PLACEMENT OF FERTILIZERS FOR ROW CROPS

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(With Plate 21 and Two Text-figures)

INTRODUCTION

In early experiments, Lawes (1847) found that superphosphate mixed with turnip seed and sown in an ordinary drill was more efficient than the same material mixed with the cultivated layer of soil. Nitrogenous fertilizers used in this way damaged plant establishment severely in dry seasons, and Lawes recommended that phosphates should be drilled with the seed and nitrogenous manures should be broadcast. Later last century mechanical distributors were introduced to broadcast fertilizer uniformly over the soil, and these were adopted by the majority of farmers. In a few restricted localities such as the Fens, fertilizer continued to be drilled either with the seed or in a broad band immediately below the seed by special drills usually manufactured locally. The farmers claimed that this practice gave improved brairding and early growth.

In America broadcast distributors have never been used as widely as in England, and combined seed and fertilizer drills were originally introduced to save labour. It was soon realized that the machines made more efficient use of fertilizer and this method of application spread rapidly. In recent years experiments in the United States have been initiated by the National Joint Committee on Fertilizer Application to determine the merits of different ways of applying fertilizers for a wide variety of crops and soils. Many of the experiments demonstrated damage to the germination of most common row crops when fertilizer was drilled either in contact with, or directly below, the seed. Bands of fertilizer a little below and to the side of the seed were not dangerous and frequently gave higher yields than the same quantity of fertilizer broadcast. Salter (1938) has summarized the results of experiments conducted before 1938 and detailed the factors responsible for the success or failure of individual placement methods. More recent summaries of American experiments and placement practice by Wolf (1947) and Cobb (1946) state that band placement is not universally the best method of applying fertilizers and that applications placed on the bottom of the furrow when ploughing may have advantages over bands in the surface soil. Maximum efficiency has often been attained by splitting the dressing of fertilizer, part being placed deeply in the soil and the remainder drilled beside the seed.

In England combined seed and fertilizer drills for grain were used in only a few areas before the War. Large numbers were imported early in the War and were so successful for drilling phosphate with the seed of wheat, oats and barley that attempts were made to drill fertilizer with the seed of row crops. Many cases of severe damage to germination of peas and sugar beet have been reported. McMillan & Hanley (1936) found that even small dressings of the common fertilizers retarded germination seriously when drilled in contact with the seed. Hanley (1947) gave a general warning on the dangers of the practice for all crops other than cereals, and stated that it was generally better to broadcast the fertilizers. In a survey of fertilizer practice carried out in fifteen counties in England and Wales, Boyd & Mathison (1947) found that the only surveyed area where combine-drilling for root crops was at all common was the fen peat of Huntingdonshire and the Isle of Ely. Here, more than half the sampled fields of carrots and one-quarter of the sampled fields of sugar beet and mangolds were drilled in this way in 1944. The average quantities of fertilizer applied by combine-drill were about 2–3 cwt/acre. The survey did not distinguish between combine-drills which place fertilizer and seed in contact in the soil by a single coulter and machines with two coulters which place a band of fertilizer directly below the seed but separated from it by a layer of soil.

Lewis (1941) tested placement in contact with the seed for mangolds, sugar beet and swedes, and obtained good results on soils acutely deficient in one or more nutrients, but the method could only be recommended for specific fertilizers in restricted areas as it involved serious risk of impaired germination. Fertilizer placed in a band below, though not in contact with, the seed, gave good results on deficient soils, but on other soils led to poor plant establishment and low yields. Lewis also tested placement of complete fertilizer in bands to the side of the seed and obtained higher yields than by broadcasting the fertilizer. He recommended that the bands should be 1·5 in. to the side and an inch or so below the level of the seed. Recently Miles (1947) has reviewed the evidence on the value of fertilizer placement for arable crops in Great Britain.

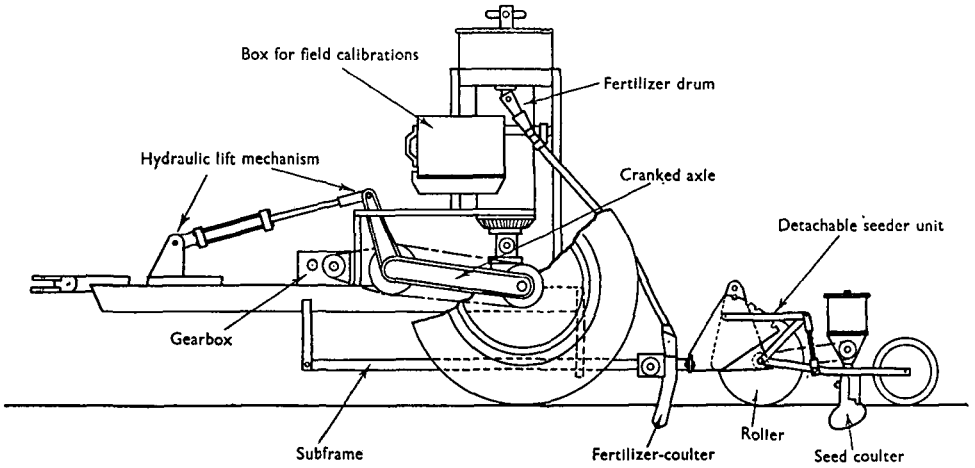
The experiments described in this paper were made to devise safe methods of placing fertilizer

near the seed of some important arable crops, and to estimate any increased efficiency of fertilizer applied in this way. No method of application can be recommended to farmers if there is even a small danger of injury to crop establishment. Methods which had caused damage to germination in earlier work were deliberately tested to provide quantitative evidence of the possible loss in crop yields.

Machinery for the experiments

Previous workers on fertilizer placement in this country have usually modified an existing commercial drill. Few row crop drills are manufactured in England with a fertilizer attachment and none has a sufficiently accurate dispensing mechanism for experimental work. For comparative trials on methods of application it is essential that the amount of fertilizer delivered to a particular plot should be known precisely, and that the machine should deliver fairly constant rates from day to day. The National Institute of Agricultural Engineering designed and constructed a special drill for this investigation. The machine, which has been described elsewhere (National Institute of Agricultural Engineering 1948), was designed to sow the seed of any crop normally grown on the flat in wide rows and to place fertilizer in either one or two bands in any position from the centre of the row to 3 in. to the side of the row. The bands of fertilizer could be deposited at any depth up to 3·5 in. below the soil surface. The fertilizer hoppers which delivered over the top by positive displacement had been studied previously (Cooke, 1947). Small variations in delivery rates which occurred from day to day were found to be due to consolidation by upward pressure of the piston, caused by its jolting over rough land, and the condition of the fertilizer. Experience with this delivery system in experiments on potatoes and, also, laboratory tests showed that granular fertilizers gave much more constant delivery rates than powders. Granular fertilizers were therefore used in all the experiments described here.

The machine is illustrated in Text-fig. 1 and in Pl. 21. It consists of three fertilizer hoppers mounted on a two-wheeled chassis and each delivering to two fertilizer coulters. The seeder units and fertilizer coulters were mounted on a toolbar at the rear of the chassis for experiments in 1947. The machine was modified for the 1948 season, both fertilizer coulters and seed units being mounted on a floating sub-frame. This arrangement proved much more satisfactory. Clods and trash do not cause blocks and, as each unit is free to move vertically, both fertilizer and seed are sown much more uniformly than when the units were rigidly mounted on the toolbar. Parallel improvements were made in the design of the fertilizer coulters, which were originally made from a cultivator point mounted on a stem with a fertilizer tube behind. These coulters disturbed the seed-bed excessively, causing loss of moisture and irregular sowing of the seed. They were replaced in 1948 by a narrow Suffolk pattern having a sharp leading edge and a hollow stem to deliver fertilizer. The bands of fertilizer deposited by these coulters were about 0·75 in. wide. Each pair of fertilizer coulters has a roller behind to regulate depth and firm the seed-bed before the seed coulters. The seed units follow the rollers and are driven from the roller spindles. The fertilizer coulters and seed units are raised out of work by a hydraulic cylinder operated by the pump unit on the tractor. The machine drills three rows at once with a fixed spacing of 20 in. between the rows. It is mounted on pneumatic tyres and is drawn from centre to centre on the road by the tractor which is used to operate the machine in the field. The track widths of both



Text-fig. 1. Fertilizer placement machine for row crops.

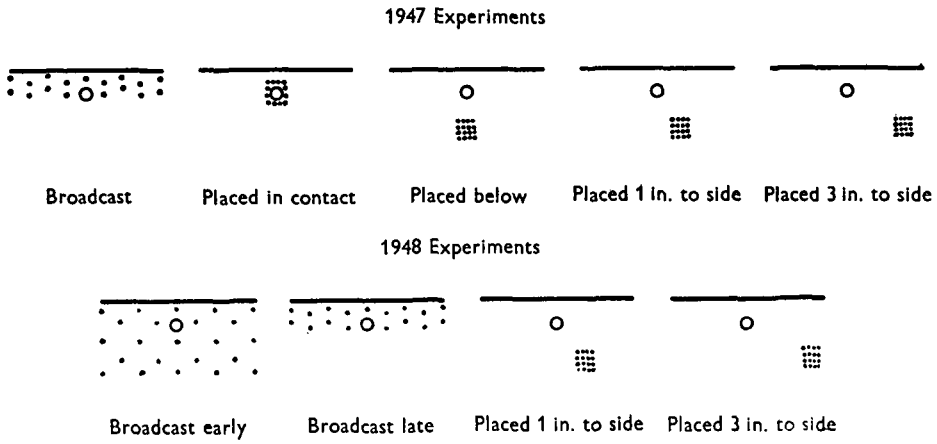
machine and tractor are 5 ft., which is convenient for road transport and also when laying down the experiments.

Special machines used for experiments on commercial farms must do work which will fit in with that done by the farmer's own machines in the same field; otherwise the choice of sites may be biased towards richer land by selecting large fields or the farms of particularly co-operative farmers. In addition, the work at each centre must be completed in a reasonable time when a number of centres on one crop have to be drilled. In the 1947 experiments adjustments to the coulters, which were mounted by clamps on the toolbar, were too tedious and time-consuming to be made at each plot boundary. Internal headlands were arranged between the two randomized blocks of each experiment; plots having the same method of fertilizer application were drilled consecutively, the drill being turned on the headlands. This way of drilling the experiments made subsequent cultivations difficult and also limited the choice of sites. In 1948, improvements allowed the coulter settings to be varied easily and quickly without the use of tools, lateral adjustment being made by sliding each coulter on a cross bar while depth adjustment was provided by a simple hand-operated crank. With this arrangement there are no restrictions on the way the experiments can be carried out. The drill is used to sow seed and fertilizer as desired, using any normal experimental pattern, and each field is usually drilled from hedge to hedge so that subsequent cultivations are quite normal.

At each centre the machine was calibrated by running it over a measured distance and diverting the flow of fertilizer into collecting boxes. A revolution counter was used to assess wheel slip, which averaged 8%. Granular fertilizers were used exclusively in the experiments, and the variations in the recorded delivery rates from centre to centre were not large. Granular National Compound no. 2 was drilled for sugar beet at twenty centres in 1947 and 1948, and the maximum variation in delivery rates from centre to centre was 10%. Difference in rates of application of this magnitude may be neglected as they have much less influence on yields than local soil irregularities occurring on each experimental area.

Scope of the experiments

In the first year (1947) the experiments were planned to give information on the effect on yield and plant establishment of fertilizer placed in different positions as well as to compare broadcast and placed fertilizer. The methods of application tested are illustrated diagrammatically in Text-fig. 2, and were:



Text-fig. 2. Methods of fertilizer application for row crops.

Broadcast and harrowed into the seed-bed (duplicate plots).

Placed in same zone as the seed.

Placed 3 in. below the soil surface and directly below the seed.

Placed in a band 3 in. below soil surface and 1 in. to the side of the seed.

Placed in a band 3 in. below soil surface and 3 in. to the side of the seed.

Each method of application was tested at two rates and the twelve treatments together with four 'no fertilizer' plots were laid down in a randomized block. Twofold replication was used. Eight experiments on sugar beet, seven on swedes and one on mangolds tested granular National Compound Fertilizer no. 2 (9% N, 7·5% P_2O_5, 4·5% K_2O) at 4·5 and 9·0 cwt./acre. Three experiments on threshed peas tested a granular fertilizer containing 10% P_2O_5 and 20% K_2O at 3 and 6 cwt./acre.

The machine was not fitted to place fertilizer and seed in contact by a single coulter (as in a combine-

drill), so the fertilizer coulters were set to deliver fertilizer into the soil zone where the seed was subsequently sown by the seed coulter. This method of contact placement allows some mixing of soil and fertilizer before sowing and is thus less drastic than sowing fertilizer and seed together by an ordinary combine-drill. For other placement methods the depth of the fertilizer bands was fixed at 3 in. below the soil surface, partly to avoid complicating the experiments further and partly because the actual depth of the band is less important than its lateral position. Sideband placement was restricted to a band at one side of the seed only. In preliminary trials with two coulters for each row, frequent blockages were caused on indifferent seed-beds by clods lodging between the coulters although they were staggered. Lewis (1941) encountered similar difficulties. Commercial drills, which must often work on poor seed-beds, would not be successful if they caused frequent stops in the work and disturbed the seed-bed. The depth of sowing followed local practice, but was usually about 1 in. for sugar beet, mangolds and swedes and 2 in. for peas. Although the fertilizer bands were only about 1 in. below the level of the seed of peas, deeper placement was not attempted owing to the risk of disturbing the seed-bed excessively.

The methods of application tested in 1948 (Text-fig. 2) were:

Broadcast fertilizer was applied to the soil after the last ploughing and worked into the soil by the normal cultivations made to prepare the seed-bed.

Broadcast on the seed-bed and harrowed in.

Placed in one band 3 in. below the soil surface and 1 in. to the side of the seed.

Placed in one band 3 in. below the soil surface and 3 in. to the side of the seed.

Each method of application was tested at two rates of fertilizer. The eight treatments together with four 'no fertilizer' plots were arranged in a randomized block. Threefold replication was used at all centres. Thirteen experiments on sugar beet and three on mangolds tested granular National Compound Fertilizer no. 2 at 5 and 10 cwt./acre. Five experiments on threshed peas tested 3 and 6 cwt./acre of granular fertilizer containing 10% P_2O_5 and 20% K_2O.

In both years broadcast fertilizer was applied exactly at the stated rates. Field calibrations of the drill showed that the differences in rates of application of broadcast and of placed fertilizer were not sufficiently large to preclude direct comparisons of the two methods.

Fertilizer placed in contact or directly below the seed damaged germination severely in 1947, and these methods were not considered worth further testing. In 1948 placement was confined to the two methods which had proved relatively safe in 1947—bands 1 in. and 3 in. to the side of the seed. Two methods of broadcasting were tested to give a comparison of deep and shallow incorporation with the soil. Early broadcasting after the last ploughing gives an opportunity to work fertilizer in deeply. On heavy soils where the furrow slice is intact when broadcasting, cultivation will incorporate the fertilizer to a depth of approximately 4 in. On light soils the furrow slice disintegrates more rapidly after ploughing and broadcast fertilizer falls on a smoother surface and will not be incorporated so deeply in preparing the seed-bed. Broadcasting fertilizer on the seed-bed is the common practice for root crops; light harrowing which usually follows works the fertilizer in approximately an inch. Phosphate and potash are not easily washed down into the soil and, if confined to the top inch, may be useless to the crop in dry periods as plant roots can take up nutrients only from moist soil.

Method of laying down the experiments

In 1947 the plots were usually 6 rows wide and 22 yd. long. Each block had 16 plots side by side; the two blocks of each experiment were parallel and were separated by a headland 8 yd. wide. Broadcast fertilizer was applied by hand to the appropriate plots. All plots having the same method of application were drilled consecutively by turning the machine on the headland between the blocks. The rate of application was varied by alterations to the gearbox fitted to the machine; the positions of the fertilizer bands were altered by adjusting the coulters. After drilling all plots having placed fertilizer, the fertilizer coulters were removed and the untreated plots and those plots having broadcast fertilizer were drilled with seed.

In 1948 the first visit was made to each experiment in late February or March, when the area was marked out and early applications of broadcast fertilizer were applied by hand. The plots were usually 6 rows wide and 22 yd. long in experiments on root crops. For pea experiments the plots were 6 rows wide and 33 yd. long with a path 5 ft. wide between the plots to facilitate harvesting. The 12 plots in each block were arranged side by side where possible. At many centres, the shape of the piece of land available made it necessary to have the experiment in a long strip, commonly of 6 × 6 plots. The seed-beds were prepared by individual farmers according to their normal practice and then a second visit was made to each site. Fertilizer was broadcast on appropriate plots by hand and, depending on local practice, the seed-bed was harrowed to work in the fertilizer either before or after drilling the seed. A string was pegged 6 in. to the right of the centre line of the experiment to serve as a guide to the tractor driver for the first line of drilling. Afterwards the wheel marks were used as guides. As the tractor

and drill had the same track width, which was half the width of one plot, this method of working allowed accurate drilling to be done within the area marked out for each plot and without using markers on the drill. Usually the field was drilled with seed from hedge to hedge. On the experimental area seed was drilled on all plots, and at plot boundaries the drill was stopped while the coulters and gearbox were adjusted so that the appropriate dressings of fertilizer could be drilled beside the seed. Drilling proceeded round the experiment in a clockwise direction until the whole area had been seeded.

After sowing, each experiment was hoed and treated in the same way as the rest of the field. Periodic observations were made to assess the effect of the treatments on germination, establishment and the growth of the crop. At harvest the centre 4 rows of each plot were harvested from experiments on root crops, a few yards at each end of the plot being discarded. The roots were weighed and counted in all the experiments. In the experiments on sugar beet the tops were also weighed and samples of roots were taken for analysis to determine the percentage of sugar. In pea experiments the whole area of each plot was pulled by hand as the peas became so tangled that the outside rows could not be separated and discarded. After allowing the peas to dry on the plot the produce was threshed and the peas were weighed. The plant populations of the pea experiment were determined by counting a length of 2·2 yd. chosen at random from each row of each plot.

RESULTS OF THE EXPERIMENTS

Experiments on threshed peas

The mean results of three experiments on peas in 1947 and five experiments in 1948 are given in Table 1. In both years the fertilizer was a granular material containing 10% P_2O_5 and 20% K_2O at the rates of 3 and 6 cwt./acre. In 1947 broadcast fertilizer gave very small responses, but fertilizer placed near the seed raised the yields considerably. Contact placement was inferior to the other placement methods; there was little difference in the yields given by the three methods of placing fertilizer below seed level. Plant population was generally improved by placed fertilizer but reduced by fertilizer in contact with the seed at the high rate.

In 1948 broadcast fertilizer gave small increases in yield; early applications on the ploughed land were slightly superior to broadcasting on the seedbed. There was little difference between the yields given by fertilizer placed either 1 in. or 3 in. to the side of the seed; both methods gave much higher yields than broadcasting the fertilizer. Fertilizer generally improved plant establishment. At Offord, Rothamsted and Silsoe the experiments had to be resown, as the original drilling was too shallow and the first crop was very poor. The bands of fertilizer were unlikely to occupy the correct position in relation to the seed after redrilling.

The increases at individual centres in yield and

Table 1. *Variation in yields and numbers of peas with different rates and methods of applying fertilizer*

Three experiments in 1947

Rate of fertilizer (cwt./acre)	No fertilizer	Fertilizer broadcast	Fertilizer placed: In contact	Below seed	1 in. to side	3 in. to side
			Yield of peas in cwt./acre			
3	—	13·0	16·2	15·8	16·7	15·8
6	—	14·0	14·5	16·7	16·1	16·7
Mean	13·2	13·5	15·4	16·3	16·4	16·3
			Plant number in thousands/acre			
3	—	134	136	138	146	129
6	—	128	109	133	136	138
Mean	130	131	123	135	141	133

Five experiments in 1948

Rate of fertilizer (cwt./acre)	No fertilizer	Fertilizer broadcast: Early	Late	Fertilizer placed: 1 in. to side	3 in. to side
		Yield of peas in cwt./acre			
3	—	13·7	13·8	15·7	15·6
6	—	14·8	13·1	15·8	16·8
Mean	12·6	14·2	13·4	15·8	16·2
		Plant number in thousands/acre			
3	—	152	149	152	165
6	—	156	147	158	159
Mean	146	154	148	155	162

plant numbers given by broadcast fertilizer, and the additional increases given by placing compared with broadcasting the fertilizer, are set out in Table 2. In 1947 broadcast fertilizer gave no significant increases in yield. The different methods of placing fertilizer gave significantly higher yields of peas than broadcasting at two of the three centres. At two centres fertilizer in contact with the seed depressed the plant population; fertilizer directly below the seed caused a significant decrease in plant at one centre. At Welbourn (where the peas were drilled on heavy soil in very wet conditions) fertilizer placed both with and below the seed gave significantly higher plant populations than broadcast fertilizer.

In all experiments in 1948, placed fertilizer gave higher yields than broadcast fertilizer and the difference in yield between the methods was significant at two centres. Early broadcasting gave higher yields than late broadcasting at all centres though none of the differences was significant. At Gransden and Offord germination was slow where 6 cwt. fertilizer/acre were placed 1 in. from the seed, and at both centres the final plant population was significantly lower than where the fertilizer had been placed 3 in. from the seed.

Table 2. *Comparison of methods of broadcasting and placing 4·5 cwt. fertilizer/acre in experiments on threshed peas in* 1947 *and* 1948

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

1947 experiments

	Without fertilizer	Increase from broadcast fertilizer	Additional increase over broadcasting from placing: In contact with seed	Below seed	1 in. to side	3 in. to side	S.E. per plot
No. of plots ...	8	8–8	4–8	4–8	4–8	4–8	—
			Yield of peas in cwt./acre				
Asgarby, Lincs	14·0	1·7	3·0*	6·0**	5·1**	6·0**	2·27
Nocton, Lincs	10·7	−1·1	0·4	−0·8	1·1	1·1	1·54
Welbourn, Lincs	15·0	0·2	2·2*	3·1**	2·4*	1·2	1·68
Mean	13·2	0·3	1·9	2·8	2·9	2·8	—
			Plant number in thousands/acre				
Asgarby, Lincs	130	6	−29	9	10	12	24·5
Nocton, Lincs	131	1	−15	−26*	5	−1	14·7
Welbourn, Lincs	129	−5	20*	31**	16	−3	14·6
Mean	130	1	−8	5	10	3	—

1948 experiments

	Without fertilizer	Increase from broadcast fertilizer	Additional increase over broadcasting from placing: 1 in. to side	3 in. to side	Early minus late broadcasting	S.E. per plot
No. of plots ...	12	12–12	6–12	6–12	6–6	—
			Yield of peas in cwt./acre			
Gransden, Cambs	5·1	3·4**	3·1**	4·8**	0·8	1·55
Offord, Hunts	11·3	1·5*	0·1	0·8	0·1	1·75
Rothamsted, Herts	16·3	1·1	1·3	1·0	0·3	1·61
Shepreth, Cambs	12·3	−0·7	4·8**	3·7**	1·1	1·69
Silsoe, Beds	17·8	1·0	0·4	1·7*	1·5	1·48
Mean	12·6	1·3	1·9	2·4	0·8	—
			Plant number in thousands/acre			
Gransden, Cambs	126	6	−9	18*	−17	14·9
Offord, Hunts	160	12	−6	15	12	15·3
Rothamsted, Herts	134	5	5	10	8	14·7
Shepreth, Cambs	138	−2	27*	21*	27*	19·2
Silsoe, Beds	174	4	1	−10	−3	12·6
Mean	146	5	4	11	5	—

Experiments on sugar beet

Eight experiments in 1947 and thirteen experiments in 1948 were carried out on sugar beet with the help of the Factory Agriculturists of the British Sugar Corporation. Granular National Compound no. 2 (9 % N, 7·5 % P_2O_5, 4·5 % K_2O) was tested in all experiments, the rates of application being 4·5 and 9·0 cwt./acre in 1947 and 5·0 and 10·0 cwt./acre in the 1948 experiments. Yields of sugar and estimates of the plant population were obtained from all the

experiments; the yields of tops were obtained from all experiments in 1947 and from twelve experiments in 1948. Measurements were made on samples of the roots from most experiments of the purity, noxious nitrogen content and electrical resistance of the juice, but as neither the rates nor methods of fertilizer application had any marked effect on these quantities, the data are not presented here. The mean yields of sugar and of tops and the plant populations for all experiments in each year are set out in Table 3. The increases given by broadcast fertilizer and comparisons of broadcasting and placement were examined for each centre by averaging the two rates of dressing; these are tabulated in Tables 4 and 5. The effects of fertilizer on plant population and on yields of sugar and of tops are discussed separately.

Table 3. *Variation in yields of sugar and tops and in numbers of sugar beet with different rates and methods of applying fertilizer*

Eight experiments in 1947

Rate of fertilizer (cwt./acre)	No fertilizer	Fertilizer broadcast	Fertilizer placed			
			In contact	Below seed	1 in. to side	3 in. to side
			Yield of sugar in cwt./acre			
4·5	—	46·6	34·9	41·6	44·5	43·9
9·0	—	45·9	25·3	36·5	39·9	46·6
Mean	44·3	46·3	30·1	39·1	42·2	45·3
			Yield of tops in tons/acre			
4·5	—	8·7	6·7	8·5	8·2	8·7
9·0	—	8·9	7·0	8·2	8·8	9·8
Mean	7·7	8·8	6·8	8·4	8·5	9·3
			Plant number in thousands/acre			
4·5	—	24·3	16·0	20·2	22·3	22·5
9·0	—	23·6	11·5	15·3	19·3	23·8
Mean	23·5	23·9	13·8	17·7	20·8	23·2

Thirteen experiments in 1948

Rate of fertilizer (cwt./acre)	No fertilizer	Fertilizer broadcast		Fertilizer placed	
		Early	Late	1 in. to side	3 in. to side
		Yield of sugar in cwt./acre			
5	—	43·8	43·6	45·4	44·1
10	—	44·2	46·1	44·3	45·6
Mean	39·6	44·0	44·8	44·9	44·8
		Yield of tops in tons/acre			
5	—	11·7	11·7	12·1	11·9
10	—	13·7	13·8	14·0	13·7
Mean	9·9	12·7	12·8	13·1	12·8
		Plant number in thousands/acre			
5	—	23·9	24·9	24·8	23·9
10	—	23·8	24·6	22·4	24·0
Mean	24·2	23·8	24·7	23·6	23·9

(Yields of tops in 1948 were determined at only twelve centres.)

Plant population of sugar beet

In 1947 contact placement and placement directly below the seed reduced establishment, and the effect was more serious at high than at low rates. Fertilizer (9 cwt./acre) placed an inch away from the seed damaged plant establishment, but the lower dressing was fairly safe.

Fertilizer in contact with the seed gave lower populations than broadcast fertilizer at every centre, and at six centres the decrease was significant (Table 4). Placement 3 in. below the soil surface became increasingly safe as the distance of the fertilizer from the seed increased, and when the band was placed 3 in. from the seed the plant population was lowered significantly at only two of the centres. Under very dry conditions at sowing, as occurred in 1947, placement may reduce plant establishment since the fertilizer coulters disturb the seed-bed and allow sufficient loss of moisture to delay germination. The fertilizer coulters used in 1947 were very wide and caused a serious disturbance in the seed-bed.

In 1948 the only marked reduction in plant establishment was caused by fertilizer placed 1 in. from the seed at 10 cwt./acre (Table 3). At nine of the thirteen centres this method gave lower average plant populations than broadcasting, the decrease

being significant at three centres (Table 5). Early broadcasting gave lower plant populations than late applications at eight centres and at three of these the decrease was significant. Observations made on the growing crops before singling showed that at eleven centres germination was delayed and frequently damaged by 10 cwt. of fertilizer placed 1 in. from the seed; at a few centres there was some damage from method of placing fertilizer gave a higher mean yield than broadcasting. Comparisons of broadcasting and placement are made at each centre in Table 4. A significant response to broadcast fertilizer was obtained at one centre. Fertilizer placed in contact with the seed gave significantly lower yields of sugar than broadcast fertilizer at four of the eight centres. Placement was consistently superior at only one

Table 4. *Comparison of broadcasting and placing* 6·75 *cwt. fertilizer per acre in experiments on sugar beet in* 1947

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

	Without fertilizer	Increase from broadcast fertilizer	Additional increase over broadcasting from placing: In contact with seed	Below seed	1 in. to side	3 in. to side	S.E. per plot
No. of plots ...	8	8–8	4–8	4–8	4–8	4–8	—
			Yield of sugar in cwt./acre				
Cantley	34·8	2·1	−8·5*	−1·5	−0·4	0·4	5·82
Ipswich	27·4	8·3*	(−28·5)	(−17·4)	−3·7	5·8	6·82
Kelham	53·5	−2·9	4·1	9·9*	5·4	−4·5	6·28
King's Lynn	46·7	2·1	−38·5**	(−46·4)	−22·5**	−12·3**	6·68
Peterborough I	56·4	0·7	−0·8	1·3	4·2	4·3	4·01
Peterborough II†	40·2	−1·7	−24·3**	−6·6*	−2·4	1·6	4·82
Rothamsted†	24·8	2·6	1·0	6·1*	7·6**	5·1*	5·02
Spalding	70·9	4·2	−33·9**	−2·9	−20·4**	−8·4	7·30
Mean	44·3	1·9	−16·2	−7·2	−4·0	−1·0	—
			Yield of tops in tons/acre				
Cantley	5·4	−0·2	0·2	1·1*	0·5	1·0*	0·62
Ipswich	4·4	2·3**	(−4·7)	(−2·3)	0·3	0·5	0·79
Kelham	10·3	0·8	0·6	1·1	0·7	1·7	1·47
King's Lynn	5·0	0·5	−3·9**	(−5·1)	−2·6**	−0·7	0·84
Peterborough I	14·5	2·6	−1·3	0·6	−0·3	0·5	2·72
Peterborough II†	6·3	0·3	−3·2**	0·4	−0·3	0·3	1·04
Rothamsted†	4·3	1·4**	0·4	1·5**	1·5**	1·6**	0·89
Spalding	11·4	0·9	−3·7**	−0·4	−1·7*	−1·0	1·21
Mean	7·7	1·1	−2·0	−0·4	−0·2	0·5	—
			Plants number in thousands/acre				
Cantley	20·6	−0·6	−3·4**	−1·0	−0·5	0·7	1·77
Ipswich	24·7	0·3	(−21·0)	(−15·7)	−4·6**	0·0	2·31
Kelham	26·0	−0·9	−1·0	3·5**	3·3**	2·5*	1·73
King's Lynn	17·4	1·5	−14·9**	(−18·3)	−9·9**	−4·1*	2·89
Peterborough I	27·8	0·9	−4·1*	−0·3	−0·8	0·7	2·27
Peterborough II†	28·7	−1·5	−20·3**	−9·6**	−2·5*	0·4	1·80
Rothamsted†	18·3	3·4**	−4·8**	−4·4**	−2·6*	−1·5	2·10
Spalding	24·8	0·0	−11·8**	−3·7*	−7·3**	−4·8**	2·37
Mean	23·5	0·4	−10·2	−6·2	−3·1	−0·8	—

† At Peterborough II there were only 6 plots without fertilizer. At Rothamsted there were 12 plots without fertilizer, 12 plots with broadcast fertilizer and six plots for each method of placing fertilizer.

Data in brackets are derived from low values excluded from the statistical analysis.

the lower dressing applied by this method. In some experiments damage was so serious that after singling the final plant was gappy; at other centres there were sufficient seedlings to leave a satisfactory plant after singling.

Yields of sugar

In 1947 the mean yields of sugar followed the trends shown by the plant numbers (Table 3). The response to broadcast fertilizer was small and no centre (Rothamsted) where fertilizer in bands below or to the side of the seed gave significantly higher yields than broadcast fertilizer.

The response to fertilizer was much larger in 1948 (Table 3). Fertilizer broadcast on the seed-bed or placed in bands to the side of the seed gave almost identical yields of sugar. Early broadcasting was inferior to late broadcasting. Broadcast fertilizer gave significant increases in yield at eight of the thirteen centres. Late was superior to early broad-

casting at seven centres but there were no significant differences between yields given by the two methods. Placement gave significantly higher yield than broadcasting at one centre when the fertilizer was contact with the seed reflect damage to the plant population. Fertilizer placed in bands 3 in. to the side of the seed gave a higher mean yield than broadcast fertilizer; other methods of placement

Table 5. *Comparison of methods of broadcasting and placing 7·5 cwt. fertilizer per acre in experiments on sugar beet in* 1948

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

	Without fertilizer	Increase from broadcast fertilizer	Additional increase over broadcasting from placing		Early minus late broadcasting	S.E. per plot
			1 in. to side	3 in. to side		
No. of plots ...	12	12–12	6–12	6–12	6–6	—
			Yield of sugar in cwt./acre			
Bardney	32·6	10·4**	0·0	−0·4	−0·7	2·76
Bury	44·1	0·0	−3·0	4·0*	−0·9	3·74
Cantley	65·8	−0·4	3·4	1·0	1·6	4·20
Colwick	42·4	−1·7	−2·8	−3·4	0·0	7·72
Ely	30·2	5·2**	3·4	−0·7	0·0	4·04
Felstead	47·8	9·0**	4·0	1·6	1·7	6·11
Ipswich	45·8	3·0	−2·0	1·4	0·1	5·48
Kelham	12·9	2·8**	4·1**	1·4	−1·6	1·84
King's Lynn	24·3	11·8**	2·4	1·8	−3·9	5·20
Peterborough I	34·9	−0·8	1·2	−1·6	−3·5	5·20
Peterborough II	61·5	7·8**	−3·4	−3·2	−1·5	5·96
Rothamsted	39·4	6·8**	0·0	−1·0	0·3	3·27
Wissington	33·6	8·1**	−1·3	3·8*	−2·0	2·74
Mean	39·6	4·8	0·5	0·4	−0·8	—
			Yield of tops in tons/acre			
Bardney	6·1	4·2**	−0·4	−1·0*	0·4	0·93
Bury	12·2	2·4**	−0·9	0·3	−0·1	1·41
Cantley	14·9	2·4**	0·1	0·1	0·2	1·44
Colwick	11·8	4·8**	−1·4	−1·2	−0·6	2·08
Ely	11·9	2·6*	0·1	−0·6	−0·3	2·33
Felstead	5·4	2·1**	0·8	−0·2	−0·5	0·89
Ipswich	14·1	4·0**	−0·8	−0·3	1·0	2·36
Kelham	7·8	2·0**	1·3*	0·1	−1·6*	1·25
King's Lynn	5·2	2·8**	0·7	1·2	−0·8	1·24
Peterborough I	13·0	1·0	1·1	0·2	0·6	1·30
Rothamsted	10·4	4·2**	1·6	1·2	0·9	1·70
Wissington	5·9	1·5**	1·9**	1·6**	−0·5	0·72
Mean	9·9	2·8	0·3	0·1	−0·1	—
			Plant number in thousands/acre			
Bardney	29·1	1·0	−4·0**	−0·2	−1·3	1·86
Bury	19·3	0·6	−2·6**	−1·2	1·3	1·33
Cantley	25·2	−1·6*	−1·0	−0·4	0·5	1·89
Colwick	18·5	0·8	−0·6	0·8	2·1	2·94
Ely	21·4	0·0	−1·1	−1·8	−3·8*	3·20
Felstead	25·0	0·4	0·2	0·4	−1·3	1·46
Ipswich	29·0	−1·4	−2·8*	1·2	0·7	2·07
Kelham	16·6	−1·1	4·2**	0·6	−2·8**	1·60
King's Lynn	16·9	2·8**	−1·8	0·5	−2·6*	2·17
Peterborough I	32·2	−0·8	1·8	−1·2	−0·3	3·02
Peterborough II	27·9	−0·6	−1·6	−3·0*	−2·7	2·45
Rothamsted	23·2	−0·2	0·4	0·0	0·1	1·02
Wissington	30·8	0·9	−0·4	−0·4	−1·6	1·72
Mean	24·2	0·1	−0·7	−0·4	−0·9	—

1 in. from the seed and at two centres when the band was 3 in. from the seed.

Yields of sugar-beet tops

On the whole, tops gave larger responses to fertilizer than were given by the yields of sugar (Table 3). In 1947 low yields given by fertilizer in below seed level were inferior to broadcasting. Comparisons set out for each centre in Table 4 show that placement in contact with the seed gave significantly lower yields of tops than broadcasting at three centres. Fertilizer below or to the side of the seed was significantly superior to broadcasting at Cantley and Rothamsted.

In the 1948 experiments early and late broadcasting and placement 3 in. to the side of the seed all gave very similar mean yields of tops (Table 3). The mean yields given by fertilizer placed 1 in. to the side of the seed were slightly higher than those given by the other methods of application. Broadcast fertilizer gave significant increases at eleven of the twelve centres where yields of tops were measured (Table 5). Fertilizer placed 1 in. from the seed gave significantly higher yields of tops than broadcasting at two centres. Fertilizer 3 in. from the seed gave a significantly higher yield than broadcasting at one centre and a significantly lower yield at one centre. of tops during the summer and one or other of the placement methods gave better growth than broadcasting. In general, early broadcasting was a little superior to late broadcasting, and placement 1 in. to the side of the seed was much superior to the other methods of application. Improved growth due to placed fertilizer continued to be visible through July and early August in 1948. Later observations were difficult owing to the heavy growth of tops, but there was no doubt that by the end of August, in many experiments, there was little difference in growth where marked differences had existed earlier in the summer.

Table 6. *Comparison of methods of broadcasting and placing 7·5 cwt. fertilizer per acre in experiments on mangolds in 1947 and 1948*

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

	Without fertilizer	Increase from broadcast fertilizer	Additional increase over broadcasting from placing: In contact with seed	Below seed	1 in. to side	3 in. to side	Early minus late broadcasting	S.E. per plot
1947 experiment (Swaffham, Cambs.)								
No. of plots ...	8	8–8	4–8	4–8	4–8	4–8	—	—
Yield roots, tons/acre	41·5	−0·4	−16·4**	−0·7	2·8	3·9	—	5·40
Plant no. thousands/acre	18·9	−2·0	−8·3**	−3·2	2·4	3·2	—	2·68
1948 experiments								
No. of plots ...	12	12–12	—	—	6–12	6–12	6–6	—
Yield of roots in tons/acre								
Boxworth, Cambs	19·0	8·2**	—	—	0·6	0·6	−0·4	4·03
Isleham, Cambs	39·0	2·4	—	—	−8·2**	0·2	2·4	4·09
Silsoe, Beds	54·0	6·6**	—	—	4·4*	1·0	3·5	3·08
Mean	37·3	5·7	—	—	−1·1	0·6	1·8	—
Plant number in thousands/acre								
Boxworth, Cambs	14·1	4·6*	—	—	−1·0	1·0	−1·1	3·90
Isleham, Cambs	12·8	0·6	—	—	−5·8**	−1·6	−0·2	1·70
Silsoe, Beds	24·5	−1·0	—	—	0·6	2·8	1·5	3·03
Mean	17·1	1·4	—	—	−2·1	0·7	0·1	—

Early development of sugar beet

In each year the experiments were visited several times during the spring and summer, and eye observations were made on the growth of the crops. Marks were assigned for vigour of growth, ignoring small reductions in plant number but eliminating plots where establishment had been badly damaged by fertilizer.

In 1947 placed fertilizer gave a better crop than broadcast fertilizer during the early part of the growing season and during July and early August. By harvest time there were no visible differences in the growth of tops from different ways of applying fertilizer. In 1948 there was no visible response to fertilizer at the Colwick centre, but in all the other experiments fertilizer had a large effect on the size

Experiments on mangolds

One experiment on mangolds in 1947 and three in 1948 tested National Compound Fertilizer no. 2 (9 % N, 7·5 % P_2O_2, 4·5 % K_2O), applied by the same methods which were tested for peas and sugar beet. The results are given in Table 6.

In the single mangold experiment, which was harvested in 1947, no method of applying fertilizer gave a significant increase in yield. The yield and plant population were depressed significantly by fertilizer placed in contact with the seed. In 1948 broadcast fertilizer increased the yield of mangolds significantly at two centres. Placement 1 in. to the side of the seed gave significantly lower plant establishment and yield than broadcasting at one centre. At Silsoe fertilizer placed 1 in. to the side of

the seed gave a significantly higher yield than broadcast fertilizer.

In both years, observations on the crops during June and July showed that placed fertilizer gave better early growth than broadcast fertilizer. Mangolds and sugar beet behave in the same way to placed fertilizer. Both crops are very easily damaged by placement in contact or directly below the seed; safe methods of placement promote better growth than broadcasting, but at harvest the yields given by either method of application are similar.

Table 7. *Variation in yields and numbers of swedes with different rates and methods of applying fertilizer*

Rate of fertilizer (cwt./acre)	No fertilizer	Fertilizer broadcast	Fertilizer placed			
			In contact	Below seed	1 in. to side	3 in. to side
			Yield in tons/acre			
4·5	—	5·71	6·35	8·99	7·95	7·00
9·0	—	7·06	6·39	8·83	8·99	8·57
Mean	3·47	6·38	6·37	8·91	8·47	7·79
			Plant number in thousands/acre			
4·5	—	22·5	17·6	23·0	22·5	21·6
9·0	—	22·8	12·2	19·5	21·2	21·4
Mean	16·9	22·7	14·9	21·3	21·9	21·5

Table 8. *Comparison of broadcasting and placing 6·75 cwt. fertilizer per acre in experiments on swedes in* 1947

(Significant effects marked ** for $P=0·01$, * for $P=0·05$.)

	Without fertilizer	Increase from broadcast fertilizer	Additional increase over broadcasting from placing				S.E. per plot
			In contact with seed	Below seed	1 in. to side	3 in. to side	
No. of plots ...	8	8–8	4–8	4–8	4–8	4–8	—
			Yield of roots in tons/acre				
Winfrith, Dorset	3·71	2·55**	1·47	2·29**	2·31**	1·61*	1·22
Shobdon, Hereford	9·35	0·52	−0·63	3·08*	1·82	1·78	2·00
Empingham, Rutland	1·58	0·36*	0·16	0·89**	0·56**	0·78**	0·26
Tinwell, Rutland	3·62	1·07*	−0·53	1·00*	0·71	0·85	0·75
Tickencote, Rutland	(0·20)	1·89**	(−1·82)	1·15**	0·13	0·44	0·55
Pitton, Wilts†	5·83	−0·73	1·57	3·30**	2·99**	2·77*	1·40
Clows Top, Worcs	(0·00)	14·74**	−0·31	5·99**	6·08**	1·61	1·61
Mean	3·47	2·91	−0·01	2·53	2·09	1·41	—
			Plant number in thousands/acre				
Winfrith, Dorset	22·8	0·3	−6·8**	−1·3	0·2	−0·5	2·82
Shobdon, Hereford	24·8	0·9	−11·1**	−5·0*	0·0	−5·6*	3·72
Empingham, Rutland	17·5	−0·1	−3·2*	−0·5	−1·0	−0·8	2·02
Tinwell, Rutland	21·2	0·1	−3·9**	4·2**	0·7	0·6	2·00
Tickencote, Rutland	8·5	7·5**	(−13·9)	−3·2*	−3·8*	−2·5	2·17
Pitton, Wilts†	23·8	−1·3	−3·5*	−1·3	0·1	1·6	1·95
Clows Top, Worcs	(0·0)	32·6**	−12·1**	−2·6	−1·7	−0·7	2·71
Mean	16·9	5·7	−7·8	−1·4	−0·8	−1·1	—

† At Pitton there were 4 plots without fertilizer and 4 plots with broadcast fertilizer.
Data in brackets are derived from low yields or numbers excluded from the statistical analysis.

Experiments on swedes

Seven experiments in 1947 tested 4·5 and 9·0 cwt. of National Compound Fertilizer no. 2 applied by the methods which were used in the pea and sugar-beet experiments described above. The mean results for all the experiments are given in Table 7. The swedes were sown in the first 3 weeks of June, and rain in late June and early July was sufficient at most centres to give good growth until the crops had been singled. Continuous drought in late July and during the whole of August prevented satisfactory growth. At harvest all yields were low, only one experiment (Clows Top, Worcestershire) had individual plots which yielded more than 20 tons/acre. Under these conditions placement gave much better yields than broadcasting. The plant establishment was generally increased by fertilizer. Contact placement at both rates of dressing and placement directly below the

seed at the high rate gave a lower mean plant population than broadcast fertilizer, but other methods of placement were safe. The average yield given by contact placement was similar to that given by broadcasting, but placement below or to the side of the seed gave considerably higher yields.

Comparisons of broadcasting and placement at individual centres are made in Table 8. Fertilizer in contact with the seed damaged the plant significantly at six centres. Other methods of placement were relatively safe, and bands at 1 in. and at 3 in. from the seed each gave significantly lower plant populations than broadcasting at one centre. Broadcast fertilizer increased yields significantly at five centres. Contact placement gave no significantly higher yield than broadcasting. Placement directly below the seed was the most successful method of application and gave significantly higher yields than broadcasting at each centre. Fertilizer placed to the side of the seed gave larger yields than broadcast fertilizer at every centre. There were four significant increases with bands at 1 in. and three significant increases with bands at 3 in. from the seed.

Weather in 1947 *and* 1948

In 1947 severe weather in February and early March was followed by heavy rain in late March and early April which prevented land work. Sowing in the sugar beet and mangold experiments began on 14 April and was not completed until 14 May. The three pea experiments were sown on 21, 22 and 23 April, while the swede experiments were sown between 3 and 19 June. Very little rain fell during May and the first 3 weeks of June; in late June heavy storms reached most districts. July rainfall was generally below average while August, September and October were dry months everywhere. In 1948 after heavy rain in January, February and March were both dry months. Early application of broadcast fertilizer was started in late February. Sowing of peas commenced on 15 March and was not completed until 7 May. The sugar-beet and mangold experiments were sown between 22 March and 16 April. In all areas covered by these experiments, April rainfall was below average, but May and June were both wet months. The summer was characterized by erratic rainfall distribution over eastern England, together with general low temperatures and a deficiency of sunshine. Rainfall was generally adequate for crop growth throughout the summer and autumn.

Damage to germination caused by placement must be associated with dry seed-beds and with long dry periods after sowing. The rainfall recorded at some centres in the early stages of growth from sowing to singling is given in Table 9. At most centres rainfall was much lower during the critical period in 1947 than in 1948. The actual extent of damage by fertilizer must depend on the amount and distribution of the rainfall from sowing until the plants are well established, on the texture of the soil and on the moisture content of the soil at the time of sowing.

Table 9. *Rainfall in* 1947 *and* 1948

Rainfall from sowing to singling of the sugar-beet experiments

Centre	Total (days)	Rainy days	Rain (in.)
	1947		
Cantley	43	8	1·33
Ipswich	44	11	1·12
Kelham	34	9	0·76
King's Lynn	37	13	0·84
Peterborough I	39	8	1·20
Peterborough II	28	10	0·94
Rothamsted	33	11	0·86
Spalding	39	16	0·46
	1948		
Bardney	46	13	1·09
Bury	49	16	2·86
Cantley	57	14	2·24
Felstead	35	10	1·66
Kelham	32	10	1·40
King's Lynn	40	14	2·01
Wissington	46	12	1·98
Rothamsted	61	30	4·42

Rainfall in inches at Rothamsted for 1947 *and* 1948

	1947	1948
January	1·47	5·01
February	1·29	1·08
March	5·06	0·90
April	2·07	1·38
May	1·16	3·04
June	2·40	2·92
July	1·53	0·93
August	0·07	2·54
September	1·35	1·78
October	0·04	2·18
November	1·04	1·66
December	2·91	2·96
Total	20·39	26·38

Damage to germination of peas in 1947 by fertilizer placed near the seed was less than had been expected, as reports are received each year of serious damage caused by quite small dressings of complete fertilizer drilled with the seed. The rainfall recorded at R.A.F. Station, Cranwell, which is within a few miles of the three centres, was:

	Rain (in.)	Rainy days
22–30 April	0·57	5
May	0·59	11
June	2·33	12
July	2·25	15
Total	5·75	43

The soils at Asgarby and Welbourn are heavy in texture and were very wet at sowing time while the soil at Nocton is light and was much drier. The

amounts of water in the soils at sowing time (expressed as a percentage of the oven-dry soil) were:

Asgarby	35·3
Nocton	16·9
Welbourn	48·6

High soil moisture at sowing and rain in the week following undoubtedly limited damage by fertilizer placed with the seed. The reduction in plant numbers on the drier, light soil at Nocton by fertilizer drilled in contact with or below the seed shows that these methods may cause serious damage in a dry seed-bed if appreciable rain does not fall soon after sowing.

DISCUSSION

An important object of the experiments was to devise safe methods of placement. The two years 1947 and 1948 gave an excellent opportunity to assess possible injury to germination, as rainfall was deficient during the time the crops were sown and subsequently. In 1947 fertilizer placed in contact with the seed of sugar beet, mangolds, swedes and peas caused serious reductions in plant establishment compared with broadcast fertilizer. Fertilizer in a band directly below the seed caused a loss of plant sufficient to reduce yields in most of the experiments on sugar beet, presumably because the primary rootlet was damaged by growing into a region of high salt concentration. These two methods of placement are much too dangerous to be suggested to farmers. Damage to germination of sugar beet, mangolds and peas was caused in 1947 and 1948 by heavy dressings of fertilizer placed an inch from the seed and such close placement should not be attempted. Experience with the special machine built for these experiments showed that the relative positions of the fertilizer and seed coulters cannot be controlled during the whole of a season's work with the precision necessary to place a band of fertilizer 1 in. away from the seed. No commercial drill designed more simply to work under all cultural conditions can be expected to retain fine adjustment of the two coulters. With crops sown deeply, such as beans and peas, bands of fertilizer 3 in. below the surface will be practically in contact with the seed if the lateral distance between seed and fertilizer is only 1 in. In both years, fertilizer in bands 3 in. to the side of the seed was safe and caused no visible check to germination. Where a satisfactory plant was established, fertilizer placed at 1 in. generally gave more vigorous early growth than the same dressing 3 in. from the seed. Bands of fertilizer should be placed as close to the seed as is consistent with avoiding any damage to germination. For the crops tested in these experiments, fertilizer should be placed at least 2 in. to the side of the seed.

The effects of placed fertilizer on yields were consistent over the 2 years. In both years placement gave higher yields of peas than broadcasting; the mean extra yield given by placing the fertilizer at the side of the seed was 2·8 cwt./acre in 1947 and 2·2 cwt./acre in 1948. Broadcasting fertilizer on the rough soil before preparing the seed-bed produced 0·8 cwt./acre more peas than late broadcasting in the 1948 experiments; farmers would be well advised to work phosphate-potash fertilizer deeply into the soil for this crop. Peas appear to be particularly sensitive to the position of nutrients in the soil and in other experiments on fertilizers broadcast responses have often been small. The large responses obtained in 1948 from fertilizer, incorporated deeply by early broadcasting, suggest that when the general manuring of a crop is being investigated the tests should include different methods of applying the manures to ensure that the value of a nutrient is not reduced merely because it has been confined to a position in the soil where it is of little use to the particular crop.

Sugar beet and mangolds gave very similar results in the 2 years. On the mean results of all experiments, fertilizer placed at safe distances from the seed had no worthwhile superiority over broadcast fertilizer. In both years, at every centre where the fertilizer had any effect during the early part of the growing season in June and July, placed fertilizer gave more vigorous growth than the same dressing broadcast. This effect was ascribed in 1947 to dry weather in spring and summer causing immobilization of broadcast fertilizer, but adequate rain fell during the summer months of 1948. Improved early growth is the normal result of placing fertilizer beside the seed for sugar beet and mangolds. Where field trials are not carried to the stage of determining the yields of roots and of tops, early vigour of crops having placed fertilizer may give misleading impressions, and may have been responsible for enthusiasm among farmers for placement for row crops. Similar transient effects caused by fertilizer placed near the seed have been reported by McMillan & Hanley (1936) for sugar beet grown in this country, and by Cumings (1943) for maize grown in America. The experiments on sugar beet were laid down on soils representative of large areas of normal beet land. Although on individual fields higher yields may be obtained by placing than by broadcasting fertilizer, the series of twenty-one experiments shows that there is no advantage, on the average, from placing the full quantity of sugar-beet fertilizer beside the seed except that labour is saved in applying the fertilizers.

The marked superiority of placed fertilizer for swedes at all centres in 1947 was probably due in part to the excessively dry weather during the summer and autumn. Swedes are very sensitive to lack of phosphate, and it is likely that phosphate in the broadcast fertilizer remained in the dry topsoil and was quite useless. Phosphate in bands near the seed

must have stimulated root growth and enabled the crop to make maximum use of the water in the soil. The very marked benefits on crop establishment and yield more than compensated for any damage due to germination caused by fertilizer placed below or beside the seed. The yields of swedes in 1947 were so low that the experiments cannot be taken as a reliable guide to the general value of placement but must be considered as an example of the success of the method for crops made sensitive to nutrient deficiency by drought.

The efficiency of placing compared with broadcasting the fertilizer will depend on the root range of the crop, the length of the growing season, the rate of uptake of nutrients during the growing season and the needs of the crop for any particular nutrient in a fully available form. Root systems of common crops have not been thoroughly examined in England, and there is little quantitative evidence on the speed and extent of root growth other than the classical work of Weaver (1926) in America. Sugar beet is a typical deep-rooting crop and has shown little permanent benefit from placed fertilizer; peas and swedes have a more shallow root system and benefit from fertilizer close to the seed. Crops with a long growing season, such as sugar beet, make much growth during the later part of the summer; backward crops having broadcast fertilizer have ample opportunity to catch up with more forward crops grown with placed fertilizer. Peas have a short growing season and any superiority established by placed fertilizer will be maintained at harvest. Recently, Halliday (1948) has summarized the literature on the rate of nutrient uptake by farm crops. Sugar beet has a very low initial rate of uptake of nitrogen, phosphate and potash in May, which rises during June to very high rates for all three nutrients in July and August, coinciding with maximum root development. Peas absorb little during the first month after sowing and Halliday states: 'thereafter nutrient uptake proceeds at a high rate until maturity'; the total period of uptake may be only 10 weeks for peas. June-sown turnips have a short period of maximum nutrient uptake during August. Such facts help to explain the superiority of placement for peas and swedes, and the indifferent value of the method for sugar beet.

Much development work on the machine used in these experiments emphasized some of the principles which should be embodied in commercial placement drills. The delivery system used in the experimental drill was designed to secure high precision in rates of application; such a mechanism is probably too intricate and costly for general use on farms. Although more irregular delivery rates may be tolerated, dressings which are heavier than intended waste fertilizer and may be responsible for damage to germination; light dressings will not give maximum yields while irregular distribution will cause a patchy crop. Fertilizer coulters should be as narrow as possible to give minimum disturbance of the seed-bed, and to avoid bringing up wet soil and losing moisture from the seed-bed. It is not easy to place two bands of fertilizer near to the seed as two coulters disturb the seed-bed and may pick up clods and cause blockages. For the same reason the fertilizer coulter must be placed a reasonable distance in front of the seed coulter. Both seed and fertilizer coulters should be mounted in a rigid frame to minimize any distortion which would cause alterations in the relative positions of seed and fertilizer. The Suffolk type of coulter, with half open stem, developed by the National Institute of Agricultural Engineering for this investigation, is probably the best for English conditions. It causes little disturbance of the soil, and is immune to blockages on wet seed-beds. The shape of the coulter holds it in work without the need for a press or weights.

SUMMARY

Fertilizer placed in contact with the seed damaged the germination of sugar beet, mangolds, swedes and peas in 1947; damage was also caused by fertilizer placed directly below the seed. In 1947 and 1948 some damage to the germination of sugar beet was caused by fertilizer in bands 3 in. below the soil surface and 1 in. to the side of the seed; in both years bands of fertilizer 3 in. to the side of the seed were safe. Where placement of medium or full fertilizer dressings is adopted for row crops, the bands should be placed not less than 2 in. from the seed to avoid the risk of injury to germination.

All methods of placing gave consistently higher yields of peas than broadcasting fertilizer, the average advantage of placing being over 2 cwt. of peas per acre. In all the experiments on peas in 1948 early applications broadcast and worked deeply into the seed-bed were somewhat superior to late applications made at sowing time.

Yields of sugar beet were reduced by methods of applying fertilizer which reduced the plant population. There was little difference between the mean yields for all experiments given by broadcast fertilizer and fertilizer placed in safe positions near the seed. Placed fertilizer promoted much more vigorous growth of sugar-beet tops than broadcast fertilizer during spring and early summer, but by harvest time this superiority had vanished. Mangolds and sugar beet behaved in much the same way to placed fertilizer.

In experiments on swedes in 1947, average yields were very low, due to drought during the summer. Fertilizer placed either directly below, or below and to the side of, the seed gave consistently higher yields of swedes than broadcast fertilizer.

Placement of fertilizer is of considerable benefit to crops with a short growing season and limited root range, and also to crops made sensitive to nutrient deficiency by the poverty of the soil or the immobilization of nutrients by drought.

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