THE FERTILISER SOCIETY

Investigations on the Agricultural Value of Nitrophosphate and Anhydrous Ammonia

by
E. G. MULDER, Ph.D.

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INTRODUCTION

THE PRESIDENT (Mr. J. Angus) introduced Dr. Mulder, agronomist of the Dutch nitrogen fertiliser industry, attached to the Agricultural Experimental Station at Groningen. Dr. Mulder, in addition to being a farmer, was, he said, a plant physiologist and a biochemist. He was the excutive editor of " Plant and Soil " and has read papers at many important Conferences including the International Union of Biological Sciences in 1947, International Grassland Congress in 1949 and the International Congress of Soil Science in 1950.

INVESTIGATIONS ON THE AGRICULTURAL VALUE OF NITROPHOSPHATE AND ANHYDROUS AMMONIA

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Experiments with Nitrophosphate

INTRODUCTION

Investigations on the availability of phosphorus in nitrophosphates have been carried out by the author for more than ten years. The N-P fertilisers used in these experiments have been made by the Dutch State Mines by dissolving phosphate rock in 50% nitric acid. The calcium nitrate precipitated upon cooling this solution is separated whereupon the solution is neutralised by ammonia. The mixture of NH_4NO_3, $CaHPO_4$ and some $NH_4H_2PO_4$ is brought to crystallisation and granulated. By removing more calcium nitrate, products with a higher amount of $NH_4H_2PO_4$ can be obtained. For a more thorough discussion of the principles underlying the preparation of nitrophosphates, the reader may be referred to the paper read by Dr. M. H. R. J. Plusjé of the Dutch State Mines for this Society in 1951 (8), see also Rogers (9).

In the agricultural investigations fertilisers with approximately 10% of their total phosphorus in a water-soluble form ($NH_4H_2PO_4$) were mostly used. In some cases products were tested in which 25 or 50% of the total phosphorus was water-soluble. These nitrophosphates have been designated as fas 10, fas 25 and fas 50 respectively. Since the granule size of dicalcium phosphate-containing fertilisers has been found by van der Paauw (7) to be of great importance for the P-effect in soil, a number of experiments has been carried out in which products of different granule size were used.

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METHODS

The agricultural value of nitrophosphates was tested in pot and field experiments. The soils used in these experiments in general were poor in available phosphorus so that a clear response to the added phosphatic fertilisers was obtained. In the pot experiments oats and in some cases rye were employed as the test plants. The field trials were laid out on arable land as well as on permanent grassland. Potato was mostly the test plant in the former case but sugar beet and cereals were also used.

The design according to which the phosphorus effect was studied consisted of comparing increasing amounts of the nitrophosphates with corresponding amounts of phosphorus in the form of superphosphate, basic slag or dicalcium phosphate. The nitrogen dressing in these experiments was brought up with ammonium nitrate to the nitrogen level of the highest nitrophosphate dose. The fertilisers were applied in early spring.

A second type of field trial had a somewhat different design. It depended on the principle that the P-requirement of a certain crop is higher when its yield is higher, i.e., when more nitrogen has been applied. Since in nitrophosphate the phosphorus supply increases in proportion to the nitrogen dose, it would be of interest to know whether on phosphorus-deficient soils the P-requirement of a crop could be covered by supplying nitrophosphate. In this type of experiment increasing amounts of nitrophosphate were compared with increasing amounts of ammonium nitrate-limestone with and without ample supplies of superphosphate.

In the pot experiments the phosphates were mixed carefully through the moist soil. Care was taken that the granules were not affected by this treatment. In the field experiments the P-fertilisers were applied on top of the soil. The superphosphate used in general was in the granulated form.

For the evaluation of the P-effect of nitrophosphate, the latter was expressed as percentage of the P-effect of superphosphate. For this calculation the amount of nitrophosphate giving yields equal to those of half-optimal amounts of superphosphate was ascertained.

Since it is a good practice of many Dutch farmers to maintain the phosphorus content of their soils at such a level that the entire phosphorus requirement of the crops can be derived from soil phosphate, knowledge of the residual P-effect of nitrophosphate is as important as that of their direct P-effect. Therefore the residual effects of the different phosphatic fertilisers were ascertained in the second year after their application by dressing the plants with ammonium nitrate and a potassium salt only. In the case of grassland the residual effect was determined in more than one cutting.

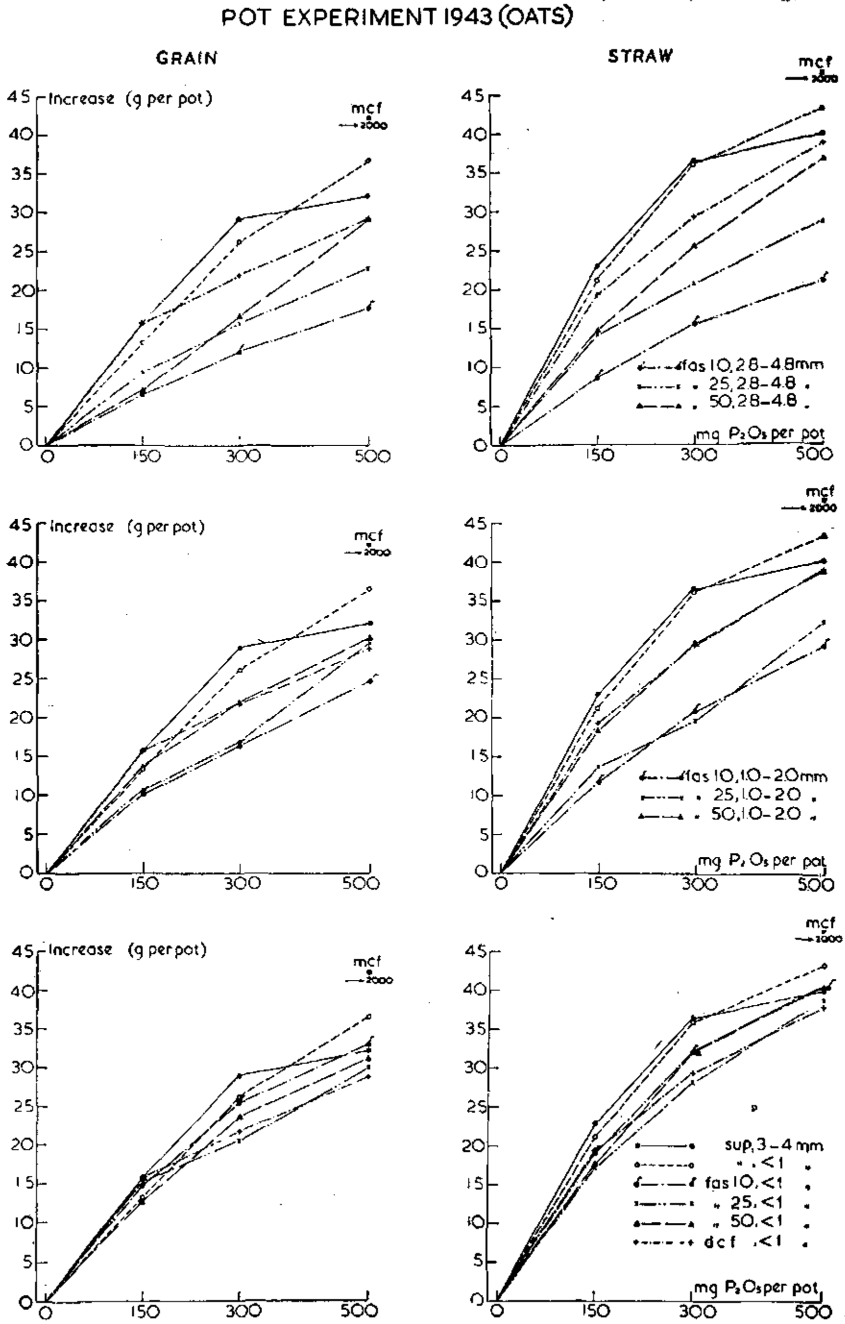


FIG. 1. *Effect of content of water-soluble phosphate and size of granules of nitrophosphate on availability of its phosphate.*

Experimental

1. *Effect of content of water-soluble phosphate and granule size of nitrophosphate on its P-effect.*

(a.) *Pot experiment with oats,* 1943. The sandy soil used in this experiment had an organic matter content of 5.4%, a pH value of 5.2, a K-value of 15 (mg. of exchangeable K_2O per 10 g. of organic matter), a P-content (water) of 0, a P-content (citric acid) of 10 (mg. of P_2O_5 per 100 g. of soil). These analytical results demonstrate that the soil was very poor in plant-available phosphorus.

Mitscherlich pots containing approximately 5 kg. of soil were used. The basic dressing applied was as follows: K_2SO_4 1.8 g., $CaSO_4.2H_2O$ 0.5 g. (added to the pots with the lowest P-dose and to those without P-manuring only), $CuSO_4.5H_2O$ 0.1 g. The nitrogen of all pots was brought up to the level of 800 mg. of N per pot with ammonium nitrate.

Phosphorus was applied in amounts of 150, 300 and 500 mg. of P_2O_5 per pot in the form of fas 10, fas 25 and fas 50 (i.e., nitrophosphates with 10, 25 and 50% respectively of their total phosphate in a water-soluble form), as superphosphate (sup) and as dicalcium phosphate (dcf). Each nitrophosphate was applied in granules of 2.8-4.8, 1.0-2.0 and < 1 mm. respectively. Superphosphate was added in two types: 3-4 and < 1 mm., while dicalcium phosphate was given as the powder only.

The results of this experiment have been plotted in Fig. 1. It will be seen that both the content of water-soluble phosphate and granule size of the nitrophosphates have had a pronounced effect on the availability of the phosphate to the oat plants. Granule size is of importance particularly in those cases where the phosphate is present as dicalcium phosphate. In fas 50 where 50 per cent of the phosphate is in the water-soluble state the effect of granulation is slight. This can also be seen from Table 1 where the phosphate effect of various products is expressed as percentage of the P-effect of superphosphate.

(b.) *Pot experiments with oats* 1944 *and* 1945. The important effect of granule size of nitrophosphate on availability of the phosphate was also shown in a pot experiment of 1944 in which a product with 10% of its phosphate in a water-soluble form was applied in granules of 3-4 mm. and as a powder. Superphosphate, basic slag and dicalcium phosphate were used for comparison. Soil as well as experimental conditions were similar to those of the pot experiment of 1943. Magnesium sulphate was included in the basic dressing however.

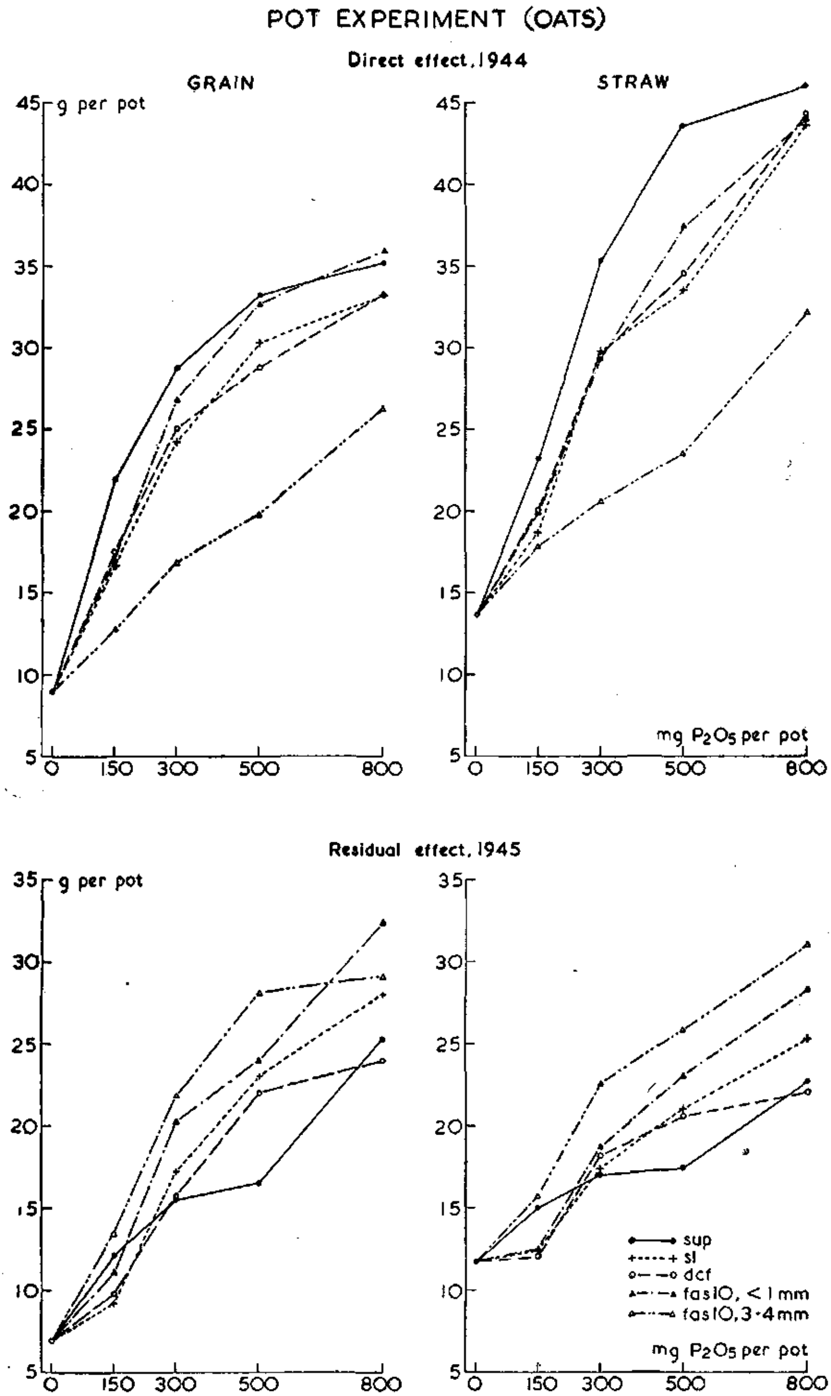


FIG. 2. *Direct and residual effect of some P-fertilisers.*

Table 1.

P-effect of various nitrophosphates and of dicalcium phosphate as % of that of superphosphate.

Product	Granule size, mm.	P-effect
fas 10	< 1	94
	1-2	52
	2.8-4.8	<50
fas 25	< 1	74
	1-2	60
	2.8-4.8	<50
fas 50	< 1	75
	1-2	79
	2.8-4.8	74
dcf	< 1	75

The powdered fas 10 has given a somewhat higher yield than dcf and basic slag but was slightly inferior to superphosphate. In granules of 3-4 mm., however, fas 10 has given much poorer yields (see Fig. 2).

In 1945 the residual effects of the phosphatic fertilisers of the above-mentioned pot experiment were determined by growing a second crop of oats. Nitrogen in the form of ammonium nitrate and potassium sulphate were supplied as in the preceding year. As will be seen from Fig. 2 the residual P-effect of superphosphate was considerably lower than that of the nitrophosphates. Dicalcium phosphate and basic slag held intermediate positions (see also Table 2).

Table 2.

P-effect of fas 10, 3-4 mm. and <1 mm., dcf and sl as % of that of superphosphate (direct effect and residual effect).

Product	P-effect	
	Direct effect 1944	Residual effect 1945
fas 10, <1 mm.	89	160
,, , 3-4 mm.	<50	200
dcf	70	114
sl	70	123

To know whether the poor after-effect of superphosphate in comparison with the nitrophosphates depended on the differences in P-removal by the first crop or on a difference in fixation of phosphate in the soil, calculations were made of the uptake of phosphorus by the two crops (Table 3). It will be seen that the uptake of phosphorus by the plants in the first year in the case of superphosphate is slightly higher than with fas 10 <1 mm. The phosphate of fas 10, 3-4 mm. was much less available. It is highly improbable, however, that the small differences in P-uptake between sup and fas 10 <1 mm. have been responsible for the reduced availability of superphosphate to the second crop. The amounts of phosphorus from sup and fas 10 <1 mm. left in the soil after the first crop has been removed are as follows (as % of added fertiliser P): sup: 64, 75, 77, 79; fas 10 <1 mm.: 67, 74, 79, 82. From these figures it can be seen that an important proportion of the added phosphate fertilisers has been left in the soil. In the case of superphosphate this soil phosphate derived from fertiliser is much less available than the phosphate from freshly applied superphosphate. In the case of fas 10 <1 mm., " soil phosphate " reacts nearly as well as directly applied fertiliser while in the case of fas 10, 3-4 mm. the second year's effect is considerably higher than the direct effect of the same product and is even considerably higher than the effect of " sup-soil phosphate ": 631 mg. of " sup-soil phosphate " has given lower yields than 448 mg. of " fas 10, 3-4 mm. soil phosphate."

More substantiated evidence for the stronger fixation of phosphorus from superphosphate than that from nitrophosphate will be given below.

c. *Field experiments.* These experiments were carried out on permanent grassland as well as on arable land. In the latter case potato was used as the test plant. Although under field conditions the differences between nitrophosphates of different grain sizes and with different contents of water-soluble phosphate were less spectacular than in the pot experiments, the results of the experiments were in agreement with those of the above-mentioned pot experiments (cf Tables 4 and 5).

2. *Comparison of increasing amounts of nitrogen in the form of nitrophosphate and of ammonium nitrate-limestone, with and without ample superphosphate.*

In the foregoing experiments the effect of increasing amounts of different phosphatic fertilisers has been compared at an optimal nitrogen nutrition of the plants. In this second type of experiment increasing amounts of nitrogen were supplied in the form of ammon-

Table 3.

Direct and residual effect of phosphate fertilisers. Pot experiments with oats, 1944 and 1945.

Fertiliser	Mg. P_2O_5 applied per pot	Increase in yield by P-dressing, g.per pot				Increase in P-uptake by P-dressing, mg. P_2O_5 per pot				
		Grain		Straw		Grain		Straw		Total in grain + straw in both years
		1944*	1945†	1944*	1945†	1944*	1945†	1944*	1945†	
sup	150	13.0	5.2	10.5	3.3	59	19	−5	−2	71
	300	19.7	8.6	21.8	5.3	78	46	−4	0	120
	500	24.3	9.7	30.0	5.7	111	69	5	4	189
	800	26.3	18.4	32.4	11.0	161	95	8	−3	261
sl	150	7.7	2.3	5.1	0.7	48	14	0	3	65
	300	15.3	10.3	16.3	5.7	84	43	−3	−4	120
	500	21.1	16.1	20.9	9.4	106	76	−5	−2	175
	800	24.3	21.1	30.0	13.6	129	110	5	−1	243
dcf	150	8.6	2.9	6.4	0.3	56	14	1	−2	69
	300	16.1	8.7	16.0	6.5	74	43	−5	−1	111
	500	19.9	15.2	20.9	8.9	99	76	−2	−2	171
	800	24.2	17.0	30.7	10.4	129	85	5	−3	216
fas 10, <1 mm	150	8.0	4.3	6.3	0.8	50	19	1	−4	66
	300	17.9	13.4	15.7	7.0	86	61	−7	−1	139
	500	23.9	17.2	23.8	11.3	109	86	−3	−1	191
	800	27.0	25.5	30.3	16.6	141	113	1	−3	252
fas 10, 3-4 mm	150	3.8	6.5	4.1	4.0	22	34	−1	0	55
	300	7.9	15.0	7.0	10.9	43	57	−2	−2	96
	500	10.9	21.2	10.9	14.1	55	89	−3	−2	139
	800	17.4	22.4	18.5	19.3	76	125	−4	2	199

* direct effect. † residual effect.

ium nitrate-limestone and of nitrophosphate respectively. In order to know whether the amount of phosphate supplied with each dose of nitrogen in the form of nitrophosphate was sufficient to satisfy the P-requirement of the plants, a third set of ammonium nitrate-limestone plots was dressed amply with superphosphate.

The results of some experiments of this type have been plotted in Fig. 3. It will be seen that on soils poor in available nitrogen and in available phosphorus, nitrophosphate may be able to serve both the phosphorus and the nitrogen requirements of the plants. In those cases, however, where available phosphorus is the limiting factor but soil nitrogen is available in relatively large amounts, a low nitrogen-phosphorus ratio in the fertiliser will give the best results. In this case the yields obtained with nitrophosphate are

Table 4.

P-effect of nitrophosphates, dcf and basic slag as % of that of superphosphate (permanent grassland)

Experiment and year	Soil type and pH	Product	Granule size m.m.	Phosphate effect		
					Residual effect	
				Direct effect	1st year 2nd cutting	2nd year 1st cutting
761, 1943	peat 5.2	fas 10	mixture	<50		170
		,, 25	,,	54		119
		dcf	<1	99		114
761, 1945		fas 10	mixture	63		
		,, 25	,,	82		
		dcf	<1	77		
763, 1943	peat 5.7	fas 10	mixture	<50		
		,, 25	,,	79		
878, 1946	peat 5.7	,, 10	1-2	<50		
		,, 25	1-2	<50		
		,, 50	1-2	<50		
		sl	<1	<50		
881, 1946	peaty clay 5.6	fas 10	1-2	65	122	
		,, 25	1-2	<50	152	
		,, 50	1-2	81	88	
		sl	<1	<50	94	
882, 1946	peaty clay 5.2	fas 10	<1	60	146	
		,, 10	1-2	<50	250	
		,, 10	3-4	<50	233	
		,, 25	<1	79	250	
		,, 25	1-2	63	318	
		,, 25	3-4	70	152	
		,, 50	<1	81	241	
		,, 50	1-2	106	156	
		,, 50	3-4	77	123	
		sl	<1	54	121	
962, 1947	peaty clay 5.4	fas 10, c.p.	mixture	<50	78	256
963, 1947	sandy 5.9	,, 10, c.p.	,,	<50		>200
997, 1948	peaty clay 5.1	,, 10, c.p.	,,	<50	<50	154

far behind those with ammonium nitrate-limestone plus superphosphate.

No difference in nitrogen effect of nitrophosphate (fas 10, c.p.) and of ammonium nitrate-limestone was found in a number of field trials on different soils and with different crops. In these experiments equal amounts of phosphate were applied on the plots with the two nitrogen fertilisers.

Table 5.

P-effect of nitrophosphates, dcf and basic slag as % of that of superphosphate (potatoes).

Experiment and year	Soil type and pH	Product	Granule size	Phosphate effect: Direct effect	Phosphate effect: Residual effect 2nd year
766, 1943	sandy 5.5	fas 10	mixture	100	
		,, 25	,,	111	
		dcf	<1	105	
814, 1944	sandy 6.0	fas 10	<1	72	
		,, 10	1-2	<50	
		,, 10	3-4	74	
		,, 25	<1	<50	
		,, 25	1-2	97	
		,, 25	3-4	67	
		,, 50	<1	125	
		,, 50	1-2	100	
		,, 50	3-4	76	
		dcf	<1	96	
		sl	<1	84	
815, 1944	peat 5.4	fas 10	<1	125	
		,, 10	1-2	58	
		,, 10	3-4	<50	
		,, 25	<1	90	
		,, 25	1-2	130	
		,, 25	3-4	<50	
		,, 50	1-2	111	
906, 1946	clay 7.3	,, 10	1-2	<50	60
		,, 25	1-2	<50	<50
		,, 50	1-2	121	125
		dcf	<1	<50	159
		sl	<1	<50	111
921, 1946	clay 5.5	fas 10	<1	111	132
		,, 10	1-2	77	182
		,, 10	3-4	63	154
		,, 25	1-2	83	128
		dcf	<1	111	200
		sl	<1	111	222
922, 1946	clay 5.5	fas 10	1-2	<50	
		,, 25	1-2	<50	
		dcf	<1	<50	
		sl	<1	<50	
1021, 1948	clay 6.1	fas	mixture	50	
		dcf	<1	100	
1023, 1948	clay 5.4	fas	mixture	67	123*
		dcf	<1	127	79*
1092, 1949	clay 7.5	fas	mixture	65	
		sl	<1	67	

* Oats.

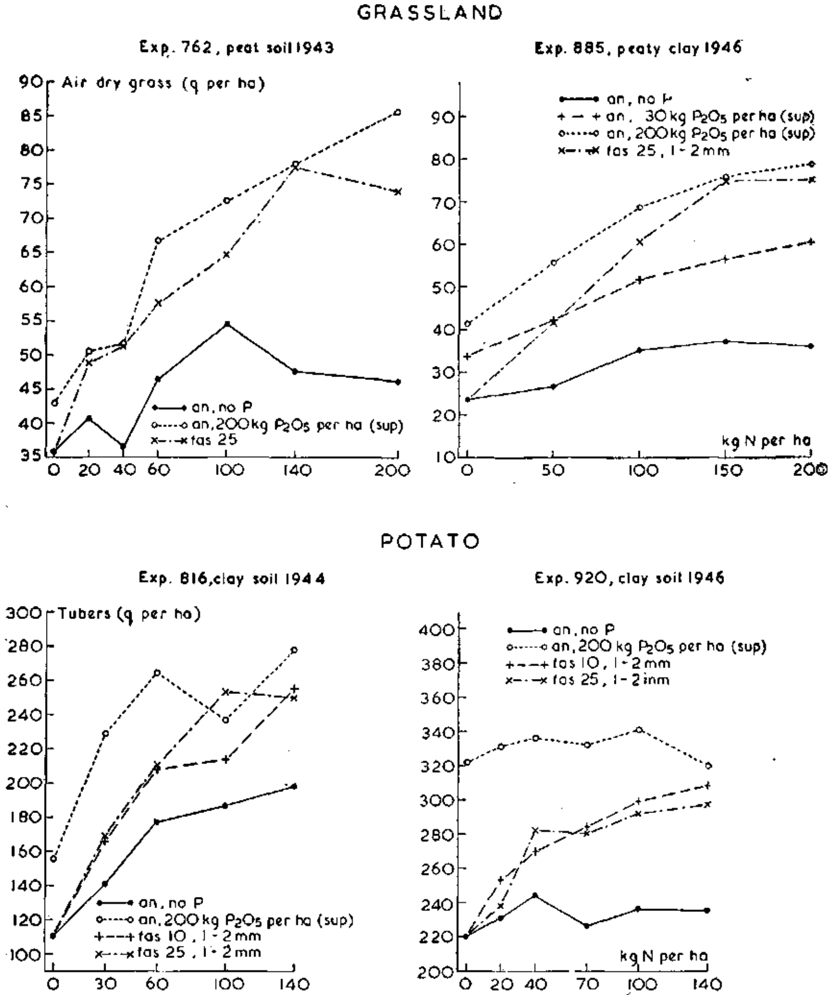


FIG. 3. *Response of grass and potato to nitrophosphate, ammonium nitrate-limestone (an) and an + ample superphosphate. Soil pH: Exp. 762: 5.2, Exp. 885: 5.3, Exp. 816: 7.2 and Exp. 920: 6.0.*

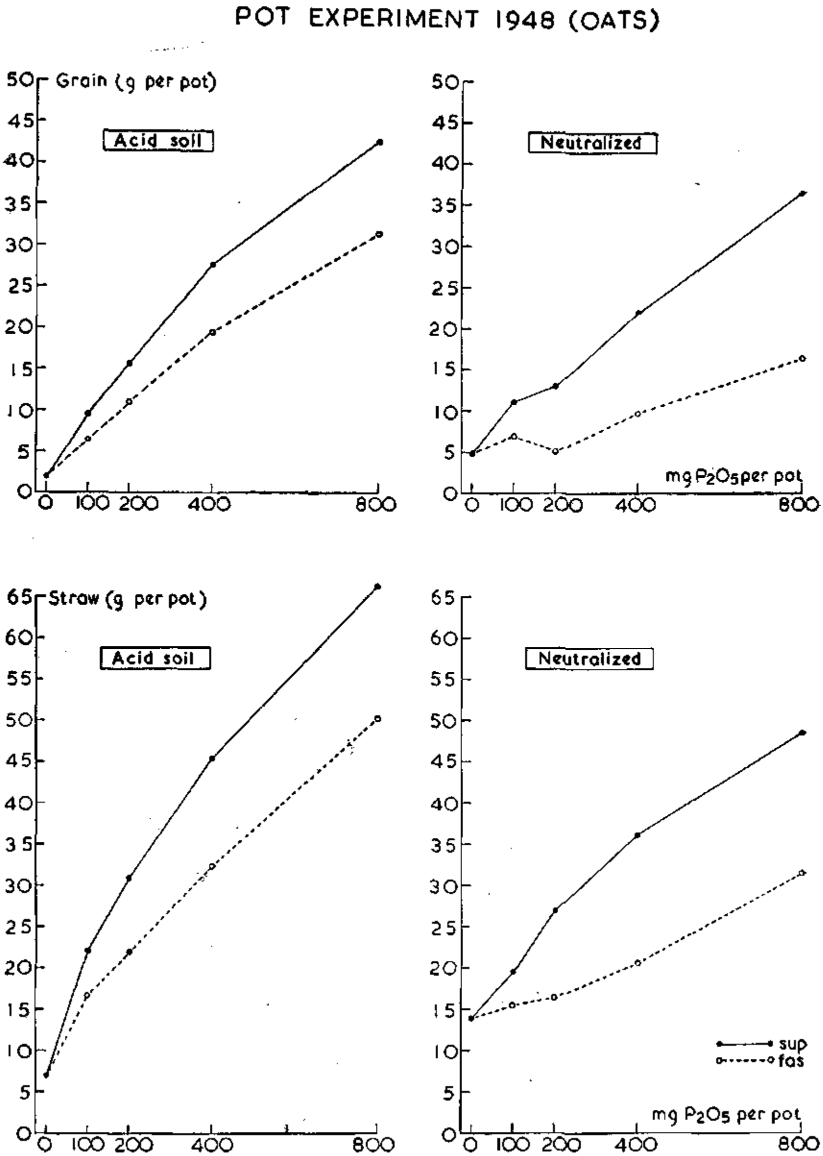


FIG. 4. *Effect of liming of a P-deficient peat soil, pH* 5.2, *on availability of phosphorus in fas* 10 *c.p. and sup.*

3. *Effect of soil pH on phosphate effect of nitrophosphate.*

The soils on which the various phosphates were tested in general had pH values below 7. Alkaline phosphorus-deficient soils are found only sporadically in the Netherlands. Although a number of field experiments have been laid out on alkaline clay soils with a low phosphate content, a response to phosphate dressings was obtained only in a few cases. It was found that on such soils the phosphate effect of nitrophosphate as compared with that of superphosphate was worse than on slightly acid soils. In one experiment in which fas 10, fas 25 and fas 50 were compared with sup a remarkable effect of content of water-soluble phosphate was observed. Fas 50 reacted like superphosphate whereas the P-effect of fas 10 was only 20 per cent of that of sup. The residual effect of fas 10 and of fas 25 which on acid soils in general is higher than that of superphosphate was lower on this alkaline clay soil. These results are in agreement with those of two pot experiments with phosphorus-deficient soil in which the influence of liming on direct and residual P-effect of superphosphate and of a commercial fas 10 has been tested. On the slightly acid soil the phosphate from nitrophosphate was approximately 60% as effective as that from superphosphate. On the limed soil (excessive amount of $CaCO_3$), however, this value was less than 30% (cf Fig. 4). The residual

POT EXPERIMENT 1948 (RYE)

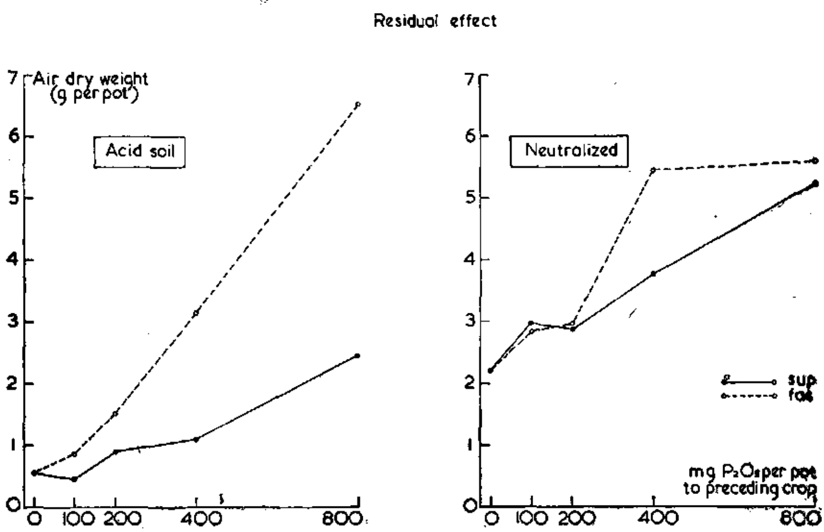


FIG. 5. *Influence of liming of a P-deficient peat soil on residual P-effect of fas* 10 *cp. and sup.*

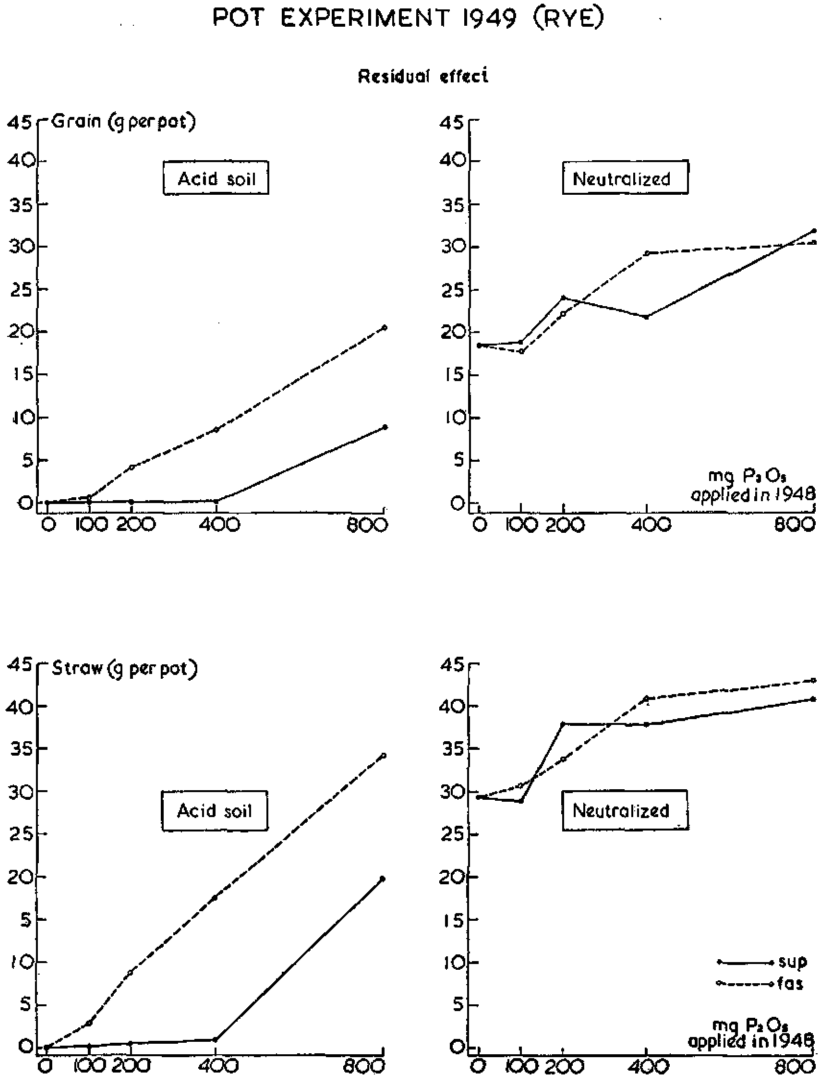


FIG. 6. *Influence of liming of a phosphorus-deficient peat soil on residual P-effect of fas* 10 *c.p. and sup.*

P-effect determined by sowing rye after the oats and cutting the green crop in the autumn was unfavourably affected by liming in the case of nitrophosphate but enhanced in the case of superphosphate (Fig. 5). This is also shown in Fig. 6 where the rye yields in the second year have been plotted. It will be seen that in the unlimed soil, superphosphate up to a dose of 400 mg. P_2O_5 per pot in the preceding year gave no residual effect. In the case of nitrophosphate a clear residual P-effect was obtained. On the neutralised soil sup and fas gave an approximately equal after-effect. This different behaviour of sup and fas presumably was due to fixation of phosphate in the acid soil by iron and aluminium. In the limed soil this precipitation was largely prevented while in addition a considerable amount of unavailable soil phosphate became available, so that even the control pots gave a reasonably good crop.

4. *Direct effect, residual effect and cumulative effect of nitrophosphate, superphosphate and basic slag.*

As has been stated earlier in this report the phosphate contents of many soils in the Netherlands are maintained by the farmers at such levels that phosphate dressings could be omitted for a number of years without seriously reducing the yields of the crops. During the second world war no fertiliser phosphorus was available during four years while in two years only 50 per cent of the usual amount could be supplied. Although at the end of this period phosphorus deficiency could be found more easily than before the war, there were no serious reductions in yield as a result of the inadequate P-supply on most soils.

As a result of the above-mentioned policy the purpose of the phosphate manuring of many farmers is to maintain the soil phosphate content on a relatively high level. Therefore, knowledge of the residual effect of a particular P-fertiliser is of as much importance as that of its direct effect.

As has been demonstrated by the above-mentioned pot experiments with oats the residual effect of nitrophosphate may be considerably more pronounced than that of superphosphate. Similar results have been obtained in a number of field experiments in which the direct effect of nitrophosphate had been considerably inferior to that of superphosphate. Fig. 7 shows the results of such an experiment on permanent grassland (pH 5.4). In the first year, 1947, nitrophosphate was less than half as effective as superphosphate ; in the second year, however, the reverse was true. This difference in after-effect can still be seen in the second cutting of 1948 and even in the first and second cuttings of 1949. On those plots on which in 1949 the same amounts of sup and fas were applied as in 1947, sup gave higher yields than fas, but the differences were smaller than in 1947.

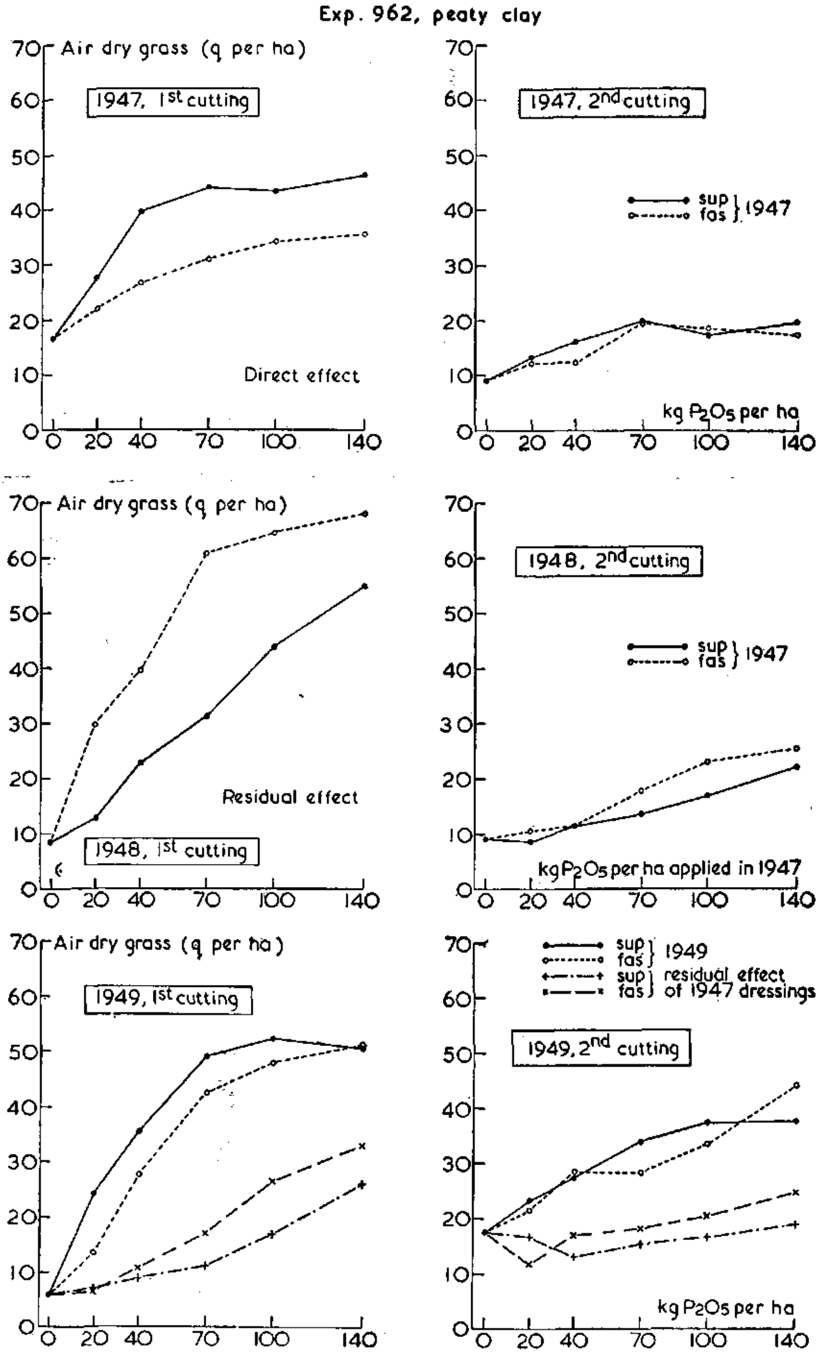


FIG. 7. *Direct and residual P-effect of fas* 10 *c.p. and sup.* (*soil pH* : 5.4).

A second example with permanent grassland is given in Fig. 8. Although the differences between superphosphate and the nitrophosphates are less pronounced than in experiment 962, the results are in general agreement with those of the latter experiment. In this case phosphorus determinations were carried out in the grass of the first cuttings of 1943 and 1944 (cf Table 6). It will be seen that the uptake of phosphorus in the first year from superphosphate was higher than from the nitrophosphates.

In the second year the figures for the nitrophosphates and for dicalcium phosphate are somewhat higher than those for superphosphate. When a comparison is made between the values for P-uptake of 1943 and those of 1944 it will be seen that the latter are much lower. This is particularly the case with superphosphate

Table 6.

Increase in P-uptake by P-dressings (Exp. 761, 1943 and 1944).

Fertiliser	P_2O_5 applied kg. per ha	Increase in P-uptake, kg. per ha.	
		1943, direct effect	1944, residual effect
sup	10	7.0	0.1
dcf	,,	4.6	0.2
fas 10	,,	3.2	−0.9
fas 25	,,	1.6	0.0
sup	20	7.6	0.3
dcf	,,	4.6	0.4
fas 10	,,	6.2	0.2
fas 25	,,	1.8	0.0
sup	40	17.7	3.6
dcf	,,	14.9	5.6
fas 10	,,	10.5	5.3
fas 25	,,	9.0	2.7
sup	70	20.9	4.7
dcf	,,	16.4	6.6
fas 10	,,	17.2	9.6
fas 25	,,	16.9	10.1
sup	100	27.9	9.7
dcf	,,	21.5	9.4
fas 10	,,	16.9	10.5
fas 25	,,	21.0	10.4

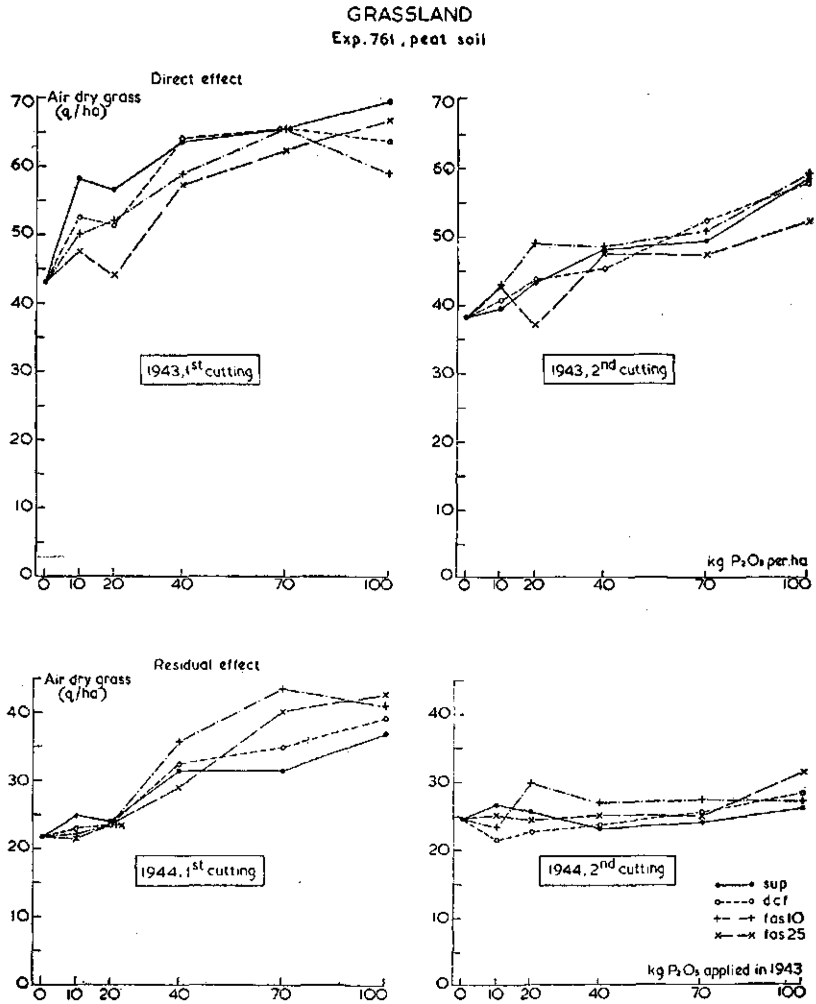


FIG. 8. *Direct and residual P-effect of fas* 10 (*mixture of different granules*), *fas* 25 (*ditto*), *sup and dcf on permanent grassland* (*pH* 5.2).

(ratio's of 0.23 and 0.35 for the doses of 70 and 100 kg. P_2O_5 per ha. as compared with 0.56 and 0.62 for fas 10). Since less than 30 per cent of the fertiliser phosphorus of these two doses had been taken up by the grass at the first cutting of 1943, the decrease in uptake of fertiliser phosphorus must have been due to decrease in availability of added phosphate, as a result of fixation in the soil. As might be expected the water-soluble superphosphate is more liable to fixation than the granulated nitrophosphate. This conclusion is in agreement with the results of the above-mentioned pot experiment and those of an experiment which will be discussed below.

In order to determine the responses of agricultural crops to nitrophosphate, superphosphate and basic slag, when these fertilisers are supplied each year, twice in three years and once in three years respectively, two field experiments have been started in 1949, one on permanent grassland (peaty clay, pH 5.1) and one on arable land (sandy soil, pH 5.0). The results of these experiments as far as available have been plotted in Figs. 9, 10 and 11, while the values for the P-effect of fas and sl have been reported in Table 7. In agreement with the results of earlier experiments superphosphate has given the highest yields of grass in the year of application of the phosphates (1949). When no P was given in 1950, nitrophosphate and basic slag, applied in 1949, gave better results than superphosphate. On those plots where the P-fertilisers had been applied in 1949 and in 1950 fas gave slightly higher yields than sup and sl. In 1951 the highest yields were obtained on the plots which had been dressed for three years with superphosphate. In this year the residual effect of phosphate dressings applied in 1950 was remarkably poor on the grassland. This may also be seen from the yield data of plots which had been dressed with phosphate in 1950 but not in 1951 (see Fig. 10). No explanation can be given of the difference in residual effect in 1950 and 1951.

On the potato field similar differences in residual effect in different years were found but here the after-effect in 1951 was much better than in 1950. On this experimental field superphosphate gave as usual the best direct P-effect. In 1949 the differences between superphosphate, nitrophosphate and basic slag were considerably more pronounced than in 1950 (cf Fig. 10 and 11). When the phosphatic fertilisers had been applied in two or three successive years the differences between the three products tested became smaller but superphosphate mostly gave the best results. In those cases where the P-supply depended on residual effect fas gave higher yields than sup (see also Table 7).

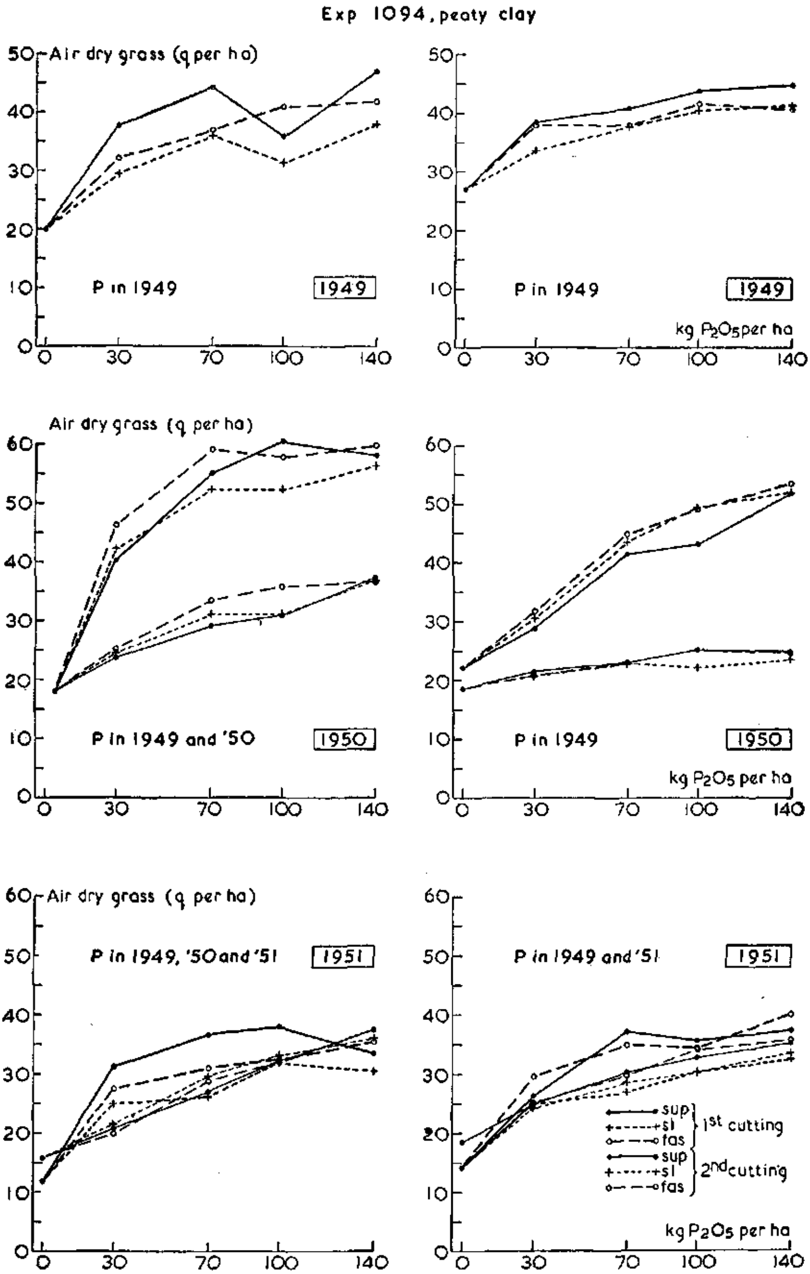


FIG. 9. *Direct, residual and cumulative P-effect of sup, sl and fas* 10 *c.p.*

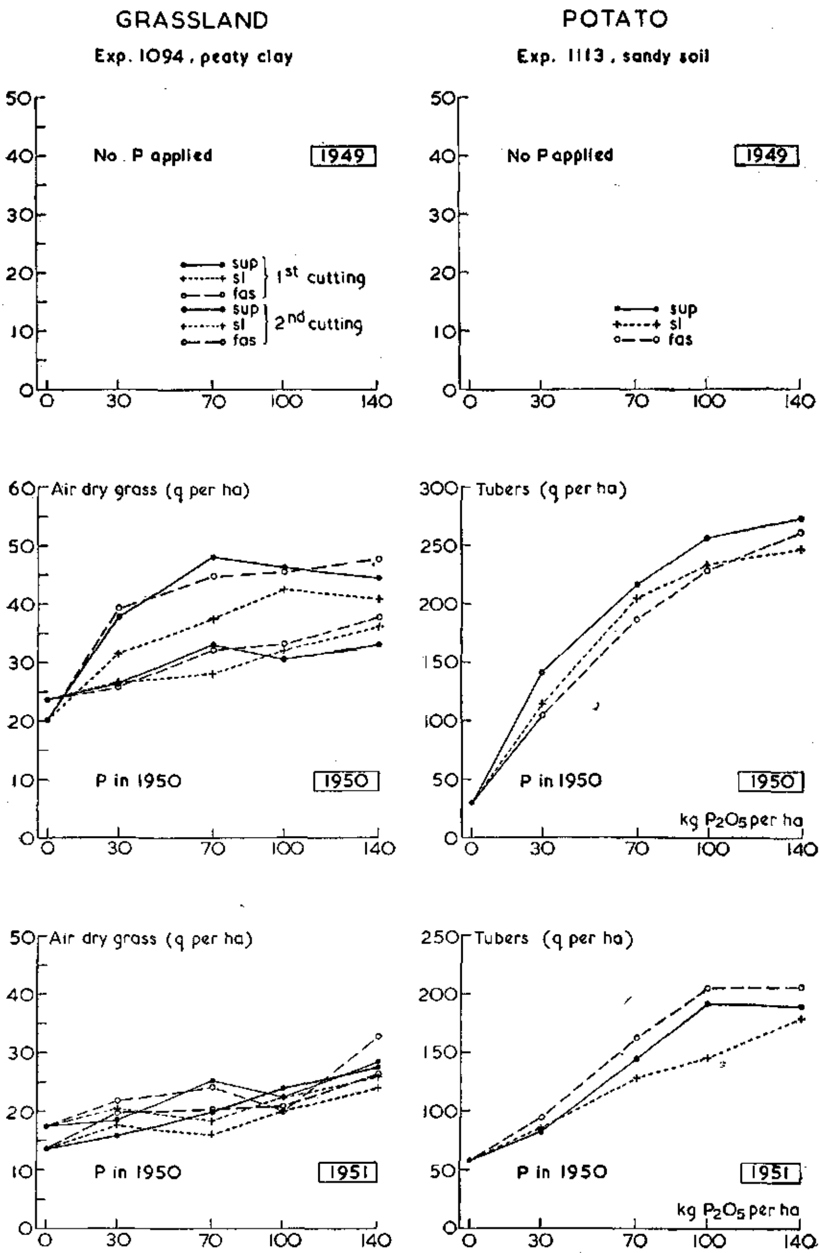


FIG. 10. *Direct and residual P-effect of sup, sl and fas 10 c.p.*

POTATO

Exp. 1113 sandy soil

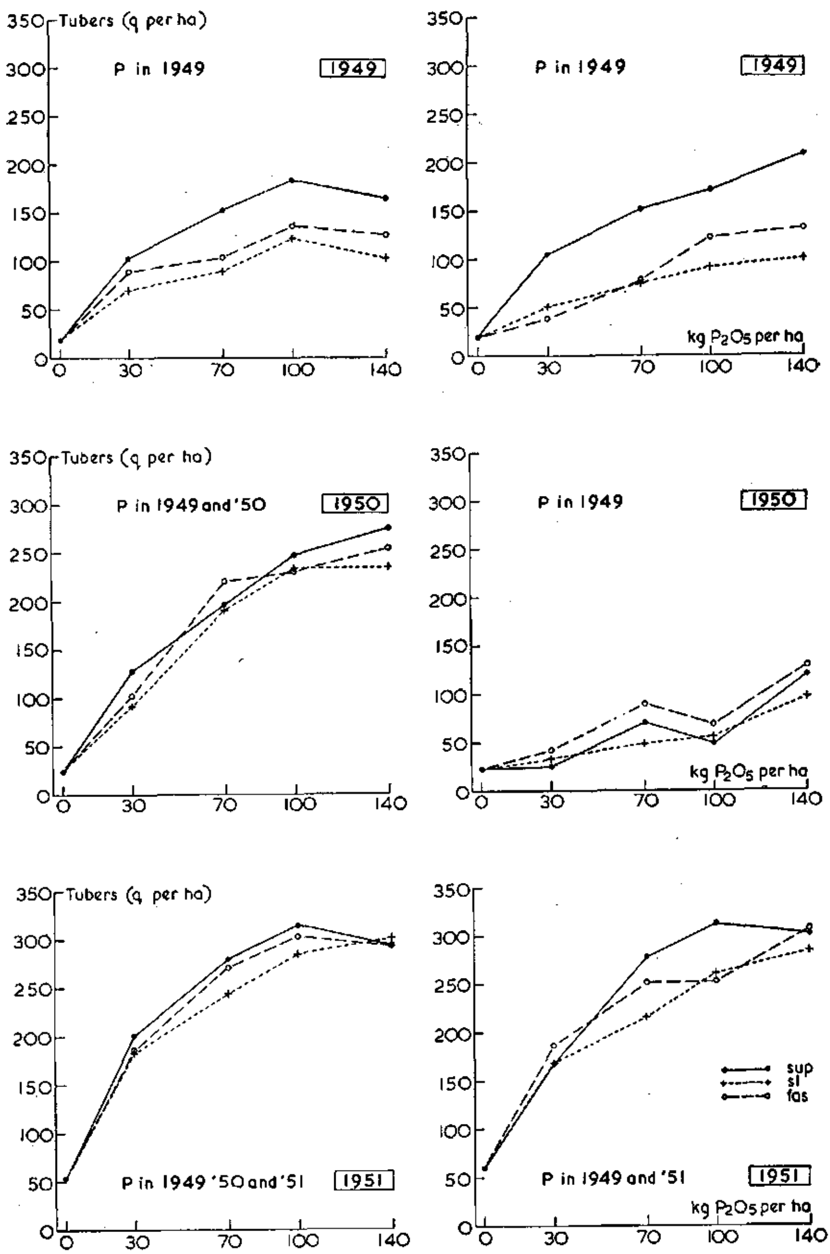


FIG. 11. *Direct, residual and cumulative P-effect of sup, sl and fas* 10 *c.p.*

Table 7.

P-effect of fas 10 (c.p.) and basic slag as % of that of superphosphate.

Exp. and crop	Year of testing	P-fert.	P-dressings applied in 1949,1950, 1951	1949, 1951	1950
1094	1949	fas	75	69	—
permanent	1949	sl	<50	58	—
grassland	1950	fas	111	141	111
1st	1950	sl	72	132	54
cutting	1951	fas	73	110	—
	1951	sl	52	50	—
1113	1949	fas	<50	—	—
potato	1949	sl	<50	—	—
	1950	fas	100	—	76
	1950	sl	87	—	85
	1951	fas	83	88	113
	1951	sl	71	70	72

Some of the above-mentioned experiments have provided evidence that water-soluble phosphates like superphosphate are more liable to fixation in the soil than is the case with the phosphate of nitrophosphate. In order to obtain more evidence as to this difference some pot experiments have been carried out in 1948 and in 1953. In April of the former year increasing amounts of phosphate in the form of superphosphate and nitrophosphate were mixed through a P-deficient sandy soil of pH 5.4. The pots were covered with dishes and maintained in a moist condition throughout the summer. In August a second set of pots were dressed in the same way. Subsequently all pots were planted with rye which was harvested some months later. Yields of dry weight as well as P-amounts taken up by the plants from the fertilisers have been plotted in Fig. 12. It will be seen that freshly-applied superphosphate was considerably more available to the rye plants than the superphosphate which had been applied four months earlier. In the case of nitrophosphate the earlier application has been somewhat more beneficial.

In a second pot experiment oats were sown in a number of phosphorus-deficient soils to which superphosphate, basic slag and nitrophosphate had been applied before and after the winter respectively. The results obtained on four soils are given in

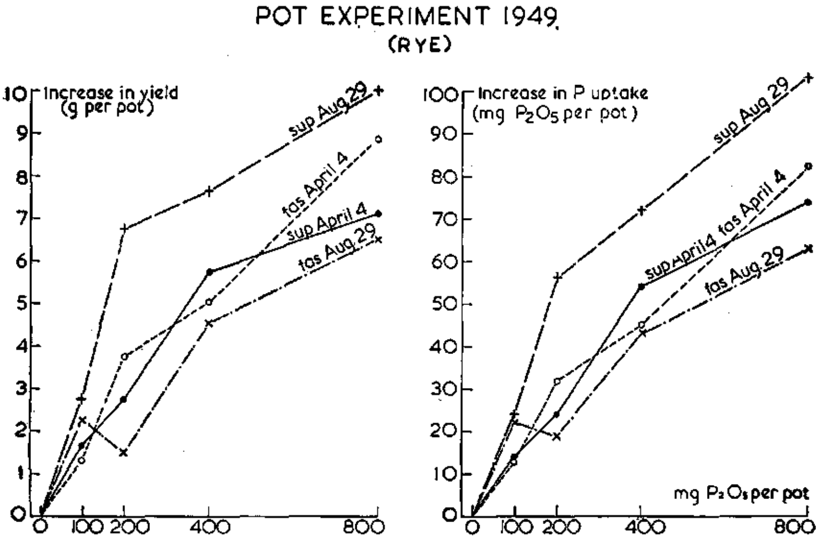


FIG. 12.

Availability of phosphorus in fas 10 *c.p. and sup after two different periods of time* (*sandy soil, pH* 5.4).

Fig. 13. It will be seen that the difference in P-effect between autumn- and spring-applied superphosphate in this experiment was negligible. In the case of clay soil the P-effect of nitrophosphate applied in autumn was considerably better than that of spring-applied fas.

CONCLUSIONS

The results of the above-mentioned pot and field experiments have shown that the direct P-effect of nitrophosphate when the latter is applied as a nitrogen fertiliser in the spring is less than that of superphosphate. Increase in content of water-soluble phosphate or decrease of granule size may enhance considerably the availability of its phosphate. The former may be undesirable from a technical point of view as large amounts of calcium nitrate will be obtained. A small granule size is not practical from an agricultural point of view. Nitrophosphate is in the first place a nitrogenous fertiliser and it is highly important that such a fertiliser should be broadcast as evenly as possible.

The residual P-effect of nitrophosphate was frequently found to be higher than that of superphosphate. Evidence was provided that this difference was due to a stronger fixation in the soil of the

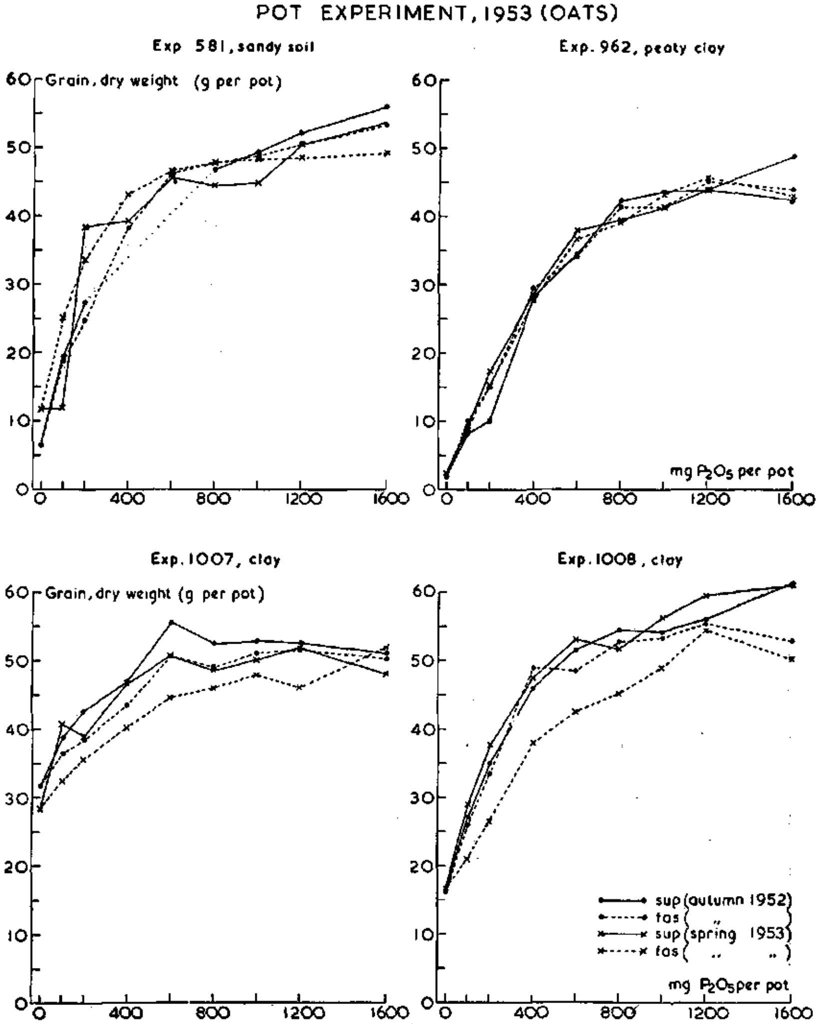


FIG. 13. *Influence of time of application on P-effect of fas* 10 *c.p. and sup. Soil pH, Exp.* 581 *:* 5.1, *Exp.* 962 *:* 5.2, *Exp.* 1007 *:* 6.4, *Exp.* 1008 *:* 7.0.

phosphate from superphosphate than that from nitrophosphate. Whether this is of general occurrence has to be further investigated.

On alkaline soils both the direct and the residual P-effect of nitrophosphate were found to be considerably less than on slightly acid soils.

Field Experiments with Anhydrous Ammonia as a Nitrogenous Fertiliser

INTRODUCTION

Anhydrous ammonia is being used successfully as a nitrogenous fertiliser in large areas of the U.S.A. Its main advantage over solid nitrogen compounds seems to be the low cost price of the nitrogen (1, 2). In addition labour costs are said to be reduced as the application process can be combined with other operations such as cultivating (3).

In experiments with corn, cotton and oats, ammonia was found to be equal or superior to ammonium nitrate (3). This was also the case with cabbage, tomatoes and beans (Campbell, 4). Where an extended dry period follows application, ammonia was usually found superior to ammonium nitrate because the ammonia is applied in most soils at a depth of approximately 10 cm. while the ammonium nitrate is usually not applied as deep (Andrews, 1, 2). In the case of corn and cotton it is stated that the favourable results obtained with ammonia are partly due to the preference of the young plants for NH_4-nitrogen and of older plants for nitrate. These conditions presumably are fulfilled when ammonia is applied shortly prior to sowing. When the plants grow older a greater part of the ammonia will have been converted to nitrate owing to the activity of nitrifying bacteria.

Large-scale experiments with anhydrous ammonia have been carried out during 1950 and 1951 in Denmark. Potatoes, swedes and mangolds were used as the test plants while ammonia, nitrate of lime and ammonium sulphate were applied as nitrogenous fertilisers. The results obtained with ammonia were found to be practically equal to those of the other nitrogenous fertilisers (5).

The effect of anhydrous ammonia on plant growth was studied by the author on arable land (oats, potatoes, sugar beets) as well as on permanent grassland. For these investigations we had the technical assistance of Mekog, IJmuiden, which imported an ammonia injector from the U.S.A. and built improved types of injectors for arable land and for grassland respectively.

METHODS

Anhydrous ammonia was compared under field conditions with ammonium sulphate, ammonium nitrate-limestone and in some cases also with nitrate of lime. The solid fertilisers were applied on top of the soil.

The apparatus used for the ammonia injection (nitrojection) was imported from the U.S.A. Since this was a rather heavy machine requiring a relatively heavy tractor, a lighter apparatus was built by Mekog. It contained nine injection shoes spaced 22 cm. apart. For grassland a special injector was built with sharp and narrow injection shoes to keep the resistance of the turf as low as possible. In both cases the depth of injection was approximately 10 cm. At a depth less than 10 cm. considerable evaporation losses occurred on grassland.

The field experiments were laid out on clay, peat and sandy soils. Since the effect of a nitrogenous fertiliser is related to the acidity of the soil and to its phosphorus, potassium and magnesium contents, soils of varying pH and varying potassium, phosphorus and magnesium contents were selected for these experiments. The clay soils used contained a few per cent of calcium carbonate. The sandy and peat soils had pH values varying from 5.0 to 6.2.

In the case of oats nitrogen was applied in amounts of 15, 30, 45, 60 and 75 kg. per ha. on the clay soils and of 20, 40, 60, 80 and 100 kg. on the sandy and peat soils. Potato and sugar beet received the following amounts of nitrogen: 30, 60, 90, 120 and 150 kg. N per ha. while on grassland these amounts were: 30, 60, 90, 120, 150 and 180 kg. N per ha. In a number of cases these amounts were applied at different rates of phosphate, potassium and magnesium so that the relationship between these nutrients and the different nitrogenous fertilisers could be ascertained. In 1950 thirteen field trials with oats, ten with potatoes and three with sugar beet were laid out. In 1951 thirteen field experiments were laid out on permanent grassland.

On the arable land the ammonia had to be applied before the sowing or planting of the crop. On wet soils this gave rise to a delay in sowing since the nitrojection required a dryer soil than the sowing of the cereals. On the wet soils sealing was hampered. Under these circumstances the depth of injection should be at least 10 cm. in order to prevent evaporation of ammonia.

Similar difficulties were encountered on a number of permanent grass fields. Owing to this, early application of nitrogen which is very important for obtaining high grass yields was not possible in a number of cases.

Results

1. *Arable crops.*

Average values have been calculated of the yields obtained with a certain N-fertiliser at different rates of application (see Tables 8, 9 and 10).

Table 8.

Effect of different N-fertilisers on yield of oats (grain).

Exp. and soil	pH	Basic dressing*	Grain yield, q. per ha.†			
			no N	am††	as††	anl††
1157 clay	7.8	full	33.6±1.5	39.9±0.6	42.2±1.1	42.3±1.4
1158 clay	7.7	,,	41.5±1.6	45.7±0.8	46.9±1.–	46.5±0.5
1161 peat	6.1	O Mg	36.4±4.–	39.9±1.3	39.6±1.3	38.3±1.6
		+ Mg	36.–±0.1	37.6±1.3	36.9±1.3	40.4±1.3
1164 sandy	5.8	O K	27.5±2.6	40.1±0.6	40.1±0.7	39.4±1.3
		O Mg	26.4±3.1	41.6±0.8	40.5±1.4	40.9±0.4
		+K+Mg	27.4±0.3	42.1±0.6	43.2±0.5	41.7±0.8
1167 sandy	5.6	O Mg	30.5±0.5	39.–±0.8	39.4±0.6	39.5±0.6
		+Mg	29.1±0.1	39.6±0.5	39.3±0.8	39.–±0.9
1168 sandy	5.9	O K	36.7±3.4	43.–±1.4	44.4±1.5	42.5±1.–
		O Mg	33.5±1.6	43.4±1.5	43.7±1.1	43.–±1.–
		+K+Mg	30.1±1.4	43.4±1.5	46.5±1.8	45.2±0.6
1169 sandy	5.6	O K	33.2±1.4	43.8±0.9	42.5±0.8	42.6±0.7
		O Mg	31.–±2.2	43.5±0.8	42.9±0.8	41.9±0.8
		+K+Mg	33.–±2.6	45.6±1.–	43.1±0.8	43.1±0.4
1171 sandy	5.–	O Mg	14.3±0.9	31.3±1.1	31.5±1.3	32.0±1.2
		+ Mg	15.4±0.8	31.8±1.1	34.2±1.1	34.2±0.9
1175 peat	5.5	O K	25.9±5.8	38.2±1.1	39.5±1.–	38.6±0.9
		+ K	23.6±7.–	36.9±0.5	37.6±1.1	38.6±0.4
1176 peat	5.6	O K	37.6±0.3	46.1±0.9	44.1±0.8	43.–±0.7
		+ K	36.1±0.8	44.4±1.1	43.–±0.7	41.6±1.–
1178 peat	5.4	O K	29.4±0.8	40.2±1.–	40.7±0.9	40.3±1.–
		+ K	30.3±3.–	42.8±1.2	42.2±1.1	41.7±0.6
1179 peat	5.6	O K	25.1±1.4	38.2±0.4	39.4±0.4	38.6±0.4
		+ K	28.4±2.5	37.9±0.6	39.8±0.4	38.1±0.8

* Phosphate was given to all plots, no and + Mg plots were dressed with K, no and + K plots with Mg.

† q. = 100 kg.

†† am = anhydrous ammonia, as = ammonium sulphate and anl = ammonium nitrate-limestone.

Table 9.

Effect of different N-fertilisers on yield of oats (straw).

Exp. and soil	pH	Basic dressing*	Straw yield, q. per ha.†			
			no N	am††	as††	anl††
1157 clay	7.8	full	40.–±1.8	53.9±1.7	58.9±1.4	60.7±1.9
1158 clay	7.7	,,	59.2±1.4	70.3±1.7	74.–±1.7	73.6±0.8
1161	6.1	O Mg	54.4±7.9	69.2±1.5	66.4±1.5	67.–±1.8
peat		+ Mg	50.–±1.3	69.4±1.–	66.4±2.–	67.9±1.7
1164	5.8	O K	37.4±4.1	57.8±0.9	58.2±1.–	57.8±1.4
sandy		O Mg	36.1±2.–	60.1±1.1	60.9±1.4	61.9±1.2
		+K+Mg	37.2±0.9	61.7±1.–	65.7±1.9	61.5±1.6
1167	5.6	O Mg	37.3±2.2	56.4±1.–	57.1±1.2	58.1±1.5
sandy		+Mg	35.2±2.7	57.–±1.1	55.9±1.–	56.1±1.4
1168	5.9	O K	40.2±5.4	58.4±2.3	62.4±2.2	60.5±2.3
sandy		O Mg	38.3±1.8	64.–±1.9	66.6±1.3	60.6±1.8
		+K+Mg	32.7±2.6	59.8±1.7	62 4±2.8	63.–±2.6
1169	5.6	O K	38.–±2.7	63.–±1.2	61.9±1.1	62.3±1.3
sandy		O Mg	35.1±3.1	63.5±1.1	68.1±2.1	63.9±2.–
		+K+Mg	39.1±2.9	65.7±1.7	64.1±1.–	61.8±1.5
1171	5.–	O Mg	22.9±2.6	44.0±1.5	43.8±1.8	41.8±2.2
sandy		+ Mg	21.2±1.–	42.7±1.4	44.7±1.5	43.9±1.4
1175	5.5	O K	31.9±7.4	55.6±2.1	55.2±1.2	53.5±1.2
peat		+ K	27.2±7.1	52.4±1.3	54.3±1.4	55.–±0.9
1176	5.6	O K	44.4±1.8	66.3±2.–	65.4±1.4	68.2±1.6
peat		+ K	39.–±2.2	67.6±1.4	63.1±1.3	61.9±1.7
1178	5.4	O K	39.–±1.8	51.2±1.2	53.2±0.9	51.9±1.2
peat		+ K	36.8±2.–	56.3±1.2	56.8±0.8	54.5±0.9
1179	5.6	O K	34.9±2.3	54.2±0.8	54.8±0.7	53.6±0.9
peat		+ K	35.4±3.4	54.9±0.9	57.2±0.8	55.3±1.–

* Phosphate was given to all plots, no and + Mg plots were dressed with K, no and + K plots with Mg.
† q. = 100 kg.
†† am = anhydrous ammonia, as = ammonium sulphate and anl = ammonium nitrate-limestone.

On the clay soils liquid ammonia gave a somewhat lower yield of oats than ammonium sulphate and ammonium nitrate-limestone. This was in agreement with the appearance of the plants which indicated a slightly inferior crop in the case of ammonia.

On the peat and sandy soils with oats, potatoes and sugar beet, ammonia gave as good results as ammonium sulphate or ammonium nitrate-limestone. No effect of soil acidity in the region from pH5 to 6 on the effect of the three nitrogenous fertilisers was observed.

Table 10.

Effect of different N-fertilisers on yield of potatoes.

Exp. and soil	pH	Basic dressing*	Yield of tubers q. per ha.†			
			no N	am††	as††	anl††
1162 sandy	5.9	O Mg	362±15.8	423± 3.8	430± 6.3	428± 6.5
		O K	359±24.6	421± 8.1	425± 8.–	409± 9.9
		+Mg+K	341±25.3	422± 9.3	436± 6.6	433± 4.2
1163 sandy	6.2	O Mg	235±16.5	378± 7.4	344±12.5	324±14.9
		+ Mg	238± 5.–	388±11.6	370±10.2	349±15.3
1165 sandy	5.5	O Mg	310±26.2	383± 5.9	381±10.–	376±14.–
		O K	328±29.4	383± 5.6	383± 6.4	394± 6.5
		+Mg+K	339±34.5	389± 7.–	381±11.3	388±10.2
1166 sandy	5.6	O Mg	169±32.–	287± 9.2	307± 6.3	314± 7.7
		+ Mg	195± 6.5	302± 9.3	322± 6.9	329± 4.3
1170 sandy	5.3	O Mg	278±26.6	352± 5.9	340± 7.8	352± 7.4
		O K	245± 7.3	280± 6.2	290± 4.8	305± 5.1
		+Mg+K	262±10.–	347± 4.2	351± 7.1	355± 5.6
1172 sandy	5.2	O Mg	250±18.4	342± 2.9	332± 4.5	351± 4.–
		+ Mg	270± 8.7	346± 3.7	340± 3.6	348± 6.–
1173 peat	5.2	O K	286± 3.–	358± 4.7	348± 4.7	351± 3.–
		+ K	271± 2.5	355± 4.1	339± 4.3	341± 3.9
1174 peat	5.7	O K	194± 9.5	301± 3.5	314± 4.2	314± 4.4
		+ K	174±29.5	303± 5.9	309± 4.1	317± 7.8
1177 peat	5.2	O K	207±30.5	310± 4.4	325± 5.9	327± 7.4
		+ K	220±12.5	311± 9.9	321± 5.4	331± 9.2
1180 peat	5.7	O K	270± 9.6	323± 5.6	349± 4.9	346± 7.6
		+ K	256±14.7	327± 7.3	348± 5.2	321± 8.5
1159** clay	7.9	full	372± 3.6	414± 5.–	409± 6.3	417± 5.5
1160** clay	7.8	full	393± 7.1	446± 4.2	455± 5.1	455± 7.2

* Phosphate was given to all plots, no and + Mg plots were dressed with K, no and + K plots with Mg.
† 1 q. = 100 kg.
†† am = anhydrous ammonia, as = ammonium sulphate and anl = ammonium nitrate-limestone.
** sugar beet.

In the case of magnesium- and potassium-deficient soils practically no difference between the effects of anhydrous ammonia and the solid nitrogen compounds has been found. On soils poor in available potassium, ammonium nitrate-limestone in some instances gave better results with potatoes than ammonia and ammonium sulphate (cf Table 10). This is in agreement with a preliminary experiment in which potato plants dressed with liquid ammonia showed more pronounced symptoms of potassium deficiency than plants dressed with ammonium nitrate-limestone.

2. *Effect of ammonia, ammonium sulphate and ammonium nitrate-limestone on soil pH.*

Although under nutrient solution conditions uptake of NH_4-nitrogen often proceeds more readily than that of nitrate, it may be expected that in the field, part of the applied fertiliser ammonium will be converted to nitric acid by nitrifying bacteria before it is absorbed by the plant roots. The increase in soil acidity which is a result of this conversion may partly disappear when the nitrate is taken up by the plant roots owing to the physiological alkalinity of nitrates. Ammonium nitrogen which is leached out of the soil after its conversion to nitrate may cause a lasting acidification of the soil.

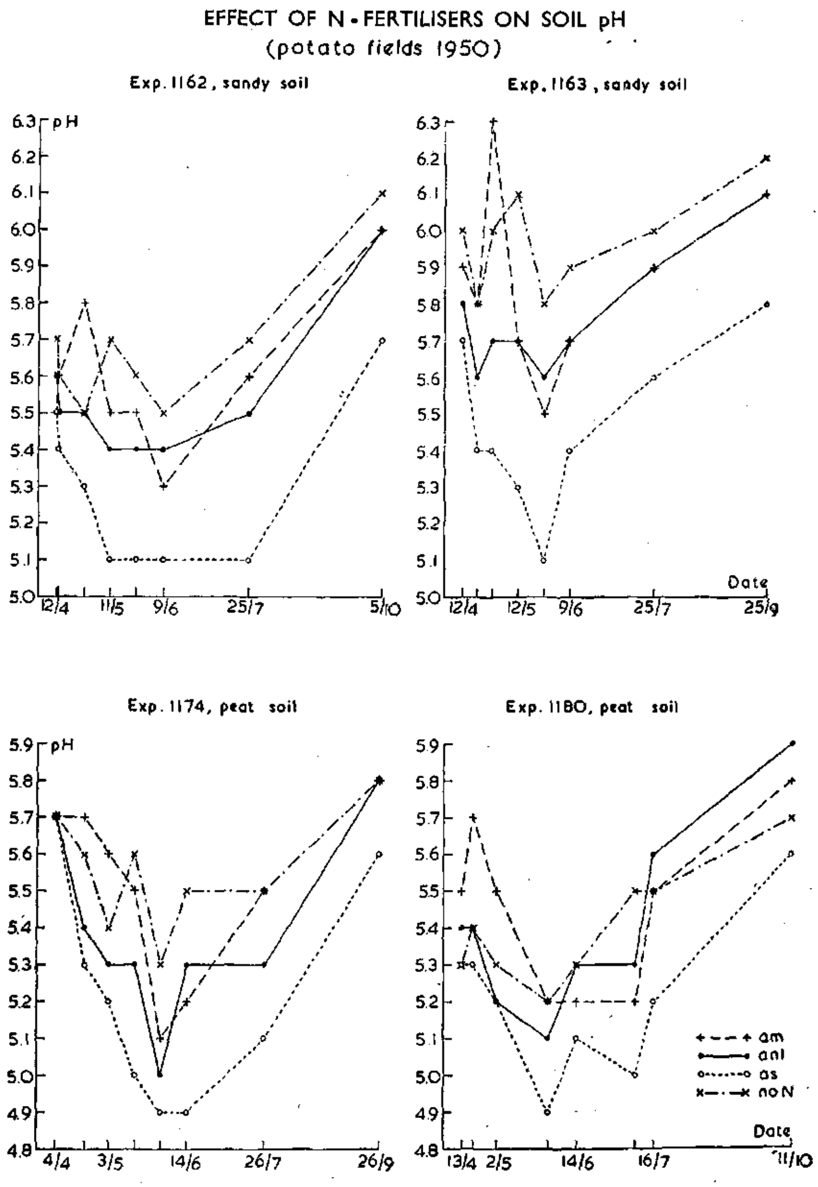
In order to estimate the effect on soil acidity of the different nitrogen compounds used in the above-mentioned experiments, pH determinations in the soil have been carried out at irregular intervals in the course of the growing period of potato plants. The results of four field trials have been plotted in Fig. 14. It will be seen that the soil acidity curves show a similar trend whether treated with different nitrogen compounds or without added nitrogen. This trend consists of a drop in pH towards the beginning of the summer followed by a rise during the second part of the summer. The increase in acidity in spring and early summer presumably was mainly due to nitrification of added ammonium fertilisers. Increase of salt concentration resulting from the addition of basic fertilisers may also have played a part. Similarly the rise in pH during the summer months has to be attributed partly to the uptake of nitrate by the plants and partly to decreased salt concentration.

Ammonium sulphate brought about the strongest acidification as was to be expected. Its effect on soil pH due to the sulphuric acid is clearly demonstrated. In the case of anhydrous ammonia the initial rise in pH was followed by a sharp drop. This indicates that a considerable part of the ammonia was oxidised to nitric acid before it was absorbed by the plant roots.

At the end of the summer when the major part of the applied fertiliser nitrogen had been taken up by the plants, the pH values of plots treated with ammonium and ammonium nitrate-limestone reached values equal to those of the no nitrogen plots. This indicates that, at least under the conditions of these experiments, ammonia like ammonium nitrate-limestone ultimately did not alter the soil pH. This result is in disagreement with the statement of Nicol (6) that anhydrous ammonia may cause a pronounced acidification of the soil.

3. *Experiments on permanent grassland.*

The field experiments were laid out on soils relatively poor in phosphorus and potassium so that by applying different amounts



EFFECT OF N - FERTILISERS ON SOIL pH
(potato fields 1950)
Exp. 1162, sandy soil
Exp. 1163, sandy soil
Exp. 1174, peat soil
Exp. 1180, peat soil
pH
6.3
6.2
6.1
6.0
5.9
5.8
5.7
5.6
5.5
5.4
5.3
5.2
5.1
5.0
4.9
4.8
12/4
11/5
9/6
25/7
5/10
12/5
25/9
Date
4/4
3/5
14/6
26/7
26/9
13/4
2/5
16/7
11/10
am
anl
as
no N

FIG. 14.

of P- and K-fertilisers a comparison could be made of the effect of increasing amounts of different nitrogenous fertilisers at different phosphorus and potassium levels of the soil. In these experiments anhydrous ammonia was compared with ammonium sulphate, ammonium nitrate-limestone and nitrate of lime. All of these fertilisers were applied in amounts of 30, 60, 90, 120, 150 and 180 kg. N per ha. Plots dressed with solid N-compounds were also treated with the injection apparatus. The effect of the mechanical treatment of the turf with the injection apparatus on grass growth and yield has been studied on separate plots treated with solid nitrogen fertilisers.

Although it was expected that soil moisture on grassland would be less important in nitrojection experiments than on arable land this appeared not to be the case. The grassland too had to be relatively dry before the injection apparatus could be employed. This was particularly true of clay soils. Under wet conditions the turf was easily damaged so that lower yields were obtained than on the untreated plots.

The grass of each experimental field was cut twice. No fertiliser dressings were applied to the grass of the second cutting.

Initially three field experiments were laid out on low moor peat, three on sandy soil and three on clay soil. The results of the experiments on peat and sandy soil were entirely unexpected: the grass of the first cutting hardly responded to the anhydrous ammonia (Figs. 15 and 16). Ammonium sulphate like the other nitrogen compounds applied on top of the grassland gave normal responses but anhydrous ammonia applied at a rate as high as 180 kg. N per ha. gave an increase in yield smaller than was obtained with 30 kg. of N in a solid form. The ammonia was not lost, however, as can be concluded from the results of the second cutting (Figs. 15, 16 and Table 11). Apparently the grass plants of these field experiments were initially unable to absorb nutrients from a depth of approximately 10 cm. beneath the surface of the soils. This presumably was not due to the absence of living roots since according to the extensive studies of Dr. M. A. J. Goedewaagen of this station these always are present at that depth in the spring. Rather it had to be ascribed to the absence of oxygen in the relatively wet turf so that no uptake of nutrient elements by the roots was possible. In the course of the summer when the soil became dryer and oxygen penetrated into it, uptake of mineral elements from deeper layers was possible. So far this hypothesis has not been confirmed experimentally, however.

In the case of clay soil the response of the grass of the first

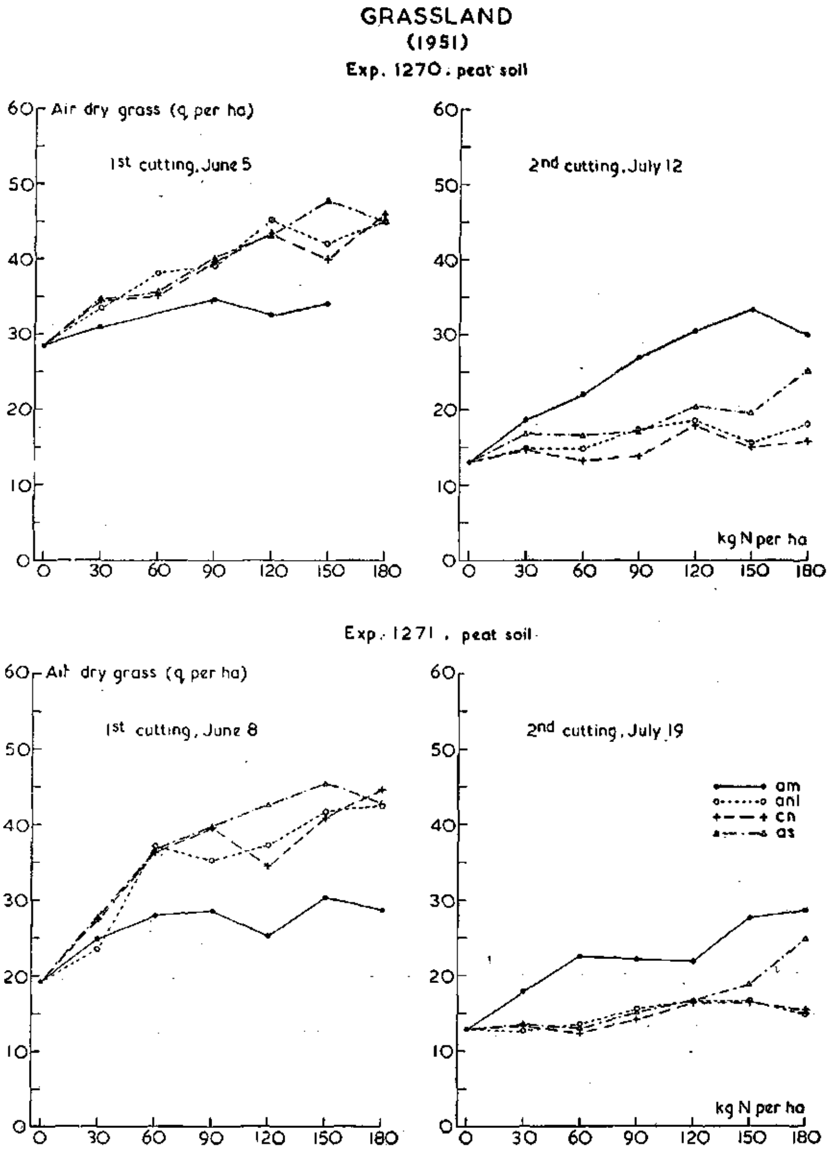


FIG. 15. *Effect of anhydrous ammonia (am), ammonium nitrate-limestone (anl), nitrate of lime (cn) and sulphate of ammonia (as) on yield of grass.*

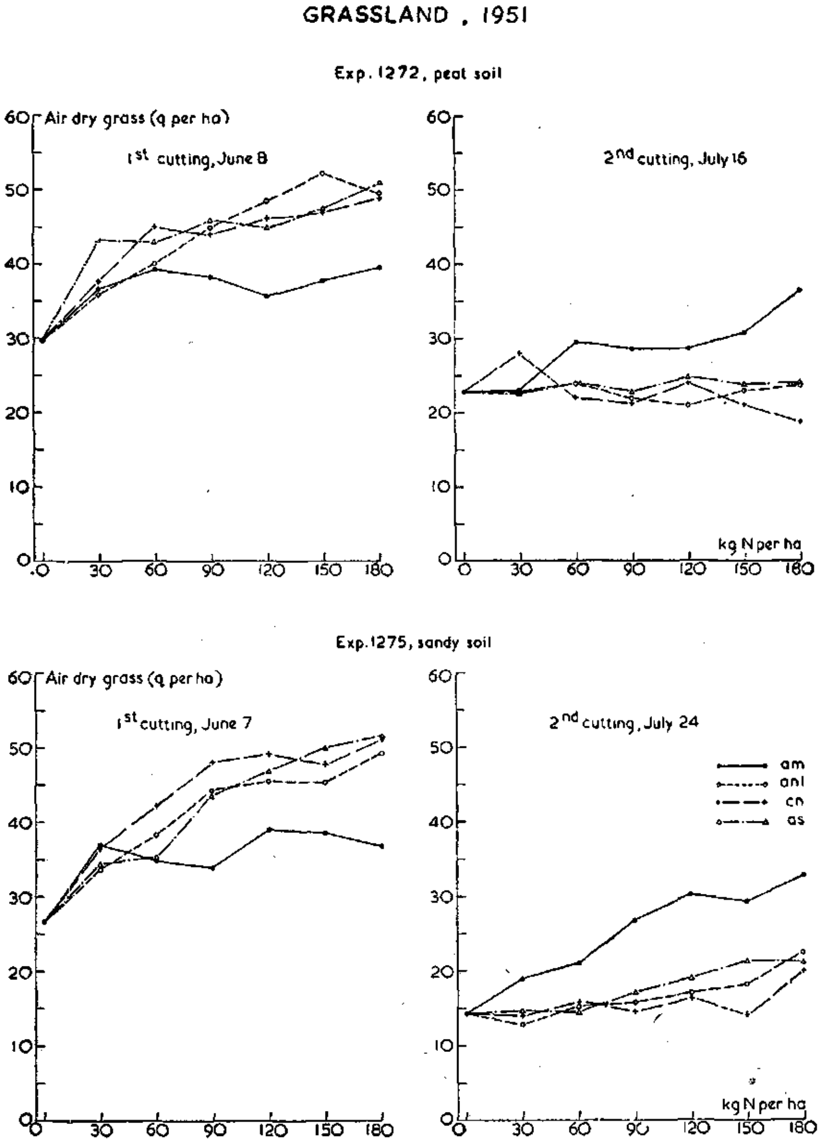


FIG. 16. *Effect of anhydrous ammonia (am), ammonium nitrate-limestone (anl), nitrate of lime (cn) and sulphate of ammonia (as) on yield of grass.*

Table 11.
Effect of different N-fertilisers on yield* (permanent grassland).

Exp., soil and pH	Basic dres-sing†	Cut-ting	Air dry grass, q. per ha.				
			no N	am	as	anl	cn
1270	O P	1st	26.4±1.–	31.4±0.9	37.2±1.–	38.2±0.4	36.8±0.9
peat	+ P	,,	28.5±0.8	33.–±0.5	41.3±0.5	40.–±0.5	40.2±0.6
5.8	O P	2nd	13.5±0.7	25.7±0.6	18.2±0.5	16.7±0.4	15.3±0.4
	+ P	,,	13.0±0.3	27.–±0.5	19.3±0.7	16.5±0.6	15.–±0.5
	O P	1st+ 2nd	39.9±1.1	57.1±1.1	55.4±1.3	54.9±0.8	52.1±1.–
	+ P	,,	41.3±0.5	60.–±0.6	60.6±0.9	56.5±1.–	55.2±1.–
1271	O K	1st	18.2±1.1	25.7±0.8	36.–±0.6	36.–±0.5	32.9±1.1
peat	O P	,,	16.5±1.1	25.6±1.–	36.4±0.8	34.3±0.7	33.4±0.8
5.9	+K+P	,,	19.2±2.–	27.5±1.–	39.2±0.6	36.2±0.9	37.1±0.8
	O K	2nd	13.3±0.8	20.5±0.6	16.7±0.7	14.7±0.6	14.9±0.8
	O P	,,	14.7±1.8	23.4±0.8	16.2±0.6	14.2±0.7	14.6±0.9
	+K+P	,,	12.8±0.6	23.4±0.8	17.–±0.7	15.–±0.4	14.7±0.4
	O K	1st+ 2nd	31.5±0.5	46.2±1.–	52.7±0.5	50.7±1.4	47.8±1.–
	O P	,,	31.2±2.7	49.–±1.3	52.6±0.8	48.5±1.2	48.–±1.–
	+K+P	,,	32.–±1.8	50.9±1.6	56.2±0.8	51.2±0.8	51.8±0.6
1272	O K	1st	30.–±0.6	35.3±0.8	41.2±0.6	41.9±0.7	39.6±0.5
peat	+ K	,,	29.6±1.8	37.8±0.9	46.–±0.7	44.8±1.6	44.7±1.–
5.6	O K	2nd	24.2±1.7	28.9±0.4	23.3±0.4	20.9±0.6	21.1±0.5
	+ K	,,	22.7±0.6	29.4±0.7	23.7±0.6	22.7±0.7	22.3±1.2
	O K	1st+ 2nd	54.2±2.1	64.2±0.9	64.5±0.5	62.8±0.6	60.9±0.6
	+ K	,,	52.3±1.8	67.2±1.–	69.7±0.5	67.5±1.5	67.–±1.2
1273	O K	1st	20.4±1.–	33.–±1.9	36.6±1.–	39.6±1.9	41.5±2.4
sandy	+ K	,,	22.7±2.8	38.1±1.8	42.2±1.2	44.8±1.6	41.1±1.7
6.1	O K	2nd	14.2±0.5	19.9±1.1	17.5±0.7	15.6±0.6	15.–±0.5
	+ K	,,	11.8±1.3	20.4±0.9	18.1±0.5	16.9±0.6	15.5±0.6
	O K	1st+ 2nd	34.6±0.9	52.9±2.3	54.1±1.5	55.2±2.1	56.5±2.4
	+ K	,,	34.5±3.1	58.5±1.6	60.3±1.–	61.7±1.7	56.6±1.6
1275	O K	1st	21.8±1.8	32.5±1.–	41.–±1.3	41.1±1.–	40.3±0.9
sandy	+ K	,,	26.6±2.2	36.7±1.–	43.7±0.8	42.7±0.7	45.6±1.3
6.1	O K	2nd	11.6±0.4	23.5±0.7	17.3±0.7	15.2±0.3	14.9±0.4
	+ K	,,	14.3±0.4	26.5±0.8	18.–±0.4	16.9±0.6	15.8±0.7
	O K	1st+ 2nd	33.4±1.6	56.–±0.8	58.3±1.6	56.3±1.–	55.2±1.–
	+ K	,,	40.9±2.–	63.2±1.–	61.7±0.9	59.6±0.9	61.4±1.4
1276	O K	1st	29.2±1.9	41.8±0.7	46.4±0.8	47.6±0.9	45.7±0.7
clay	+ K	,,	28.3±1.2	43.3±0.9	50.3±0.5	49.2±0.7	48.4±0.7
6.–	O K	2nd	26.5±1.2	31.4±1.1	33.1±0.7	30.2±0.9	30.–±1.1
	+ K	,,	26.1±1.5	30.9±1.1	34.1±0.8	31.5±1.1	29.1±0.7
	O K	1st+ 2nd	55.7±2.2	73.2±1.4	79.5±0.7	77.8±1.3	75.7±0.9
	+ K	,,	54.4±0.7	74.2±1.6	84.4±0.8	80.7±1.3	77.5±1.–
1277	O K	1st	34.–±1.4	45.8±1.1	46.–±1.1	48.8±0.9	48.6±0.9
clay 6.8	+ K	,,	34.8±2.3	45.7±1.–	46.8±0.8	48.6±0.8	48.4±0.8
1278	O K	,,	35.2±0.6	46.8±1.–	45.1±0.9	50.8±0.8	50.3±0.7
clay 6.1	+ K	,,	34.1±1.6	49.1±0.6	45.9±0.4	50.4±1.1	49.6±0.8

Exp., soil and pH	Basic dres-sing†	Cut-ting	Air dry grass, q. per ha.				
			no N	am	as	anl	cn
1303‡ sandy 5.5	full	1st	23.3±2.4	35.5±1.–	35.5±0.8	38.3±0.8	
		2nd	30.5±4.3	31.8±0.9	28.5±1.5	28.1±1.1	
		1st+2nd	53.8±6.4	67.3±1.1	64.0±2.1	66.4±1.8	
1304‡ sandy 5.6	full	1st	20.2±2.–	26.8±0.6	30.–±0.5	31.9±0.9	
1305‡ peat 6.–	full	1st	22.6±1.5	31.0±0.5	33.2±0.7	32.7±0.7	
1306‡ peat 6.–	full	1st	13.7±1.–	18.4±0.9	28.–±0.8	29.1±0.7	
		2nd	13.5±0.6	18.1±1.–	19.6±0.4	16.5±0.4	
		1st+2nd	27.2±0.4	36.5±1.7	47.6±0.5	45.6±1.–	

* Average yields of all nitrogen dressings.
† O P and + P plots were dressed with K, O K and + K plots with P.
‡ Laid out in June, 1951

cutting to the added ammonia was more satisfactory than on the peat and sandy soils. The results of one field trial on clay soil have been plotted in Fig. 17.

In order to know if better results with anhydrous ammonia could be obtained when it was applied later in the season, four field experiments were laid out on sandy and peat soil at the beginning of June, 1951. Although under these circumstances ammonia gave higher yields in the first cutting than was the case with spring application, the results were inferior to those obtained with the other nitrogenous compounds used in these experiments (cf Fig. 17). In the latter experiment the residual effect of ammonia in the second cutting which, in general, was found to be much higher than the after-effect of solid nitrogen fertilisers, was less pronounced than that of ammonium sulphate.

The results of the grassland trials clearly show that liquid ammonia applied under the conditions of these experiments to permanent grassland is a poor nitrogen fertiliser. Loss of injected ammonia does not take place, however, so that the nitrogen left in the soil will be available to the aftermath. Although under certain circumstances this prolonged effect may have some advantages, in the case of an intensive agriculture like that of the Netherlands this delayed nitrogen uptake is a great disadvantage.

A further objection to nitrojection on grassland is the mech-

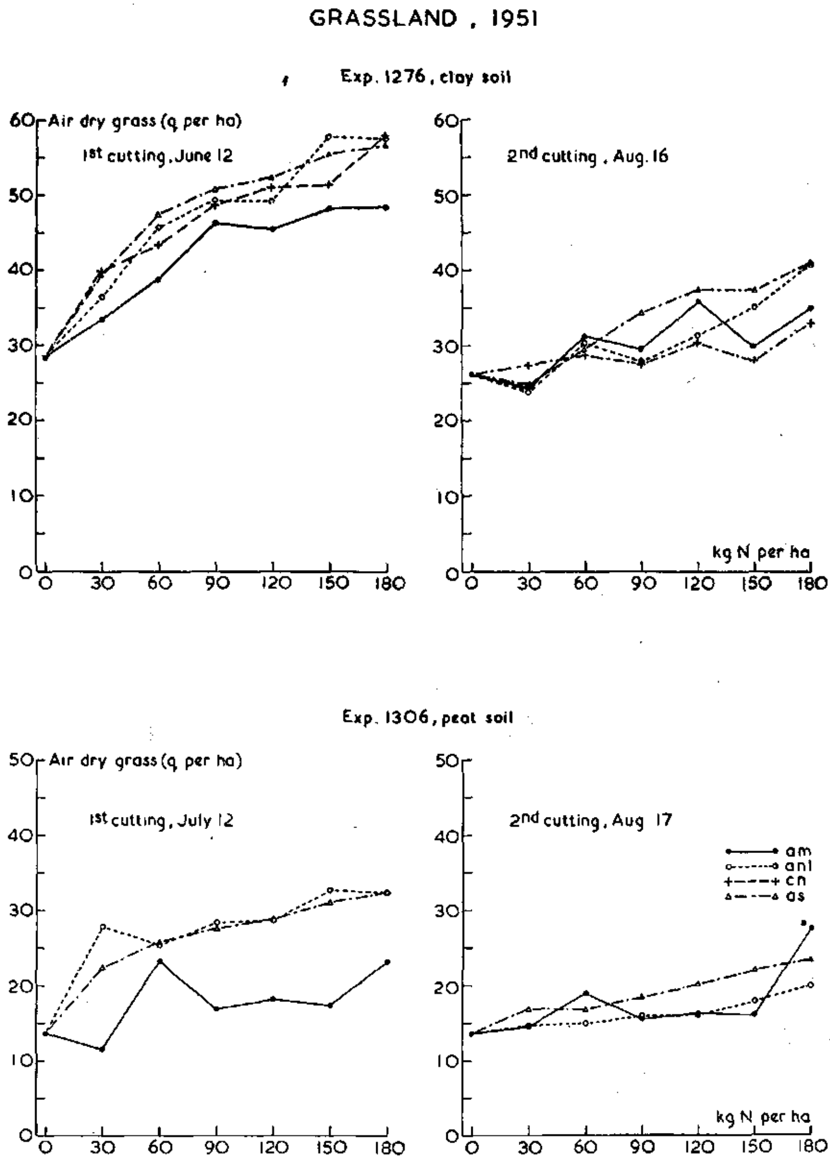


FIG. 17. *Effect of anhydrous ammonium (am), ammonium nitrate-limestone (anl), nitrate of lime (cn) and sulphate of ammonia (as) on yield of grass.*

Table 12.

Effect of mechanical damage of turf by the injection apparatus on yield of grass.

Exp., soil and pH	Treatment* by nitro-jection apparatus	Cutting	Air dry grass, q. per ha.			
			no N	as	anl	cn
1271 peat 5.9	+	1st	19.2±2.–	39.2±0.6	36.2±0.9	37.1±0.8
	–	,,	21.5±0.2	40.6±1.1	36.2±1.–	37.3±1.3
	+	2nd	12.8±0.6	17.–±0.7	15.–±0.4	14.7±0.4
	–	,,	12.7±1.–	11.3±0.3	14.2±0.8	15.–±0.8
	+	1st+2nd	32.–±1.8	56.2±0.8	51.2±0.8	51.8±0.6
	–	,,	34.2±1.2	51.9±1.–	50.4±0.9	52.3±1.2
1272 peat 5.6	+	1st	29.6±1.8	45.6±0.7	44.4±1.6	42.8±1.–
	–	,,	39.7±4.2	52.8±0.2	52.–±0.5	53.1±0.9
	+	2nd	22.7±0.6	23.2±0.6	22.4±0.7	23.2±1.2
	–	,,	26.1±2.1	26.1±0.7	23.7±1.4	22.2±0.5
	+	1st+2nd	52.3±1.8	68.8±0.5	66.8±1.5	66.–±1.2
	–	,,	65.8±2.1	78.9±0.9	75.7±1.2	75.3±0.6
1273 sandy 6.1	+	1st	22.7±2.8	38.3±1.2	43.5±1.6	39.–±1.7
	–	,,	20.9±4.8	43.1±2.1	43.8±1.7	47.3±1.7
	+	2nd	11.8±1.3	16.9±0.5	16.3±0.6	15.8±0.6
	–	,,	14.–±0.8	15.6±0.3	13.1±0.3	14.2±0.6
	+	1st+2nd	34.5±3.1	55.2±1.–	59.8±1.7	54.8±1.6
	–	,,	34.9±4.–	58.7±1.7	56.9±2.–	61.5±1.2
1275 sandy 6.1	+	1st	26.6±2.2	47.–±0.8	41.1±0.7	47.8±1.3
	–	,,	30.8±3.7	49.1±2.7	43.4±1.–	49.6±0.2
	+	2nd	14.3±0.4	19.3±0.4	15.6±0.6	14.3±0.7
	–	,,	13.1±1.8	16.–±1.4	14.6±0.6	15.3±1.5
	+	1st+2nd	40.9±2.–	66.3±0.9	56.7±0.9	62.1±1.4
	–	,,	43.9±3.2	65.1±1.9	58.–±1.–	64.9±1.3
1276 clay 6.–	+	1st	28.3±1.2	48.5±0.5	47.7±0.7	46.2±0.7
	–	,,	30.7±3.1	47.1±0.9	44.4±0.4	48.–±0.8
	+	2nd	26.1±1.5	32.2±0.8	28.9±1.1	27.6±0.7
	–	,,	23.5±0.8	29.5±0.5	27.2±0.5	25.2±0.4
	+	1st+2nd	54.4±0.7	80.7±0.8	76.6±1.3	73.8±1.–
	–	,,	54.2±3.9	76.6±0.8	71.6±1.4	73.2±0.9
1277 clay 6.8	+	1st	34.8±2.3	46.5±0.8	47.5±0.8	46.4±0.8
	–	,,	45.4±2.6	53.2±1.3	57.2±0.5	54.–±0.6
1278 clay 6.1	+	1st	34.1±1.6	45.3±0.4	48.4±1.1	47.7±0.8
	–	,,	45.3±0.5	57.7±1.6	60.9±1.7	60.5±1.9

* + = treatment, – = no treatment.

anical damage to the turf caused by the injection apparatus. This damage in some cases was found to be rather substantial (see Table 12). The effect was of short duration so that in the second cutting the differences had disappeared.

No particular interaction between ammonia and the other nitrogen fertilisers on one hand and phosphorus or potassium supply on the other has been observed in these grassland trials. This is in disagreement with results of earlier investigations carried out by the author (unpublished) in which it was found that on soils relatively poor in available phosphorus, ammonium sulphate gives better results than nitrates.

As to the effect of ammonium sulphate compared with that of ammonium nitrate-limestone and nitrate of lime the following can be said. On the peat soils which were characterised by a high moisture content, ammonium sulphate gave higher yields than ammonium and calcium nitrates respectively. This was particularly true of the residual effect in the aftermath. The lowest yields were obtained with nitrate of lime. These results are in agreement with earlier experiments with different nitrogen fertilisers on grassland (unpublished) in which it was found that under wet climatic conditions ammonium salts gave higher yields than nitrates. In dry years the reverse was found to be true.

Conclusions

The general conclusions which can be drawn from our experiments with anhydrous ammonia can be summarised as follows. With arable crops the effect of ammonia as a nitrogen source is equal to that of ammonium sulphate or ammonium nitrate-limestone. This applies to oats, potatoes and presumably sugar beet on sandy, peat and clay soils. There is some evidence that on the latter soils anhydrous ammonia is somewhat inferior to the solid nitrogen compounds tested.

Since the Dutch climate is a typically marine one with mild and wet winters, application of nitrogen to winter crops can take place only after the winter. In those cases in which anhydrous ammonia was supplied before the winter a considerable loss of nitrogen was found owing to nitrification of the ammonia in the autumn followed by leaching of the nitrate during the rainy winter months. Therefore in the Netherlands, liquid ammonia, if applied according to the method used in these experiments, can be applied only to summer crops before sowing or planting. But even for these crops application of ammonia may give difficulties, since the sowing of the cereals or the sugar beet requires less dry soil than the application of ammonia, so that on ammonia-treated fields the summer crops often have to be sown at a later date due to wet soils.

From an economic point of view in the Netherlands, grassland should be more suitable to ammonia injection than arable land owing to a more even distribution of nitrogen application throughout the growing season of the grass. The uptake of ammonia injected at a depth of approximately 10 cm. was so slow, however, that application on permanent grassland under Dutch conditions will in many cases be inadvisable. Although under less humid soil conditions anhydrous ammonia presumably will give more favourable results, it should be stressed that permanent grassland often has been laid down on wet soils. In addition to the inadequate effect of ammonia its application on such soils frequently may give great difficulties.

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DISCUSSION.

The President thanked Dr. Mulder for his interesting and stimulating talk. Members of the Society already knew of him through his experimental work on trace elements and would now wish to commend him heartily on his work on nitrogen and phosphorus.

Dr. G. W. Cooke, in opening the discussion, congratulated Dr. Mulder on his sound command of English and on the excellent paper which he had given. Dr. Mulder had described how the product, the manufacture of which was described by Dr. Plusjé in Proceedings No. 13 of the Society, compared with other forms of nitrogen and phosphorus. Dr. Cooke said he would review, from the conclusions of Dr. Mulder's experiments, the possible uses of nitrophosphate and anhydrous ammonia under British farming conditions. It was possible that these newer fertilisers might not be entirely suited to British agriculture.

For many British crops and soils fertilisers containing a high proportion of water-soluble phosphate were needed. Dr. Mulder had stated that the manufacturing of nitrophosphates with high water-soluble phosphate gave large amounts of calcium nitrate which had to be separated. (It was however, possible to produce nitrophosphates containing more water-soluble phosphorus by other processes). Furthermore Dr. Mulder had pointed out that finely ground nitrophosphate was more effective than granular material but both farmers and manufacturers preferred a coarsely granulated product. The ideal procedure would be to drill a granular material which became a powder when it reached the soil.

Dr. Mulder had emphasised the high residual effects of the phosphate in nitrophosphate, particularly on soils which " fixed " phosphate. On many English soils phosphates were not easily " fixed " to form compounds which were quite useless to crops, on such soils the high residual effects of nitrophosphate were not so likely to be important. In Dr. Mulder's experiments nitrophosphate was most efficient on soils which were somewhat acid. Lime deficiency still limited production seriously in many parts of Britain but it was not practicable for farmers to lime their soils to some definite pH on the acid side of neutrality. It was much easier to neutralise acid soils completely and to maintain them either at neutrality or slightly on the alkaline side. On soils containing even small reserves of calcium carbonate, the immediate and residual effects of nitrophosphates were likely to be inferior to those of water-soluble phosphate. It seemed therefore that phosphate supplied as nitrophosphate would be inferior to water-soluble phosphate over the greater part of Southern and Eastern England.

Dr. Mulder justified the use of nitrophosphate under suitable conditions on the basis of its high residual value. In Holland it was considered important to maintain high reserves of soil phosphate, and nitrophosphate was very suitable for this purpose. Whilst the Dutch farmer might regard applications of phosphate as being intended to " feed " the soil by building up reserves of soil phosphate, the British farmer considered phosphates as " food " for crops and being more interested in the immediate effects of the fertilisers did not find nitrophosphates so generally useful. It would be interesting to have Dr. Mulder's opinion on the merits of nitrophosphate compared with other NP fertilisers.

Dr. Cooke congratulated Dr. Mulder on his initiative in carrying out experiments on anhydrous ammonia. This material also had certain disadvantages. When applied for arable crops Dr. Mulder had shown that the soil must be drier than was necessary for seed sowing. In a difficult spring in the U.K. there would be very little time for applying anhydrous ammonia before drilling. Any delays in sowing caused by waiting for the soil to dry out sufficiently for the ammonia application might have disastrous effects on yields. Anhydrous ammonia would be most difficult to apply on grassland in the wetter areas where grass grows so well and is a most important crop. A further disadvantage was that on wet soils anhydrous ammonia appeared to act slowly ; it was therefore unsuitable for applications in late winter which were intended to extend the grazing season by producing " early bite."

If nitrophosphate and anhydrous ammonia were used in the U.K. it seemed that they would be introduced for political and economic reasons rather than because they were as satisfactory as the nitrogen and phosphate fertilisers used at present.

Dr. Mulder hesitated to give an opinion as to the merits of nitrophosphate compared with other fertilisers under British conditions. The results he had given demonstrated that nitrophosphate could be considered as an excellent fertiliser for acid soils with pH values up to 6.0. In the Netherlands practically all the sandy and peaty soils had pH values in this region. When the pH was nearly neutral, or was alkaline, the immediate phosphate effect of nitrophosphate was considerably lower and also the after effect was reduced. Under such conditions superphosphate would be a better phosphate fertiliser than nitrophosphate, unless the amount of water-soluble phosphate in the latter was considerably increased.

Dr. Mulder said that further experiments would have to be done on the placement of nitrophosphate. Preliminary trials had shown that the differences in the immediate effects of nitrophosphate and superphosphate disappeared to a large extent with correct placement. While the P_2O_5 in powdered nitrophosphate was more effective than that in the granular product, a granular material was essential in Holland where most fertilisers were broadcast. He agreed with Dr. Cooke's comment that nitrophosphate was regarded in Holland primarily as a nitrogenous fertiliser, its phosphorus content being of secondary importance. The addition of sulphuric acid to the nitric acid might improve the immediate performance of P_2O_5 but he was not convinced of the need to include it as he placed more value on residual effect.

MR. A. E. SELL said that when he had been shown by Dr. Mulder, some years previously, preliminary field trials on the application of anhydrous ammonia to permanent grassland, " striping " or " ribboning " had occurred along the line where the injector apparatus had entered the soil, which suggested that there had been very little diffusion of ammonia. He asked whether recent trials had produced similar results.

DR. MULDER said that since these preliminary trials, improvements had been made in the design of the injection apparatus and the " ribboning " did not occur.

MR. W. D. CARSON suggested that if such great importance was to be attached to the residual value of P_2O_5, applications of basic slag or ground mineral phosphate might be just as effective.

DR. MULDER agreed that basic slag was an excellent fertiliser — indeed it formed between 40% and 50% of the P_2O_5 used in Holland. He doubted whether ground mineral phosphate would be of much use on most of the soils of Holland.

DR. E. M. CROWTHER thought that Dr. Mulder might have given too much emphasis to comparisons of residual values, especially as he expressed many of his comparisons in terms of relative yields, not absolute ones. Even if the residual effect of nitrophosphate was twice that of superphosphate, this would not matter very much if the residual benefit from either of the materials was small and could be matched by supplying quite small quantities of fresh fertiliser. In Fig. 7 it appeared that the third-year residues from 100 kg. P_2O_5 per ha. as nitrophosphate were equivalent to the immediate effect of about 20 kg. P_2O_5 per ha. as fresh superphosphate. A little gain in the third year would not balance a large loss in the first year. Repeated small applications of superphosphate might give more profitable returns than relying on small residual effects from heavy dressings of nitrophosphate or other fertilisers in previous years. Dr. Mulder had given a somewhat analogous case in his very interesting experiments with anhydrous ammonia on peat and sandy soils. The ammonia was placed too deeply for the plant roots to use it early in the season and the injected ammonia then showed a pronounced residual effect at the second cutting — many times that from the normal nitrogen fertilisers. This is analogous to his findings on the residual effects of phosphate fertilisers. The nitrophosphate granules contained insoluble phosphate which could not be taken up quickly enough to exert the full effect in the first crop. They therefore acted slowly and showed residual effects. The water-soluble phosphates — like the nitrogen fertilisers on the soil surface — were designed to act more quickly and did so. It was no detriment that the solid ammonium salts and the soluble phosphates did what they were intended to do.

DR. MULDER considered that the building up of reserves of P_2O_5 was as important as the application of fertilisers for the immediate use of the plant. Holland had been saved from starvation during the war when supplies of phosphatic fertilisers were almost unobtainable, because Dutch farmers had built up phosphate reserves in the soil. They were still conscious of the strategic importance of this aspect of good husbandry and wished to maintain their soil phosphate at higher levels than were common in Great Britain. A similar policy for nitrogen was impracticable under Western European climatic conditions since a large proportion of the fertiliser nitrogen applied before the winter would be washed out of the soil during the wet winter months. Only by using stable manure or by green manuring with leguminous crops was it possible to build up nitrogenous reserves in the soil.

MR. A. J. LOW pointed out that British soils were not generally low in phosphorus. As in Holland great difficulty had been found in locating soils sufficiently deficient in phosphorus for the British field trials on nitrophosphate. He asked Dr. Mulder if he knew what was the residual effect of nitrophosphate on the average soils of Holland which showed little response to superphosphates and nitrophosphate as these would be the soils to which it would be applied if its use became general. Were the P-deficient soils used for the trials really typical ?

DR. MULDER said that it was difficult to measure accurately the effects of these fertilisers on average soils except by the use of radioactive phosphorus. Such trials presumably would be carried out in the future. He did not think that results of such experiments would differ very much from those of the pot and field trials already outlined.

MR. T. P. DEE commented that Dr. Mulder had considered only the nitrophosphates made by the Dutch State Mines process. His remarks that nitrophosphate had the wrong $N \div P$ ratio for some soils, and that it was undesirable from a technical point of view to have much more than 10% of the P_2O_5 in the water-soluble form, did not apply to nitrophosphates in general. The second limitation on the Dutch State Mines product was of importance, since Dr. Mulder had shown that a nitrophosphate with 50% water-soluble P_2O_5 gave as good results on an alkaline clay soil as did superphosphate, while some figures for this material in Table 5 (on soils of pH values 6.0 and 7.3) were even better than those for superphosphate. Such a material could be made, for instance, where both phosphoric acid and nitric acid were available, and he suggested that further agronomic investigation was desirable of nitrophosphates with water-soluble P_2O_5 contents of 30% to 50%.

From the results given in Fig. 14, it appeared that even ammonium sulphate did not cause cumulative acidification of the soil.

DR. MULDER agreed that an increased content of water-soluble P_2O_5 produced better results on some soils but the Dutch State Mines considered it was a disadvantage to have large amounts of calcium nitrate formed in the manufacturing process, which had to be removed. He did not agree that nitrogenous fertilisers left the pH values of the soil at the end of a season in much the same condition as they were at the beginning. This was so with ammonia and ammonium nitrate-limestone but the soils treated with sulphate of ammonia had consistently lower pH values than those which received no nitrogen dressings. The acidifying effect of sulphate of ammonia was observed in many cases and it caused pronounced leaching of available magnesium.

MR. D. E. SIMPSON asked Dr. Mulder by what means a good phosphate status in the soil was assessed in Holland.

DR. MULDER said that this was expressed in mg. of P_2O_5 soluble in 1% citric acid per 100 grms. of soil. Values of 40 to 60 were considered satisfactory on arable land, while on grassland 60 to 100 were desirable. When such values had been attained, a small dressing (20 — 30 kg. P_2O_5 per ha.) was sufficient to maintain a good phosphate status. At values higher than 60 on arable land and higher than 100 on grassland, phosphorus dressings could generally be omitted.

THE PRESIDENT asked if there was any difference in response between nitrophosphate made from Curaçao phosphate and that made from Morocco or other phosphate with a high fluorine content.

DR. MULDER said that nitrophosphate of high fluorine content had given good results although the reverse had been expected. It appeared therefore that the presence of fluorine was not very important.

DR. J. MANNING asked whether Dr. Mulder thought it was correct to say that anhydrous ammonia, compared with other nitrogenous fertilisers, was more difficult to apply, more costly and not so effective as a plant food.

DR. MULDER said that present indications were that in Holland the cost of anhydrous ammonia, including spreading costs, was higher than that of ammonium nitrate-limestone, but he was not entirely familiar with the details of manufacturing costs. In the United States, however, he believed that both the production and application of anhydrous ammonia were cheaper.

MR. W. D. CARSON asked whether it would not be cheaper and equally effective to build up a good phosphate status with adequate dressings of superphosphate ?

DR. MULDER agreed that, on alkaline soils, superphosphate would be better. On acid soils, however, where there was a considerable fixation of superphosphate, granulated nitrophosphate was probably more effective.

MR. W. D. CARSON asked whether it would not be possible to lime acid soils and still use superphosphate ?

DR. MULDER said that after the soil had been limed to neutrality, superphosphate was probably more effective than nitrophosphate containing only 10% of its P_2O_5 in a water-soluble form.

DR. E. M. CROWTHER, in proposing a vote of thanks to Dr. Mulder, congratulated him on the excellent preparation and delivery of his paper and on the clarity with which he had answered members' questions. Those who, like him, had been concerned with field experiments knew how much laborious work must have gone into the preparation and execution of the experiments so ably summarised in Dr. Mulder's paper.

MR. R. A. HAMILTON said that it gave him great pleasure to second the vote of thanks to Dr. Mulder whom he had met a few years ago when he was concerned on grassland trials. His researches in this particular field were outstanding — indeed the Dutch were second to none in the extent and efficiency of their grassland work. These researches in the nitrophosphate field were just a small part of the extensive work carried out on all forms of fertilisers. It had been mentioned during the discussion that Dutch farmers looked on phosphatic fertilisers as soil fertility builders rather than as food for the plant. Dutch farmers' usage of fertilisers was just about twice that of the British farmers on an acreage basis. Not only did they build up the status of their soil but their crop yields were much higher. The reason for this, lay not in the cheapness of Dutch fertilisers, for they were no cheaper than those sold in the United Kingdom but, he believed, in the tremendous number of experiments which were carried out every year, summarised promptly, passed on to the agricultural advisory services and quickly adopted by farmers. It was an example to the British fertiliser industry, to the N.A.A.S. and to the research institutions who could not do better than organise field experiments on the scale which had just been described.

DR. MULDER thanked Mr. Angus, Dr. Crowther and Mr. Hamilton for their words of appreciation. He had recently been on an extensive tour of the United Kingdom with Dr. Crowther and Dr. Cooke and had been struck by the lack of educational facilities for farmers. Relatively few sons of British farmers, it appeared to him, attended agricultural colleges whereas in Holland most farmers had been to an agricultural school, or on an agricultural course, and were familiar with the merits of various fertilisers.