decreases in yield in each of these comparisons.

Table 3. *Mean differences between the yields of potatoes given by ammonium sulphate, by calcium nitrate and by urea and the numbers of positive and significant positive effects*

(P = 0·05 or less.)

	Yield of total tubers in tons/acre				No. of positive effects				No. of significant positive effects			
Year	1955	1956	1957	All years	1955	1956	1957	Total (3 years)	1955	1956	1957	Total (3 years)
No. of expts. ...	7	8	7	22								
N applied (cwt./acre)												
Ammonium sulphate minus calcium nitrate												
0·5	0·09	0·01	0·10	0·06	3	3	3	9	0	1	0	1
1·0	0·08	0·27	0·05	0·14	3	4	4	11	0	1	1	2
1·5	1·06	0·83	0·27	0·72	7	6	5	18	1	3	0	4
Ammonium sulphate minus urea												
				(15 experiments)				(2 years)				(2 years)
0·5	—	0·21	−0·23	0·00	—	7	4	11	—	0	0	0
1·0	—	0·78	0·04	0·44	—	5	3	8	—	2	0	2
1·5	—	1·67	−0·10	0·84	—	7	2	9	—	4	0	4

Table 4. *Mean yields of kale in tons per acre given by seedbed dressings of ammonium sulphate, calcium nitrate and urea and with top-dressings of 'Nitro-Chalk'*

Dressing applied, cwt./acre of N: On seedbed	As top-dressing	Yields Without nitrogen	Fertilizer applied on seedbed: Ammonium sulphate	Calcium nitrate	Urea
			Mean of 2 experiments in 1955		
0·6	0·0	16·30	20·10	20·52	—
0·6	0·6		23·20	22·42	—
1·2	0·0		21·56	21·84	—
1·2	0·6		24·34	25·56	—
1·8	0·0		24·76	23·95	—
			Mean of 2 experiments in 1956		
1·0	0·0	9·35	20·98	18·68	17·48
1·0	1·0		22·98	21·14	20·57
2·0	0·0		20·80	21·76	18·40
			Mean of 2 experiments in 1957		
1·0	0·0	18·97	24·86	22·73	24·49
1·0	1·0		25·97	25·24	25·94
2·0	0·0		25·66	21·20	25·14
			1 experiment in 1958		
1·0	0·0	5·98	16·07	27·08	18·24
1·0	1·0		27·32	35·27	31·07
2·0	0·0		25·51	32·12	30·60

Table 5. *The effects of nitrogen fertilizers on numbers of kale plants (in thousands per acre) at Sandridge in* 1957 *and at Leverstock Green in* 1958

(Significant effects are marked * for $P = 0{\cdot}05$–$0{\cdot}01$; **for $P < 0{\cdot}01$.)

Dressing applied, cwt./acre of N: On seedbed	As top-dressing	Numbers without nitrogen	Effect on plant population of: Ammonium sulphate	Calcium nitrate	Urea	S.E. of effect
				Sandridge (1957)		
1·0	0·0	16·7	−0·5	−5·3**	−1·7*	±0·79
1·0	1·0		−1·6	−4·1**	−2·2**	
2·0	0·0		−2·8**	−11·0**	−5·8**	
				Leverstock Green (1958)		
1·0	0·0	176·5	−26·4*	−33·6**	−44·9**	±11·07
1·0	1·0		−47·7**	−72·1**	−69·4**	
2·0	0·0		−56·6**	−92·5**	−82·8**	

ammonium sulphate at the heavy rate of application. The granulated urea tested in 1956 contained 4·5% of biuret; it reduced plant establishment seriously at Sandridge and, to a lesser extent, at Stagenhoe; it gave lower average yields than the other two fertilizers. In 1957 purer crystalline urea was much 'safer' than the granulated product used in 1956, but at the high rate of dressing it reduced yields at Sandridge. The average yields given by urea and ammonium sulphate were similar in 1957, but calcium nitrate was inferior to the other two nitrogen fertilizers. This was because emergence was severely affected at Sandridge, where both levels of calcium nitrate reduced yields below those obtained with no nitrogen at all (Appendix Table 2). In 1958 dressings of both calcium nitrate and urea applied to the seedbed at Leverstock Green reduced plant establishment considerably; both these fertilizers gave higher yields than ammonium sulphate, however, probably because there were advantages from thinning a heavily manured crop of kale. Effects of fertilizer on plant number are shown in Table 5. It is clear that a high seed rate (used at Leverstock Green) decreased the harmful effects of calcium nitrate and urea on germination; at Sandridge, where the general plant density was very much less, the thinner crop could not compensate for this initial damage and yields were reduced.

The gains in yield from giving part of the nitrogen as a mid-season top-dressing, as compared with applying it all to the seedbed are also indicated in Table 4. On average there were gains from splitting the dressings of nitrogen in this way; divided dressings (partly to the seedbed and partly as a top-dressing) gave higher yields than equivalent seedbed dressings in eleven of the thirteen possible comparisons.

DISCUSSION

Experiments on potatoes

The long-term average rainfall at Rothamsted and the departures from average in each month of the growing seasons of the three years are shown in Table 6, together with the numbers of rainy days and variations from average temperatures. The seasons were far from 'average' in each of the three years and the peculiar weather may explain the small responses to nitrogen in 1956 and 1957.

All the experiments in 1955 were planted in good conditions in March and April. Wet weather in May and early June, coupled with low temperatures, delayed growth. Afterwards there was a long warm and dry spell, which lasted until the experiments were harvested and restricted the crop responses to nitrogen. In 1956 planting conditions were satisfactory at most centres although the seedbed on the heavy clay loam at Folkingham was wet and sticky. Rainfall in March, April, May and the first half of June was well below average; during the remainder of the growing season there was an excess of rain, a deficit of sunshine and low temperatures. In humid and sunless conditions potato blight spread rapidly during August and most centres suffered to some extent. The attack was particularly severe at Rearsby and Folkingham where the tops were burned off prematurely to prevent the disease spreading to the tubers. In 1957 it was impossible to prepare adequate seedbeds on the heavier soils due to little frost during the previous winter. The experiments at Birdbrook, St Neots and Twinstead, which were all situated on heavy Boulder Clays, were planted under rough and cloddy conditions; seedbeds at the other centres were better. All the experiments were planted in April. Rainfall was well below average in March, April, May and the first half of June. Plant emergence was delayed and growth was very irregular on the heavy-textured soils. Heavy rain in late June and in July was too late to make up for the poor start and the crops did not grow well until September when adequate rainfall and the absence of blight encouraged the potatoes to 'bulk up' late in the season.

There were good responses to nitrogen dressings up to the level of 1·0 cwt. N/acre in 1955; there was a small gain from an additional 0·5 cwt. N applied as ammonium sulphate but none from calcium nitrate. Rainfall in May 1955 was more than twice the average and there was no check to emergence from high dressings of either of the fertilizers in any of the experiments. The crops grown in 1956 were much less responsive and there was little gain in yield from the second and third increments of ammonium sulphate. Calcium nitrate and ammonium sulphate behaved in the same way at the lower rate of dressing, but heavier dressings of the nitrate depressed yields, particularly when 1·5 cwt. of N/acre was given. Granulated urea (containing 4·5% of biuret) was inferior to ammonium sulphate at each level of manuring, and applied at 1·5 cwt. N/acre it gave lower yields than were obtained with no nitrogen fertilizer. Losses of yield from the medium and heavy dressings of urea and the high rate of calcium nitrate were associated with a severe check to early growth. The effect was pronounced at Eversholt, Folkingham and Hambleton where the fertilizers were broadcast over furrows and concentrated round the seed potatoes when the ridges were split back. Less severe checks were observed at centres where fertilizers were broadcast on the flat before machine-planting. In 1957 responses were even lower than those obtained in the previous year and there was no justification for applying more than 0·5 cwt. of N/acre by any of the fertilizers tested. Purer crystalline urea (with less than 1% of biuret) used in 1957 had no harmful effects on emergence. At Ashwell (where the fertilizers were applied over furrows) the medium and heavy dressings of calcium nitrate checked emergence severely but urea caused no damage.

The experiments show that heavy dressings of nitrates applied to the seedbed are likely to affect early growth adversely and so produce lower yields than ammonium sulphate; damage of this kind will be accentuated when dressings are concentrated too

Table 6. *Weather at Rothamsted in* 1955, 1956 *and* 1957

	Rain (in.)				Number of rainy days			Air temperature (° F)			
	Average	Departure from average						Average	Departure from average		
	1880–1939	1955	1956	1957	1955	1956	1957	1878–1939	1955	1956	1957
April	2·00	−1·51	−0·85	−1·68	9	9	8	45·4	+3·0	−2·1	+1·5
May	2·02	+2·60	−1·39	−0·63	16	8	11	51·8	−2·1	+1·8	−1·8
June	2·13	−0·02	+1·80	+0·30	9	16	11	57·2	−0·2	−2·7	+2·5
July	2·60	−2·35	−0·06	+0·04	4	13	17	60·7	+2·1	−0·6	+1·2
August	2·51	−1·70	+2·83	−0·24	8	24	17	60·0	+3·9	−3·7	−0·1
September	2·34	−0·46	−0·06	+0·99	14	15	17	55·8	+1·9	+1·9	−1·1
Total	13·60	−3·44	+2·27	−1·22	60	85	81	—	—	—	—

close to the seed and will be less when there is adequate rain early in the growing season. General comparisons between urea and ammonium sulphate are complicated by the use in 1956 of granulated urea containing biuret. Results with the crystalline material used in 1957 suggest that *pure* urea may be as satisfactory as ammonium sulphate for potatoes.

Experiments on kale

As the kale experiments were each harvested at several cuttings the choice of sites and soils was restricted and all the centres were within 15 miles of Rothamsted. In 1955 there was adequate rain in the early part of the growing season; calcium nitrate and ammonium sulphate gave similar yields at the rates of nitrogen tested. The experiments at Sandridge and at Stagenhoe were on the same farms in 1956 and 1957. At Sandridge the fertilizers were applied on the flat after the seedbed had been prepared; the land was set up in ridges 28 in. apart and seed was sown immediately. The kale was thinned by hand hoe when 2–3 in. high. At Stagenhoe the fertilizers were applied on the flat and worked in with the final seedbed cultivations. The seed was then drilled on the flat in rows 14 in. apart and the plants were not thinned. The experiments at Sandridge were sown in early April, whereas those at Stagenhoe were not sown until the middle of May. In 1956 the experiment at Sandridge had to be resown because of an attack of flea beetle and the complete failure of the kale on plots that had received the heavy dressing of urea (weeds on these urea-treated plots also died). A satisfactory plant was established at the second sowing but yields with urea were considerably less than those obtained with equivalent dressings of calcium nitrate and ammonium sulphate. In 1957 plant population was reduced seriously on this farm by both levels of calcium nitrate and by the heavy dressing of urea. At Stagenhoe, where the kale was grown in narrow rows and adequate rain followed sowing, the plant was thinned slightly by the heavy dressings of calcium nitrate and by granulated urea in 1956 and by the heavy dressing of the nitrate in 1957. This check was not severe enough to reduce final yields. In the 1958 experiment at Leverstock Green the kale was grown in rows 22 in. apart and heavy dressings of calcium nitrate and urea reduced plant establishment considerably. The initial plant population was high which allowed the crop to compensate for the loss of numbers and final yields were not affected.

The value of the three fertilizers for kale was largely determined by the type of weather following sowing and by the way the kale was grown. In dry weather calcium nitrate that had been worked into the seedbed reduced plant establishment severely, urea was less harmful than the nitrate provided that it contained little biuret. Heavy dressings of ammonium sulphate were much safer although they decreased the plant at Leverstock Green. When adequate rain followed sowing there was little damage from calcium nitrate and from urea that was substantially free from biuret; these two fertilizers then gave yields similar to those obtained with ammonium sulphate.

Comparisons between single and divided dressings of nitrogen for kale showed some advantage at several centres from applying part of the normal amount as a top-dressing later in the season.

General conclusions

For both potatoes and kale the chief disadvantage of calcium nitrate and urea, as compared with ammonium sulphate, was the risk of injury to plant establishment when the fertilizers were concentrated too close to the seed. Calcium nitrate applied at high rates damaged the establishment of kale and potatoes in this work; when combine-drilled with the seed of cereals it also checked germination in experiments reported by Widdowson *et al.* (1959). This damage can only be caused by high concentrations of nitrate ions. Severe damage with the granulated urea used in 1956 was no doubt mainly caused by the high biuret content of this product. The purer urea fertilizers used in 1957 and 1958 also damaged establishment, though less severely; it is likely that some cause other than biuret toxicity was responsible. It is possible that, when urea decomposes in the soil to form ammonium carbonate, alkalinity becomes high locally and damages germinating seeds and kills potato sprouts. Urea containing much biuret should not be used as a fertilizer. American experience (summarized by Smika & Smith, 1957) suggests that urea applied to soil should not contain more than 2·5 % of biuret and when used as a foliar spray the content should not exceed 0·25 %.

More work is needed on the nature of the damage to young plants caused by nitrates and by pure urea. Safe methods of using these nitrogen fertilizers should be developed for, when damage can be avoided, they are at least as effective as ammonium sulphate for many purposes and, if there are industrial advantages in making nitrates or urea, they may provide cheaper nitrogen. One possibility is to develop methods of applying part or all of the nitrogen after crops are established; both nitrate and urea are very soluble and are particularly suitable for top-dressings. Dressings of urea applied well before planting, to allow time for the complete breakdown of urea to ammonium and for the decomposition of any biuret present, might be better than applying the fertilizer just before sowing as was done in these experiments. There was no suggestion from this work, or from the parallel work on cereals, that calcium nitrate was less efficient than ammonium sulphate because nitrate leached from the top-soil, even when crops were growing for 6 months after the fertilizers were applied. Most of the sites were on medium and heavy soils and there may be greater risk of losing nitrate from coarse sands.

SUMMARY

1. Twenty-two experiments on main-crop potatoes in 1955–7 compared calcium nitrate and ammonium sulphate applied to the seedbeds before planting. Urea was also tested in fifteen of the experiments in 1956–7. The three fertilizers were compared at rates that supplied 0·5, 1·0 and 1·5 cwt. N/acre.

2. Seven experiments on kale in 1955–8 compared seedbed dressings of calcium nitrate and ammonium sulphate. Urea was also tested in five of the experiments in 1956–8. The rates used were 0·6, 1·2 and 1·8 cwt. N/acre in 1955 and 1·0 and 2·0 cwt. N/acre subsequently. Single dressings applied to the seedbed were also compared with divided dressings applied partly to the seedbed and partly in mid-season.

3. Generally the potatoes gave only small responses to N; there was no worthwhile gain from applying more than 1·0 cwt. N/acre in 1955 and 0·5 cwt. N in 1956 and 1957. Nitrogen gave much larger proportionate increases in yields of kale, at several of the centres crops continued to respond up to dressings of 2·0 cwt. N/acre.

4. Calcium nitrate generally gave lower yields of potatoes than ammonium sulphate and the superiority of ammonium sulphate was greater with the higher dressings. Losses in yield with the nitrate were usually associated with a severe check to early growth occurring in dry springs and with dressings concentrated close to the seed, but lower yields were also obtained at some centres where early growth was not damaged. Calcium nitrate and ammonium sulphate were roughly equivalent for kale when the nitrate did not damage germination; heavy seedbed dressings of the nitrate reduced kale plant numbers severely unless there was adequate rain after sowing.

5. Granulated urea tested in 1956 contained 4·5 % of biuret, it delayed emergence and reduced plant establishment seriously in several of the potato experiments; damage increased with the level of manuring and was accentuated when dressings were broadcast over furrows before hand-planting. Yields given by this batch of urea were less than with other N fertilizers and when 1·5 cwt. N/acre was applied they were less than with no nitrogen at all. Purer crystalline urea (having less than 1 % of biuret) used in the 1957 experiments caused no damage to emergence of potatoes and gave yields similar to those obtained with ammonium sulphate. There were similar effects in the kale experiments; granulated urea containing much biuret damaged germination severely in 1956; the purer products containing little biuret used in later years reduced plant numbers at one centre in 1957 and at the single 1958 centre. Where there was no damage to the establishment of kale, urea and ammonium sulphate gave similar yields.

6. Dressings applied partly to the seedbed and partly in mid-season gave slightly higher average yields of kale than an equivalent total amount of nitrogen all applied before sowing.

The authors thank members of the National Agricultural Advisory Service for help in finding sites for the experiments, J. H. A. Dunwoody for the statistical analyses of the results, and other members of the Rothamsted Staff for much assistance in the work. We also wish to thank Staatsmijnen in Limburg (Netherlands) for providing the calcium nitrate used in all three years and the urea used in 1958, and Imperial Chemical Industries Ltd. for supplying the urea tested in the 1957 experiments.

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Appendix Table 1. *Yields (in tons per acre) of main-crop potatoes without nitrogen fertilizer, and the increases given by seedbed dressings of ammonium sulphate, calcium nitrate and urea*

(Significant effects marked: * for $P = 0{\cdot}05$–$0{\cdot}01$, ** for $P = 0{\cdot}01$ or less.)

	Yield without nitrogen	Increases from ammonium sulphate			Increases from calcium nitrate			Increases from urea			Standard error of increase
		Low rate	Medium rate	High rate	Low rate	Medium rate	High rate	Low rate	Medium rate	High rate	
					Fertilizers applied over furrows						
1955											
Eversholt, Beds	7·18	0·90	0·45	1·53*	−0·18	1·37	−0·21	—	—	—	±0·671
Hambleton, Rutland	10·50	0·71	0·89	1·15*	0·86	1·08*	0·44	—	—	—	±0·485
Spalding, Lincs	9·38	2·01	3·17**	4·06**	2·38*	4·22**	2·72*	—	—	—	±0·984
Takely, Essex	4·85	0·71	3·20**	3·00**	1·50*	1·82**	2·45**	—	—	—	±0·646
1956											
Eversholt, Beds	11·50	0·45	1·25	1·23	1·00	1·25	−0·45	0·10	−3·10**	−2·72**	±0·690
Folkingham, Lincs	9·92	0·92	1·62*	1·06	1·59*	0·15	−1·33	0·08	−0·24	−1·15	±0·636
Hambleton, Rutland	14·04	0·72	1·69	2·85**	0·89	1·59	0·37	1·21	1·46	−1·69	±0·898
1957											
Ashwell, Rutland	5·72	−0·22	0·24	−0·27	−0·09	−0·96**	−0·91**	0·12	0·26	−0·07	±0·318
Mean of 1956–7 experiments	10·30	0·47	1·20	1·22	0·85	0·51	−0·58	0·38	−0·40	−1·41	—
Mean of 1955–7 experiments	9·14	0·78	1·56	1·83	0·99	1·32	0·38	—	—	—	—
					Fertilizers applied on flat						
1955											
Great Stukely, Hunts	6·20	−0·02	0·46	1·43**	0·43	0·82	0·64	—	—	—	±0·470
Landbeach, Cambs	7·14	1·41*	1·86**	1·83**	0·20	1·02	0·49	—	—	—	±0·573
Rearsby, Leics	4·93	3·25**	4·67**	4·46**	3·12**	3·80**	3·49**	—	—	—	±0·770
1956											
Abbotsley, Hunts	6·23	1·23*	0·59	0·95	0·10	0·24	1·34*	0·96	1·36*	0·34	±0·516
Birdbrook, Essex	11·10	0·79	1·14	0·69	1·82**	1·32*	0·24	0·51	0·50	0·53	±0·612
Landbeach, Cambs	11·58	0·42	−0·04	−0·43	0·67	0·38	0·61	0·28	0·54	−0·07	±0·616
Rearsby, Leics	8·47	1·55*	1·61*	0·84	0·40	0·74	0·35	1·37*	0·90	0·74	±0·611
Twinstead, Essex	10·66	2·36*	2·05*	3·05**	2·10*	2·05*	2·50**	2·26*	2·23*	0·92	±0·896
1957											
Bassingbourn, Cambs.	9·73	1·76*	2·64**	2·87**	1·98**	2·92**	2·47**	1·69*	2·11**	2·80**	±0·682
Birdbrook, Essex	8·52	1·27**	1·11*	0·66	0·40	1·08*	1·29**	0·93*	1·43**	0·90	±0·448
Langham, Rutland	10·60	−0·73	−1·01	−1·48*	−1·11	−1·17	−1·50*	−1·01	−1·94**	−2·04**	±0·609
Rearsby, Leics	9·73	−0·46	−0·75*	−0·85*	0·33	−0·18	−0·24	0·12	0·00	−0·81*	±0·351
St Neots, Hunts	7·71	−0·61	−0·21	0·50	0·42	−0·29	−0·26	1·61	−0·92	0·89	±1·008
Twinstead, Essex	10·42	2·58*	1·50	2·29*	0·95	1·74	0·97	1·74	2·29*	2·76*	±1·103
Mean of 1956–7 experiments	9·52	0·92	0·78	0·83	0·71	0·80	0·71	0·95	0·77	0·63	—
Mean of 1955–7 experiments	8·79	1·06	1·12	1·20	0·83	1·03	0·88	—	—	—	—

Appendix Table 2. *Yields of kale (in tons per acre) without nitrogen fertilizer and the increases in yield from seedbed dressings of ammonium sulphate, calcium nitrate and urea and from top-dressings of 'Nitro-Chalk'*

(Significant effects marked: * for $P = 0{\cdot}05$–$0{\cdot}01$, ** for $P = 0{\cdot}01$ or less.)

Year	1955		1956		1957		1958
Centre	Harpenden	Hitchin	Sandridge	Stagenhoe	Sandridge	Stagenhoe	Leverstock Green
Yields without nitrogen	15·13	17·46	11·25	7·45	28·15	9·79	5·98
Increases from ammonium sulphate applied to seedbed							
Low rate	5·72**	1·88	13·04**	10·22**	2·25	9·54**	10·09**
Medium rate	7·44**	3·08	—	—	—	—	—
High rate	9·79**	7·15**	9·94**	12·97**	2·40	10·98**	19·53**
Low rate plus top-dressing of 'Nitro-Chalk'	8·62**	5·20**	13·35**	13·92**	3·43**	10·57**	21·34**
Medium rate plus top-dressing of 'Nitro-Chalk'	10·35**	5·73**	—	—	—	—	—
Increases from calcium nitrate applied to seedbed							
Low rate	4·20**	4·24*	9·15**	9·51**	−1·34	8·86**	21·10**
Medium rate	7·04**	4·04*	—	—	—	—	—
High rate	9·00**	6·31**	11·19**	13·62**	−7·83**	12·30**	26·14**
Low rate plus top-dressing of 'Nitro-Chalk'	8·84**	3·41	10·42**	13·17**	0·53	12·00**	29·29**
Medium rate plus top-dressing of 'Nitro-Chalk'	9·30**	9·24**	—	—	—	—	—
Increases from urea applied to seedbed							
Low rate	—	—	6·94**	9·31**	2·49*	8·55**	12·26**
High rate	—	—	6·04**	12·06**	−0·58	12·91**	24·62**
Low rate plus top-dressing of 'Nitro-Chalk'	—	—	8·89**	13·55**	1·81	12·13**	25·09**
Standard error of increase	±1·089	±1·751	±2·166	±0·940	±1·196	±1·278	±2·995

Note. The low, medium and high rates of dressing in 1955 were 0·6, 1·2 and 1·8 cwt. N/acre. Low and high rates used in 1956, 1957 and 1958 were 1·0 and 2·0 cwt. N/acre. Top-dressings provided 0·6 cwt. N in 1955, and 1·0 cwt. N in 1956, 1957 and 1958.