Plant and Soil VIII, no 3 March 1957

FERTILIZER PLACEMENT EXPERIMENTS

by J. PRUMMEL

Institute for Soil Fertility, Groningen, Netherlands

1. INTRODUCTION

Placed fertilizer is localized in bands by special distributing machines at some definite position in the soil close to the seed or seed potatoes. In some countries this method has been a common practice for a good many years, because the combination of sowing and fertilizing reduces labour costs. For example, in the United States, placement has been carried out extensively, particularly for crops grown in widely spaced rows such as maize, tobacco, cotton and potatoes. It was soon found that better yields could be obtained with placed compared with broadcast fertilizer, giving the additional advantage of saving fertilizer. During World War II placement was therefore introduced into England to restrict the use of fertilizers.

In the Netherlands the usual way of applying fertilizers is to broadcast them evenly over the surface after ploughing and before the seedbed is prepared. The fertilizers are mixed with the soil by cultivating of harrowing, so that they are localized in the upper layer of the soil (Roemer [14]). With this traditional method the plant roots do not make sufficient contact with the fertilizer particles, especially during dry periods. It is essential to apply the fertilizer below the surface into moist soil; a correct distribution in a vertical direction is therefore more important than in a horizontal direction (Torstensson [16]). Moreover, fertilizer supplements such as phosphate and potash quickly become fixed when mixed thoroughly throughout the soil and, consequently, there is a rather small uptake of nutrients when broadcast. As has been found elsewhere (Cooke [3]) our investigations show that placement gives marked advantages.

The present paper describes the results of field trials in the Netherlands. Goedewaagen [6] has already demonstrated a stimulation of branching and development of plant roots around placed fertilizer, often resulting in a total increase in the root system. De Wit [18] has recently developed a theory concerning fertilizer placement, based on experimental data, so as to gain an insight into the underlying principles; in this article his theories are tested against our results.

2. METHODS

The investigations have been carried out for several seasons on different kinds of crops and types of soil by our Institute, partly assisted by the Agricultural Advisory Service. A large number of the experiments deals with the comparison between placement and broadcasting of phosphate with oats, maize, pulse crops, potatoes and beets on soils varying in phosphate content and in phosphate fixation. The investigation with potash has been confined to potash-fixing river clay soils for spring wheat and potatoes. In addition, placement experiments with nitrogen have been tried on oats, potatoes and beets.

In most of the experiments the two methods of application were tested at three or four rates of fertilizer, in addition to controls. The fertilizers used were superphosphate, sulphate of potash, and nitrochalk.

Broadcast fertilizer was applied to the seedbed and harrowed in shallowly; placed fertilizer was localized by hand in grooves at a certain distance from the seed (tuber). Later the experiments of our Institute were carried out by a special machine, suitable for experimental work in combination with seed sowing.

This machine, built after English design [1], consists of a Saxonia sowing machine with 2–4 seed coulters (row distance 25–67 cm), mounted on a self-propelled 4-wheeled chassis. The engine is fitted behind the tractor driver. In front, two fertilizer cylinders are erected, each delivering to two coulters (Fig. 1). The cylindrical feeding units, working on a positive-displacement top-delivery principle, place a definite quantity of fertilizer in any desired position relative to the seed. For cereals, bands were placed 2 cm and for other crops, 5–7 cm to the side of the seed. In all cases the fertilizer was applied about 2 cm below the level of the seed, for crops grown in closely spaced rows (cereals and pulse crops) in a single band on only one side of the row (a single band is preferable from a practical standpoint), for crops in widely spaced rows (maize, potatoes and beets), in two bands on both sides of the row. The width of the band was 3–5 cm. Only granular fertilizers are suitable for accurate placement; powdered fertilizers become compacted partly through jolting and vibration from the machine and partly through the upward pressure of the piston and cause blockages in the freed tubes and coulters. It is possible to apply 48 different quantities of fertilizer by means of a gear box; the quantity from each tube is adjusted by scrapers. The machine works satisfactorily provided certain precautions are taken [1]. The variations in delivery rates are calculated by weighing the fertilizer delivered into collecting boxes

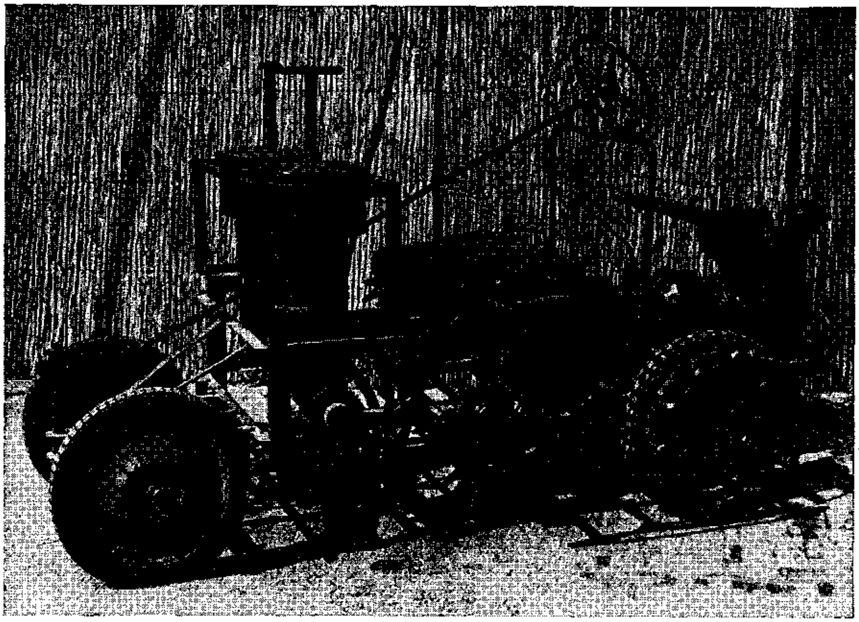


Fig. 1. Experimental fertilizer placement drill.

while travelling over a measured distance before and after the application of the fertilizer for each treatment. The coefficient of variation was 2.7%. In combination with the application of the fertilizer, the crop is sown in rows. Potatoes are afterwards hand-planted midway between the two fertilizer bands.

3. EXPERIMENTAL RESULTS

Since more than 100 experiments were carried out during 1948–1955 to compare placement with broadcasting, a detailed discussion of the results of all the experiments would be impracticable. We have therefore tried to establish for each field trial the difference between the effect of the two methods of application on the yield in terms of a comparative value. Before discussing these comparative figures, we shall give the results of some experiments to show the significance of the effect of placement.

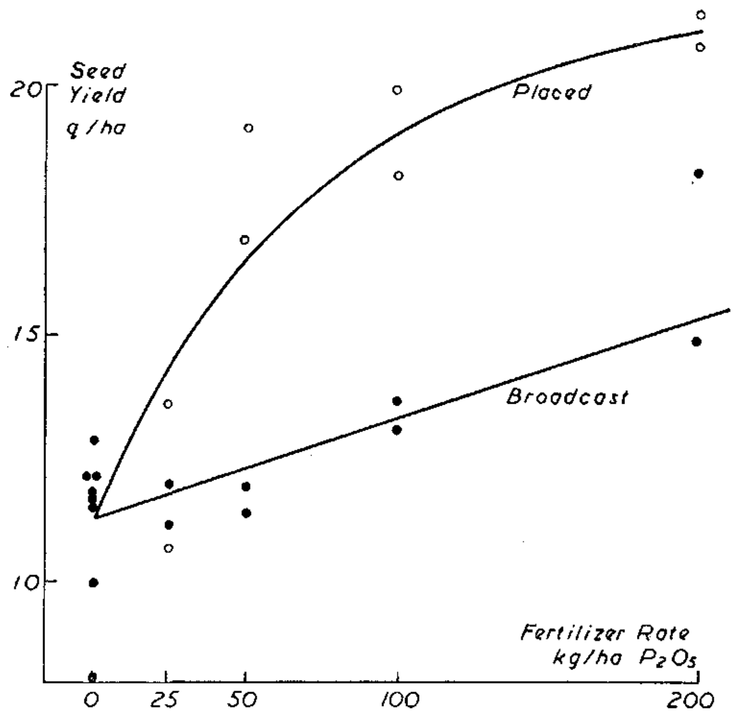


Fig. 2. Comparison between placement (○) and broadcasting (•) with phophate for beans on sandy soil (Exp. Pr 1146).

A very spectacular advantage of placement was found on soils deficient in phopshate, especially with pulse crops, maize and cereals For beans this is illustrated in Fig. 2, in which yields are plotted against the quantities of phosphate applied by placement and by broadcasting. Maize was markedly stimulated by placement of superphosphate; the crop grow more quickly, ripening was promoted and higher yields were obtained than with the broadcast dressing (Fig. 3). Fig. 4 presents the results of another of our experiments with maize. This trial was carried out to compare placement with broadcasting according to the phosphate content (P-citr value=

phosphoric acid soluble in 1% citric acid) of the soil. As a result of different dressings in previous years widely divergent phosphate contents were found. On the basis of these different phosphate conditions, both methods of application are compared at 30, 70 and 150 kg P_2O_5 as superphosphate per ha; there were also a number of control plots. The yield is considerably increased by phosphate dressing. A small quantity of merely 30 kg P_2O_5 per ha increases the yield even as much as a difference of 6 units P-citr on non-fertilized soil (6 units correspond with *ca* 260 kg. P_2O_5 per ha). The effect of phosphate placed in bands is even considerably better.

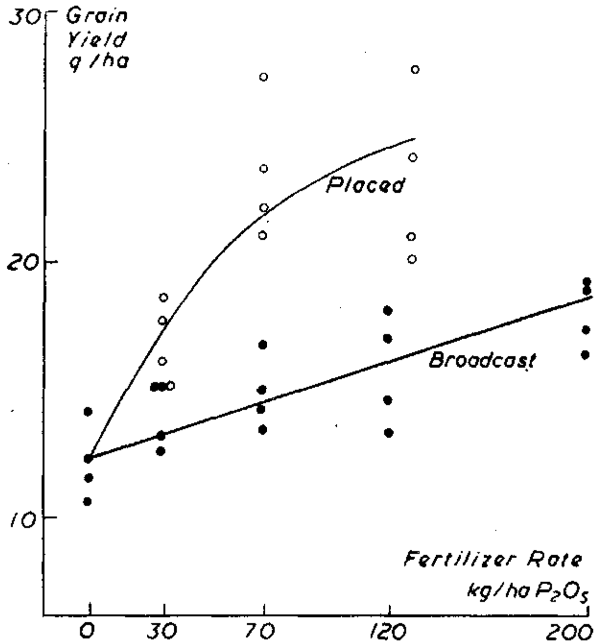


Fig. 3. Comparison between placement (o) and broadcasting (•) with phosphate for maize on sandy soil (Exp. Pr 1498).

Another example of the favourable effect of placement with superphosphate is given in Table I for oats. In this experiment placement was tested at different distances from the seed and at different depths. The result shows that deep placement (4 cm below the seed level) is more profitable than a shallow one and that a distance of about 4 cm in a horizontal direction gives the best results. Bands

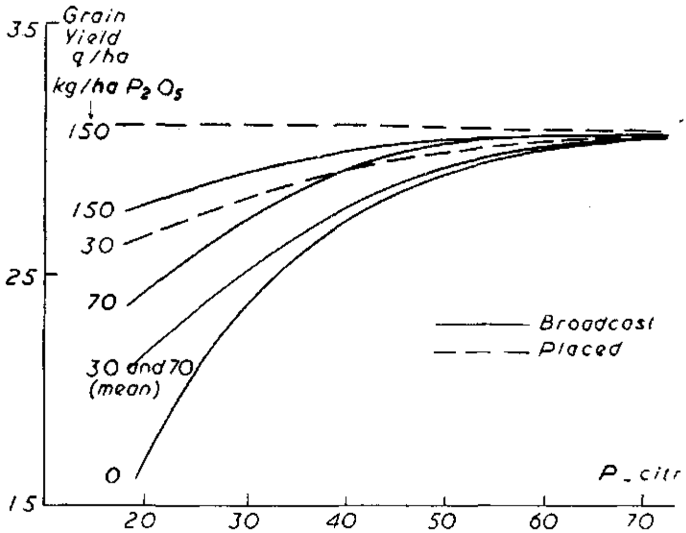


Fig. 4. Comparison between placement and broadcasting with phosphate for maize in dependence on P-citr on sandy soil (Exp. Pr 1482).

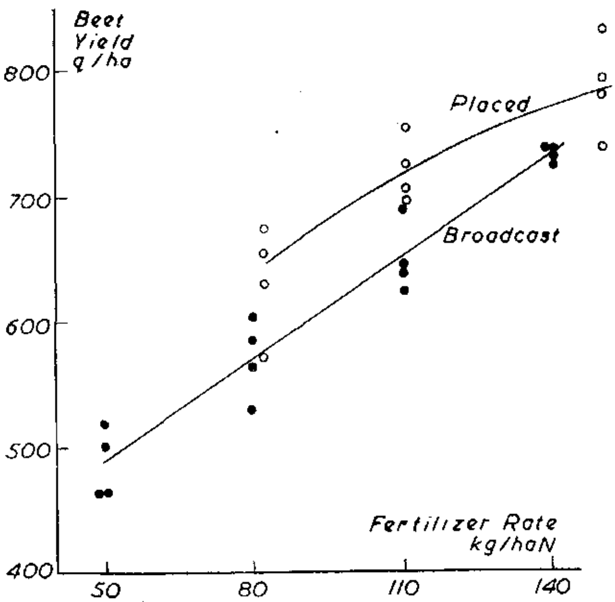


Fig. 5. Comparison between placement and broadcasting with nitrogen for beets on marine clay soil (Exp. Pr 1422).

placed at 8 cm from the seed are too far away and retard the early growth (Table II), the crop being unable to make up for this lag later on.

TABLE I

Yields of grain (oats) in q/ha on reclaimed heath soil (Exp. Pr 1052)

Method of application	Distance*, cm	Depth **, cm	P_2O_5, kg/ha 0	40	80	200
Broadcast			0	8.6	15.9	23.7
Placed -	4	0		10.0	16.3	14.9
	4	2		14.3	22.4	22.4
	4	4		19.1	20.9	23.4
Broadcast	8	0		10.5	14.4	19.2
	8	2		17.4	17.9	20.9
	8	4		18.9	16.2	21.9

* Distance of the fertilizer band from the seed.
** Depth of the fertilizer band below the seed.

TABLE II

Vigour score for oats on reclaimed heath soil on May 25 (Exp. Pr 1001)

Method of application	Distance +, cm	P_2O_5, kg/ha 0	25	50	100	200
Broadcast		1½	2½	5−	6	8+
Placed	2		6−	8−	7½	8−
	8		3½	4½	6	6

+ Distance of the fertilizer band from the seed.

TABLE III

Yields of grain (oats) in q/ha (Exp. Pr 1283)

Method of application	N, kg/ha 20	40	60	80
Broadcast	18.5	24.2	32.0	37.8
Placed	18.6	28.8	36.1	38.3

Similar advantageous results are obtained by placing sulphate of potash on river clay deficient in potash for spring wheat and potatoes. Yields given by a single dressing of sulphate of potash placed in bands were about equal to the yields given by double dressings of broadcast fertilizer. Placing nitrogenous fertilizer also shows a

TABLE IV*a*

Relative value of placement in comparison with broadcasting (= 1.00) for **nitrogen** fertilizers

Cereals			Potatoes			Beets		
Soil		Relative value	Soil		Relative value	Soil		Relative value
Exptl. field	Type		Exptl. field	Type		Exptl. field	Type	
Pr 1283	sandy	1.35	Pr 1199	marine clay	1.00	Pr 1421	sandy	1.15
Pr 1284	sandy	1.00	Pr 1419	sandy	1.25	Pr 1422	marine clay	1.25
Pr 1285	sandy	1.55	Pr 1420	marine clay	1.25	Pr 1487	sandy	1.25
Pr 1286	sandy	1.65	Pr 1486	sandy	1.15	Pr 1490	marine clay	1.15
Pr 1290E	marine clay	1.15	Pr 1489	marine clay	1.15			
Pr 1336	marine clay	1.35	Pr 1602	sandy	1.15			
Pr 1337	marine clay	1.25	Pr 1612	marine clay	1.00			
Pr 1338	sandy	1.25						
Pr 1367	sandy	1.00						
Pr 1413	sandy	1.55						
Pr 1414	sandy	1.00						
Pr 1415	marine clay	1.15						
Pr 1416	marine clay	1.25						
Pr 1485	marine clay	1.15						
Mean		1.25			1.15			1.20

TABLE IV*b*

Relative value of placement in comparison with broadcasting (= 1.00) for **phosphorus** fertilizer

Cereals				Potatoes				Beets				Maize					Pulse crops				
Soil			Rel. value	Soil			Rel. value	Soil			Rel. value	Soil			Relative value **)		Soil			Relative value **)	
Exptl. field	Type	P-citr. *)		Exptl. field	Type	P-citr. *)		Exptl. field	Type	P-citr. *)		Exptl. field	Type	P-citr. *)			Exptl. field	Type	P-citr. *)		
Pr 1001	reclaimed heath	9	1.65	Pr 1198	marine clay	21	1.00	Pr 1148	sandy	28	1.00	L 1337	sandy	11	1.00	(4.00)	Pr 1146	sandy	28	5.00	
Pr 1002	sandy	28	3.35	PO 409	ferrous sandy	26	1.65	WB 1893	marine clay	18	0.50	OB 3141	ferrous sandy	23	—††	(5.00)	Pr 1147	sandy	28	10.00	
Pr 1052	reclaimed heath	4	2.50	OB 3139	ferrous sandy	42	2.00	ZGr 1004	ferrous sandy	26	1.00	Pr 1423	sandy	18	2.20	(2.50)	ZGr 972	sandy	23	—††	(7.00)
Pr 1053	marine clay	15	2.50	WB 1890	river clay	14	0.50	OO 1502	ferrous sandy	12	1.65	Pr 1424	sandy	32	4.00	(5.00)					
Pr 1056	marine clay	20	5.00	Pr 1366	sandy	28	e† 4.00	ZGr 1148	ferrous sandy	10	2.00	NL 98	sandy	29	1.00	(2.00)					
Pr 1057	marine clay	29	4.00	Pr 1366	sandy	28	l† 1.55	NOB 492	river clay	10	1.00	Horst	sandy		—††	(5.00)					
Pr 1058	sandy	15	1.80	Pr 1425	marine clay	18	1.00					Pr 1498	sandy	23	5.00	(10.00)					
Pr 1064	ferrous sandy	7	1.80	ZGr 1000	ferrous sandy	7	2.00					Pr 1499	sandy	23	—††	(5.00)					
Pr 1065	loess	7	2.20	NL 99	ferrous sandy	29	2.50					OO 1504	sandy	44	1.65	(3.35)					
Pr 1066	loess	14	2.20	ZGe 889	river clay	9	1.00					MB 147	sandy	45	—††	(4.00)					
Pr 1067	loess	15	1.80	VPr 250	sandy limed	24	4.00					MB 148	sandy	17	—††	(4.00)					
Pr 1138	reclaimed heath	6	1.00	ZGr 1149	ferrous sandy	10	2.00					NL 200	sandy	20	5.00	(2.50)					
OB 3250	ferrous sandy	15	2.00									NL 220	sandy	20	2.50	(2.50)					
ZGr 1003	ferrous sandy	10	3.35									NOB 485	sandy	22	4.00	(2.00)					
Pr 1491	reclaimed heath	8	1.55																		
Mean			2.45				1.90				1.20				2.90	(4.05)				7.50	

* P-citr = soil-P soluble in 1% citric acid.
** In parentheses: relative value calculated from vigour scores.

† e = *lifted early*, l = *lifted late*.
†† Without phosphate response or not harvested.

TABLE IV*c*

Relative value of placement in comparison with broadcasting (= 100), for **potash** fertilizer

Cereals			Potatoes										Beets		
River clay soils		Rel. value	River clay soils, *low* pH				Rel. value	River clay soils, *high* pH				Rel. value	River clay soils		Rel. value
Exptl. field	K-HCl *)		Exptl. field	K-HCl *)	pH (KCl) **)	$CaCO_3$ content		Exptl. field	K-HCl *)	pH (KCl) **)	$CaCO_3$ content		Exptl. field	K-HCl *)	
Pr 1068	0.010	4.00	Pr 1209	0.012	5		0.50	Pr 1210	0.013	7.1	—	2.20	Pr 1488†	9††	1.00
Pr 1200	0.010		WB 1901	0.010	5.1		1.00	WB 1898	0.010	7.15	—	2.00	Pr 1608	0.011	1.00
Pr 1201	0.012	3.35	Pr 1341	0.009	5.3		1.00	WB 1899	0.010	7.4	9.6	1.00	Pr 1609	0.012	1.00
Pr 1203	0.013		U 862	0.013	4.85		0.50	Pr 1342	0.012	6.9	2.7	1.45	Pr 1610	0.016	1.00
			NOB 465	0.012	4.05		1.00	WB 1982	0.014	7.2	3.7	1.00			
			NOB 466	0.009	4.25		1.00	WB 1984	0.009	7.1	6.5	1.65			
			Pr 1604	0.011	4.6		1.00	WB 1985	0.011	7.05	6.8	1.65			
			Pr 1606	0.014	4.7		1.00	WB 2030	0.012	7.3	7	2.20			
			VPr 250	0.011	5.25	0.1	2.00	WB 2031	0.010	7.6	13	1.55			
								WB 2032	0.019	7.6	11	2.20			
								Pr 1428	0.013	7.55	0.7	1.00			
								WB 2170	0.010	7.25	7	1.25			
								Pr 1607	0.014	7.0	—	1.00			
								VPr 250	0.012	6.75	1.2	2.00			
								WB 2273	0.012	7.25	5	1.55			
Mean		3.65					1.00					1.60			1.00

* K-HCl = soil potash soluble in 0.1 *N* HCl.
** pH(KCl) = pH measured in 1 *N* KCl.
† sandy soil.
†† K-number = soil potash soluble in 0.1 *N* HCl related to the soil humus content.

marked effect, though less than that of phosphate and potash fertilizers (Table III for oats and Fig. 5 for beets).

Placement of nitrogenous fertilizer prolongs the period of growth of potatoes and beets compared with broadcast manuring (see Plate I); in regions with a long and mild autumn the resulting increased assimilation period can significantly increase the yield.

If nitrogenous fertilizer at high rates is placed too near the seed (at a distance less than 2 cm for cereals and 5 cm for beets) germination is adversely affected on sandy soils because of the excessively high concentration. Heavy dressings of nitrogen (200 kg N per ha) in bands can also retard the early growth of potatoes; later, however, the crop grows more quickly than with broadcast fertilizer. In contrast, placing phosphate and potash fertilizers never caused any injury to the crops in our field trials. Preliminary pot experiments showed that the germination of the crop was severely injured when the fertilizer was drilled in contact with or directly below the seed, especially when highly soluble fertilizers (nitrochalk and sulphate of potash) were used on pulse crops and beets. For cereals, bands placed 2 cm and for other crops, 5–7 cm to the side of the seed, were safe in avoiding injury.

A summary of the results of all experiments is given in the Tables IV*a* , *b* and *c*, for nitrogen, phosphate, and potash respectively. In these tables comparative values are presented, being the ratio between the amounts of fertilizer required to give the same yield for broadcasting and placement. If, in the case of placement for example, a dressing of g kg of fertilizer per ha gives the same yield as a $5/2g$ kg per ha by broadcasting, then the value for placement in comparison with broadcasting is 2.5, which means that placement gives a saving of 60% on the fertilizer. In such a case the relation between yield y and rate of fertilizer x may be represented by $y=f(ax)$ for placement, when this relation is $y = f(x)$ for broadcasting. Therefore if in one graph, the yields for placement are plotted against the fertilizer dressings and the yields for broadcasting are plotted against the fertilizer dressings divided by a, the two arrays of points will determine the same curve $y = f(x)$. The correctness of the assumption that the curve $y = f(x)$ for broadcasting and $y = f(ax)$ for placement are the same, will be considered later on.

The transformation of the abscissa of the curve for broadcasting is carried out as follows. The yields for broadcasting are plotted against the fertilizer dressings on a glass plate. This array of points is projected vertically by parallel light(sunlight) onto an underlying graph representing the relation between yield and rate of fertilizer by placement. By rotating the glass plate about the ordinate (fertilizer dressing zero) the projected points are adjusted to coincide with the array of points on the placement graph (projective transformation).

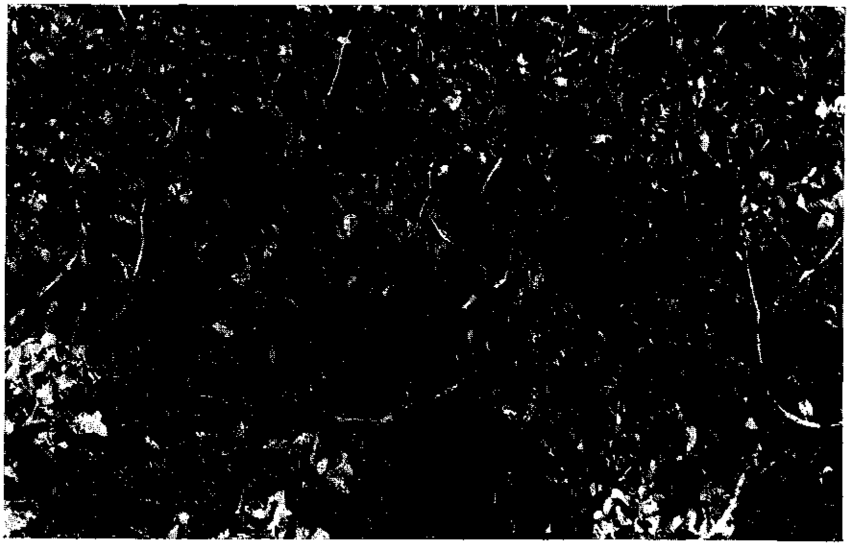
Tables IV*a*, *b* and *c* show that the value of placement in comparison with broadcasting depends in the first place upon the nature of the plant nutrient. For nitrogen application, this value (as a mean of all experiments) was found to be 1.20 for cereals, potatoes and beets. In the case of phosphate it was 7.50 for pulse crops, 2.90 for maize, 2.45 for cereals, 1.90 for potatoes, and 1.20 for beets, whilst in the case of potash on river clay it was 3.65 for cereals, 1.00 for potatoes at low pH and 1.60 at high pH, and 1.00 for beets *.

These figures show clearly that applying nitrogenous fertilizer in bands is more effective than broadcasting; phosphorus and potassium fertilizers sometimes give even more spectacular results when placed in the same way near the seed. This may be attributed to the rather small uptake of phosphate and potash when broadcast as a result of fixation; a localized concentration of fertilizer reduces fixation to a minimum and will therefore have a favourable influence on uptake.

The effect of placed superphosphate is greatest with pulse crops, followed by cereals and maize with a somewhat lower advantage. Placement of phosphate for potatoes and particularly for beets is less profitable. The effect of placed sulphate of potash is again less for potatoes than for cereals, whilst for beets placement has no advantage whatever. Cooke [3] relates these differences in the effect of placement for different crops to the nature of the root system. In his opinion placement is of particular value for rapidly growing crops with a limited root range (cereals and pulse crops); crops with an extensive root system (potatoes and beets) utilise nutrients more efficiently in the soil between the rows and show smaller benefits from a localized concentration of fertilizers. An investigation by van der Paauw [11] demonstrates the different behaviour of oats and potatoes with respect to an uneven distribution of fertilizer. Oats withdraw nutrients locally because of their relatively small root system; thus a distance of 8 cm from the plant to the fertilizer is an appreciable barrier. In contrast, potatoes with a well

* These figures differ slightly from those given in a previous paper [13], because somewhat more data are now available, and the treatment of the results of some experiments has improved.

A



B

Plate I. Influence of placement of nitrogen on dying off of potatoes (Pr 1489, marine clay soil). **A**: 110 kg N per ha, placed. **B**: the same amount, broadcast.

developed lateral root system can take up nutrients situated further away and are therefore not hindered by an uneven distribution of fertilizer. Our investigations confirm the interpretations of Cooke with the exception of the results with maize. This crop has an extensive root system, yet placing superphosphate proved much better than broadcasting. It is well-known that in the early stages of growth maize can suffer severely from phosphate deficiency. Although some of the first formed roots grow in a more or less horizontal direction, they may not quite reach the broadcast fertilizer when shallowly incorporated; the nodal roots generally grow deeply and are unable to take full advantage of the fertilizer when broadcast.

Our experiments with potatoes showed a better effect of placement of superphosphate only on iron-rich soils. An experiment on a sandy soil (VPr 250, see Table IV*b*) also indicated that placement is of particular value when the availability of soil phosphate is low; in this experiment the phosphate nutrition was originally fair but was markedly decreased by liming, as indicated by the P-water value (van der Paauw [12]). This deficiency in phosphate resulted in a markedly decreased yield and a phosphate dressing increased the yield considerably, particularly in the case of placement.

There are indications that the advantage of placement of sulphate of potash for potatoes on river clay is greater at a high than at a low pH; it is known that the availability of potash for this crop is extremely low at high pH (Ferrari [4]). No advantage of placement over broadcasting was found with potash for beets, either on a non-fixing sandy soil or on a river clay soil deficient in potash.

To test the hypothesis H_0, that, if the relation between yield y and fertilizer dressing x for broadcasting is $y = f(x)$, this relation is $y = f(ax)$ for placement, with constant a for a given experiment, the method of m-rankings of Friedman was used (see Kendall [9]).

Per experiment the abscissa for broadcasting was transformed and a common curve was constructed through the resulting arrays of points for both methods of application. The deviations of the mean yield per dressing from this common curve were determined (with the proper sign). These deviations were ranked per experiment separately for broadcasting and for placement, and the ranks per dressing were added up over all experiments. From the rank sums the coefficient of concordance W was calculated in the ordinary way and tested for significant difference from zero (Table V), column "common curve", row *a* and *b*). No distinction is made between crops because the numbers of field trials for the different crops were too small for individual testing, and there is no reason to suppose that the crops should behave differently in this respect. The experiments with potash have been added to those with phosphate, again owing to the small number of experiments. The experiments with 3 and with 4 fertilizer levels have been kept separate.

TABLE V

Levels of significance p of the rankings for the common curve and for the placement curve

Deviations	Nitrogen				Phosphate and potash			
	Common curve		Curve for placement		Common curve		Curve for placement	
	3*	4*	3	4	3	4	3	4
a. Broadcast-yield minus curve	0.60	0.31	0.54	0.38	0.53	0.32	0.58	0.32
b. Placement-yield minus curve	0.02	0.38	0.11	0.44	0.35	0.48	0.48	0.66
c. Broadcast-yield minus curve and curve minus placement-yield	0.10	0.60	0.11	0.66	0.26	0.79	0.36	0.97
Number of data	19	20	19	20	27	31	27	31

* Number of fertilizer levels.

If the hypothesis H_0 is not true, the mean yields for some or all levels of dressing of one or both methods of application will deviate systematically from the mean curve and so the rankings of the deviates will not be random permutations, *i.e.* the coefficient of concordance will show a significant difference from zero. From Table V the column for "common curve" shows, that only in the case of nitrogen the means for placement indicate that there are not quite random deviations from the common curve.

As the common curve was drawn through the array of points for both broadcasting and placement, systematic deviations may be expected not to be very large. Therefore the same calculations were made for deviations from the curve drawn only through the array of points for placement. Of course the means for placement gave not-significant values of W, indicating only that the curves were really drawn through the points; but the means for broadcasting gave also not-significant values of W (Table V, column "curve for placement", row *a* and *b*). This result renders our hypothesis more evident, because in this test the position of the treatment means for broadcasting is examined by means of a curve which is entirely independent of the array of points for broadcasting.

To strengthen these two results and to discover especially if the curves for broadcasting and for placement both crossed the common curve, the rankings for broadcasting were calculated for the deviations "mean yield minus yield according to curve" and those for placement for the deviations "yield according to curve minus mean yield"; these $2n$ rankings (for n experiments) per level of dressing were afterwards added and from these sums the coefficients of concordance was calculated. Here again no significant values of W were found (Table V, row c).

As the coefficient of concordance W was just significant different from zero only in one out of 24 (although not quite independent) cases, the assumption that the effect of g kg of a fertilizer per ha if placed is aequivalent to ag kg per ha if broadcast, whatever the value of g, would therefore appear valid. The general form of the yield curves can thus be described as follows: broadcasting and placement give the same maximum yield, which, in the case of placement however, is attained at a lower level of fertilizer.

4. THEORETICAL CONCEPTS OF PLACEMENT BY DE WIT

The conclusion at the end of the preceding section required a critical consideration of the theory of de Wit[18]. According to this theory the determination of a constant ratio between the effect of the two methods of application for the whole fertilizer dressing—yield curve, as made by us, would not be possible.

De Wit has tried to gain an insight into the underlying principles, in order to predict the effect of placement under definite conditions; he considers the uptake of nutrients as the main factor, since in general, the yield is determined by this. The theory may be summed up as follows.

If x_b is the distance between the crop rows and M_b the amount of broadcast fertilizer in kg per ha, the uptake in this case is compared with that for placement at a level of $\frac{x_r}{x_b} \times M_b$ kg/ha, were x_r is the width of the fertilizer band.

In this comparison the concentration of fertilizer per unit area of fertilized soil is the same for the two methods of application, hence the reaction between soil and fertilizer is also the same. Therefore the uptake for the two methods of application can only be compared from the time when the roots have developed over the whole area; the ratio between the amounts of roots in the fertilized soil should then agree theoretically with the ratio in volume of fertilized soil exploited.

There is, however, an important difference in uptake, owing to the fact that with placement a smaller part of the root system is in contact with fertilized soil. Goedewaagen [6] pointed out that it is not necessary for the fertilizer to be in contact with all the roots; it is sufficient that the requisite quantity of plant nutrients is available to part of the root system. A compensation of uptake will then occur, resulting in an increasing uptake in the bands per unit area of roots (physiological compensation). Furthermore this process is often augmented by a more vigorous root development in the bands (morphological compensation). De Wit has applied this phenomenon of compensation in the elaboration of his theory.

In Fig. 6 * the curve C represents the relation between the ratio of the fertilized area (x_r/x_b) and the ratio of uptake (U_r/U_b) for the two methods of application, when the concentration in the fertilized soil is the same. De Wit has computed this relation from experiments (pot and field trials) encountered in the literature.

Designating the uptake, when M_b kg fertilizer per ha is broadcast, by U_b kg per ha, it is found that as a result of compensation the uptake is 0.75 U_b if 0.5 M_b is placed in bands with a width equal to half the row distance ($x_r/x_b = 0.5$). Starting from the rate—uptake curve for broadcasting, the curve for placement can be constructed by multiplying the uptake for broadcasting by 0.75 (Fig. 7). This assumes that the uptake ratio between the two methods of application is independent of the concentration of the fertilizer.

It is characteristic of Fig. 7 that the uptake curve for placement intersects that for broadcasting, so that the uptake in the case of placement at low fertilizer levels is more, but at high fertilizer levels is less than that for broadcasting. The point of intersection shifts to lower rates as the band width is decreased.

From the uptake curves (known for broadcasting from experience

* The Figures 6—8 have been taken from the publication of De Wit [18].

and calculated for placement by means of the compensation function in dependence on the band width) and the relation between uptake and yield, the rate—yield curve for placement can be calculated. The uptake—yield relation is usually independent of the method of application, exept in the case of antagonistic effects: if

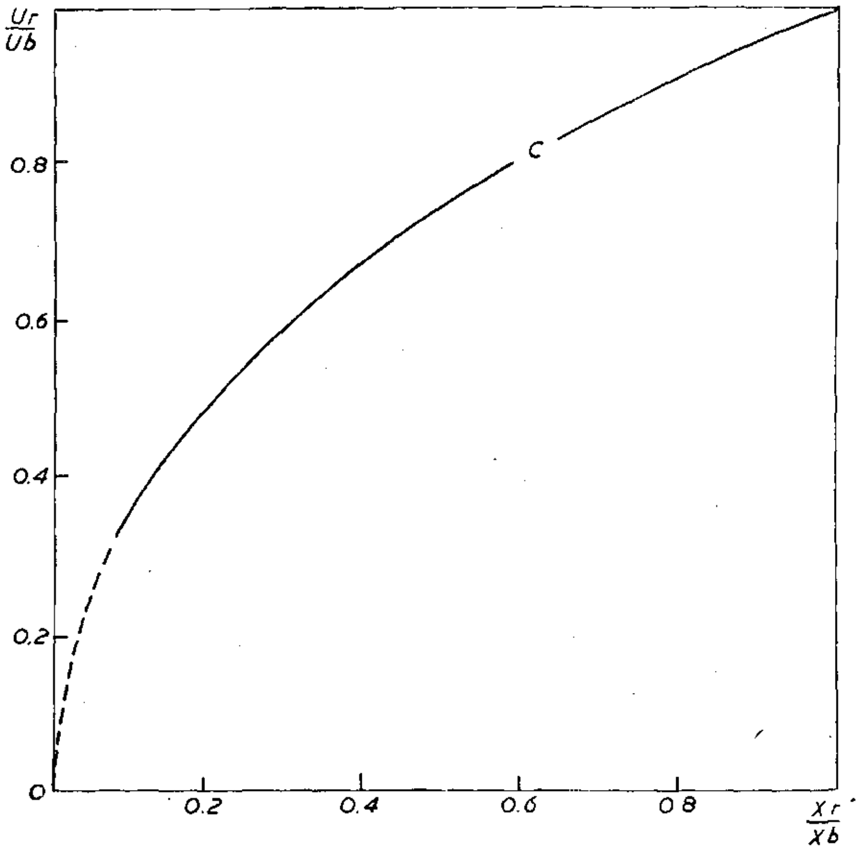


Fig. 6. Relation between the ratio of fertilized area (x_r/x_b) and the ratio of uptake (U_r/U_b) for placement and broadcasting according to de Wit[18].

application of the fertilizer decreases the availability of some other nutrient, the effect, according to de Wit, is less serious when the fertilizer is placed than when it is broadcast. Thus the yield corresponding to a certain quantity of the fertilizer nutrient absorbed by the plant, will be greater with placement than with broadcasting.

The reverse situation is also possible. Fig. 8 represents the four possibilities, according to de Wit.

An important conclusion from this theory is that higher returns can be obtained by placing light dressings in narrow bands, but that heavy dressings in narrow bands produce lower yields than broadcasting; therefore the width of the fertilizer band should not be too narrow.

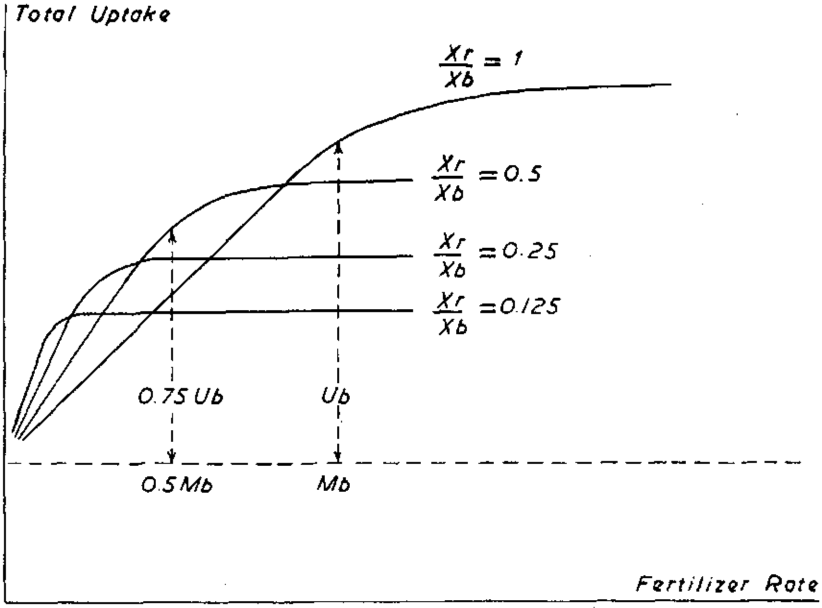


Fig. 7. Relation between fertilizer rate and uptake for placement and broadcasting in dependence on the width of the fertilizer band according to de Wit [17].

5. TESTING THE THEORY OF DE WIT AGAINST THE RESULTS OF OUR EXPERIMENTS

We now return to our own investigations. It is clear that according to de Wit a transformation of the abscissa of the curve for broadcasting as done by us will not be admissible because, in 3 out of the 4 possible cases as shown in Fig. 8, the two curves are of different shape. After transformation the treatment means would be situated systematically about the common curve. In Section 3 however it has been shown that the curves may be considered as similar. Only Fig. 8, 1a (2nd quadrant) provides a correct representation.

In giving a definite judgement on the theory of de Wit, the presence of the point of intersection between the rate—uptake curves for placement and for broadcasting (Fig. 7) is decisive. This intersection is characteristic of all the examples given in Fig. 8 and would occur, if the supposition that the compensation is independent of the concentration should be correct.

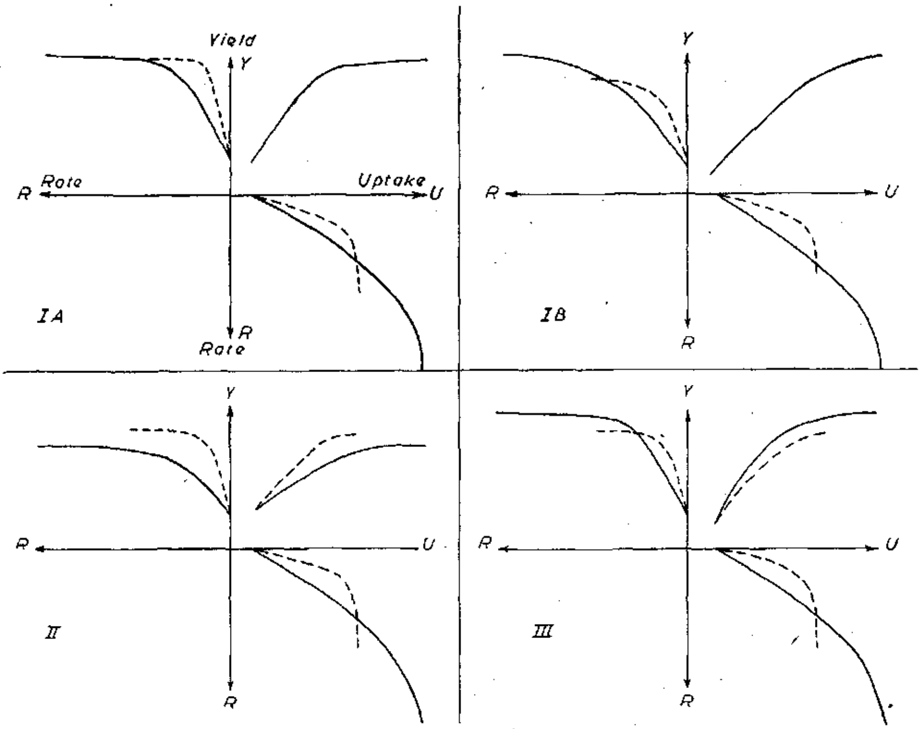


Fig. 8. Relation between fertilizer rate (R), uptake (U) and yield (Y) for placement and broadcasting according to de Wit [18]. Cases IA and IB without, cases II and III with antagonistic reaction (—— broadcasting, - - - - - placement).

This intersection, however, has seldom been found in our experiments, although the fertilizer band in our experiments is narrower than that with which de Wit has worked in developing his theory ($^1/_5$—$^1/_8$ the distance between the crop rows in our experiments and

$^1/_4$ in the case of de Wit), so that it would certainly have been expected, if the suppositions of de Wit are valid.

So as to be quite definite about this point, the observations themselves have been used in the sign test. This test is carried out for the experiments with both phosphate and potash. The experiments with nitrogen are omitted because there were rather a large number of cases in which the two rate—uptake curves were linear; in this case the result would turn out too favourably for our claim that there is no point of intersection. For each fertilizer dressing the number of cases in which the uptake for placement exceeds that for broadcasting is determined. With increasing fertilizer dressings this, as a percentage of the total number of cases, turns out to be 82, 75, 71 and 56 (number of cases 27, 28, 24 and 25, respectively). The lower confidence limits (one-sided symmetrical, $p = 0.95$) are 64, 57, 51 and 38%, respectively.

Generally speaking the uptake for placement exceeds that for broadcasting. According to the above lower confidence limits an intersection, if any, would occur above the third * level of fertilizer dressing (except for a probability of 5% **). De Wit's conclusion concerning the minimum width of the fertilizer band (about one-fourth of the distance between the crop rows), based on the presence of this intersection at a normal fertilizer dressing, has therefore to be rejected in practice.

It is possible that compensation increases with the concentration, so that the maximum uptakes obtainable from placement and broadcasting are the same. The experimental foundation of the theory of de Wit should be strengthened by an inquiry into the dependence between compensation and concentration.

It is also possible that a comparison between uptakes for the two methods of application in field trials as made by de Wit is inadmissible. Broadcast fertilizer will be localized shallowly in rather dry soil. In this case the uptake will fall behind that with placement where the fertilizer lies deeper. In this connection a study of the

* In our experiments this fertilizer rate varied from 80–140 kg P_2O_5 or K_2O per ha (in the case of potash for root crops, to 200 kg K_2O per ha), respectively.

** Our conclusion as to the situation of the point of intersection could be drawn with satisfactory reliability by using the simple, though not very powerful sign test, which only distinguishes between high and low uptakes. A check by a more powerful test is unnecessary for this reason.

influence of depth of application and the moisture status of the soil on uptake is desirable.

Another objection is that the significance of the uptake during early growth, before the roots have developed under the entire soil surface, may have been underestimated by de Wit. He assumes that the yield is closely related to the total quantity of plant nutrients taken up; this implies that the nutrient contents are the same when a kg fertilizer per ha applied by placement gives a yield as high as b kg fertilizer per ha applied by broadcasting ($a < b$). However, chemical analysis of the crop in this case showed lower nutrient contents with lower level of fertilizer applied in bands. Therefore an equal yield is obtained with a smaller quantity of the fertilizer nutrient absorbed by the plant; this would suggest that the intensity of uptake as related to time is important. It is known that the growth of a crop benefits particularly from manuring in the early stages when the later observed differences in yield already mainly have been predetermined [2 7]. It is therefore presumed that in the case of placement, the crop, which, from the very beginning, is able to utilize the total quantity of fertilizer applied, obtains a start which initially determines the differences in yield. In the case of broadcasting however, some of the fertilizer is initially out of reach of the roots; later, when the roots permeate the whole space between the crop rows, more plant nutrients can then be taken up. In the case of equal yield this can give rise to a higher nutrient content in the plant compared with placement. Therefore a similar uptake of plant nutrients is not a condition for equal yields. Experiments with radioactive isotopes clearly show this fundamental difference in uptake between the two methods of application [5 8 10 15 17].

When such a difference does occur, de Wit assumes that in the case of placement, this is the result of a decreased antagonistic effect on some other plant nutrient resulting in a higher yield. We, however, are not satisfied by this conception as an explanation for the significant differences in yield, *e.g.* in the case of phosphate.

The ratio between the amounts of roots exploiting the fertilized soil at the critical moment when the roots have not developed completely under the entire soil surface, is not equal to the ratio between the width of the fertilizer band and the distance between the crop rows. A comparison between total uptakes at the same concentration from the time when the roots penetrate the whole distance between the crop rows, is doubtful, because the influence of the time of uptake is left out of consideration. The importance of the ratio between the fertilized area of the soil and the compensation factor therefore becomes smaller.

SUMMARY

The results are given of an investigation in the Netherlands, made over a number of years, on placement of fertilizers. This new method of application has been tested in field trials, in which placement has been compared with the usual method of broadcasting at certain increasing levels of fertilizer. The experiments relate to nitrogen, phosphate and potash on different kinds of crops and soils.

Generally speaking, it would appear that placement is better than broadcasting. The difference between the two methods of application can be represented by a factor indicating the ratio between the amounts of fertilizer giving the same yield for both. Nitrogen applied in bands is about 1.20 times as effective as broadcasting for cereals, potatoes and beets; phosphate for pulse crops 7.50, for maize 2.90, for cereals 2.45, for potatoes 1.90 and for beets 1.20; potash on river clay for cereals 3.65, for potatoes 1.00 at low pH and 1.60 at high pH and for beets 1.00. There are indications that the prevention of fixation and a better early growth as a result of the localisation of the fertilizer near the seed at an adequate depth are reasons why placement is successful.

The conclusions of de Wit with regard to the effect of placement are not corroborated. It appears that placement gives higher yields at light dressings, and at heavy dressings yields as high as broadcasting, whereas, according to de Wit, a favourable effect would be attained, as a rule, with light dressings and an unfavourable effect with heavy dressings.

ACKNOWLEDGMENTS

The author is much indebted to Messrs. J. T. N. Venekamp (Institute for Soil Fertility), J. C. A. Zaat and E. F. Drion (Statistics Department T.N.O.) for their very helpful assistance with the mathematical treatment of the results.

Acknowledgement is also made to the Agricultural Advisory Service for the opportunity to use the results of their experiments.

Received May 24, 1956.

LITERATURE

1 Anonymous, Agr. Eng. Records **1**, 171–172, 240–244 (1945/1947).

2 Brenchley, W. E., The phosphate requirement of barley at different periods of growth. Ann. Botany **43**, 89–110 (1929).

3 Cooke, G. W., Recent advances in fertilizer placement II. Fertilizer placement in England. J. Sci. Food Agr. **5**, 429–440 (1954).

4 Ferrari, Th. J., An agronomic research with potatoes on the river ridge soils of the Bommelerwaard (Du. with Eng. summary). Verslag. Landbouwkund. Onderzoek. **58**.1 (1952).

5 Garderen, J. van, Walt, C. F. J. van der, and Stein, L. H., Radioactive phosphorus in a field study on phosphorus uptake by maize. S. African J. Sci. **48**, 226–231 (1952).

6 Goedewaagen, M. A. J., Het wortelstelsel der landbouwgewassen. Edited by Dir. van de Landbouw, The Hague (1942).

7 Jones, L. G. and Warren, G. E., The efficiency of various methods of application of phosphorus for tomatoes. Proc. Am. Soc. Hort. Sci. **63**, 309–319 (1954).

8 Jordan, J., Simkins, C., Corey, G., Knight, R., and Baker, C. O., Uptake and movement of fertilizer phosphorus. Soil Sci. **73**, 305–313 (1952).

9 Kendall, M. C., Rank Correlation Methods. Charles Griffin and Company Lim., London (1946).

10 Nelson, W. L., Krantz, B. A., Welch, C. D. and Hall, N. S., Utilization of phosphorus as affected by placement: II. Cotton and corn in North Carolina. Soil Sci. **68**, 137–144 (1949).

11 Paauw, F. van der, Die Bedeutung einer gleichmäszigen Verteilung der Kunstdünger (Du. with Germ. summary). Verslag. Landbouwkund. Onderzoek. **46** (10) A (1940).

12 Paauw, F. van der, Relation between the lime status and the availability of phosphate on a sandy soil (Du. with Eng. summary).Verslag. Landbouwkund. Onderzoek. **56**.8 (1950).

13 Prummel, J., Placement of fertilizers. Trans. Sixth. Intern. Congr. Soil Sci. Paris 1956 **IV**, 167–171 (1956).

14 Roemer, Th., Die Verteilung der Düngemittel im Boden. Ernähr. Pflanze **30**, 203 (1934).

15 Scharrer, R. and Kühn, H., Studien über die Aufnahme der Phosphorsäure aus markiertem Superphosphat. Landwirtsch. Forschung **7**, 163–169 1955.

16 Torstensson, G., Ein Beitrag zur Frage der Verteilung der Düngerphosphorsäure im Ackerboden bei verschiedener Art der Aufbringung. Lantbrukshögsk. Ann. **4** (1937).

17 Welch, C. D., Hall, N. S. and Nelson, W. L., Utilization of fertilizer and soil phosphorus by soybeans. Soil Sci. Soc. Amer. Proc. 1949, **14**, 231–235 (1950).

18 Wit, C. T. de, A physical theory on placement of fertilizers. Verslag. Landbouwkund. Onderzoek. **59**.4 (1953).