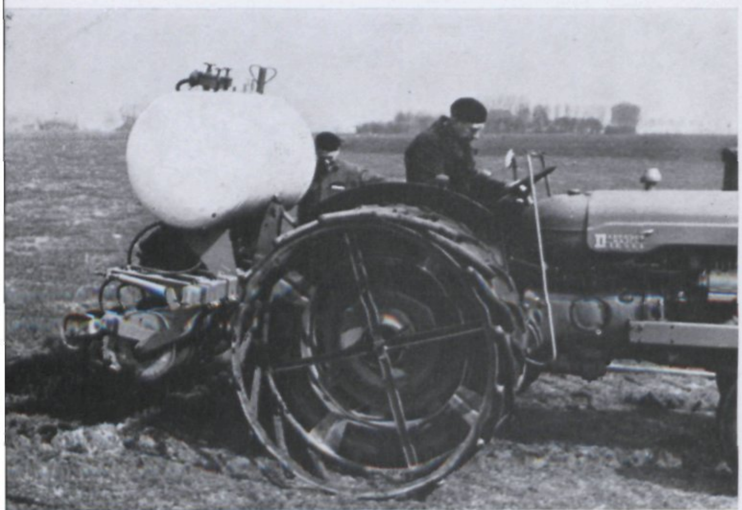
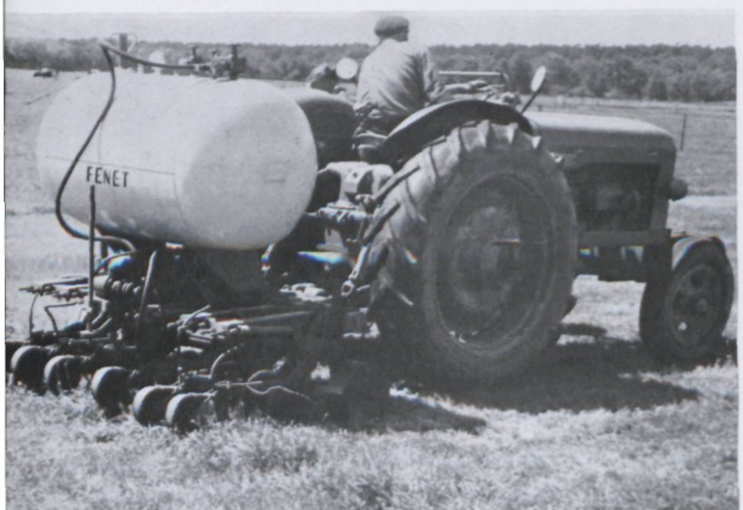
the fertilizer value of anhydrous ammonia on permanent grassland

P. F. J. VAN BURG and G. D. VAN BRAKEL

plate 1 and 2





Anhydrous ammonia (NH_3) contains 82% nitrogen. At normal temperature and pressure it is a colourless gas with a pungent smell; it can, however, be readily liquefied at high pressure and so is stored as a liquid.

When used as a fertilizer ammonia has to be applied beneath the soil surface (injected). During application the ammonia, reverting to normal atmospheric pressure, quickly evaporates and would escape were not subsurface application employed. Specialized equipment is needed for its injection.

The use of ammonia as a fertilizer material has expanded considerably since the Second World War, particularly in the USA. In 1962 ammonia accounted for about 25% of all nitrogen used in that country and was employed mainly on arable land. In recent years fertilizing with ammonia has also aroused increasing interest in Western Europe, particularly in Denmark and France. In 1963 about 13% of all the nitrogen fertilizer used in Denmark was applied in the form of ammonia, again almost entirely on arable land. Ammonia has in general been shown to be an extremely good nitrogenous fertilizer on arable land [1, 2, 3, 6].

In the Netherlands only about 25% of all the nitrogenous fertilizers used are applied to arable land; the great preponderance, 70%, goes on grassland.

Nitrogen usage on grassland has risen steeply in recent years and the average nitrogen dressing amounts to about 150 kg N per hectare per year. However, much less research work has been carried out with anhydrous ammonia on grassland than on arable land.

Trials in Mississippi indicated that in years with average rainfall ammonia is just as effective a fertilizer as ammonium nitrate, while in a dry year it is

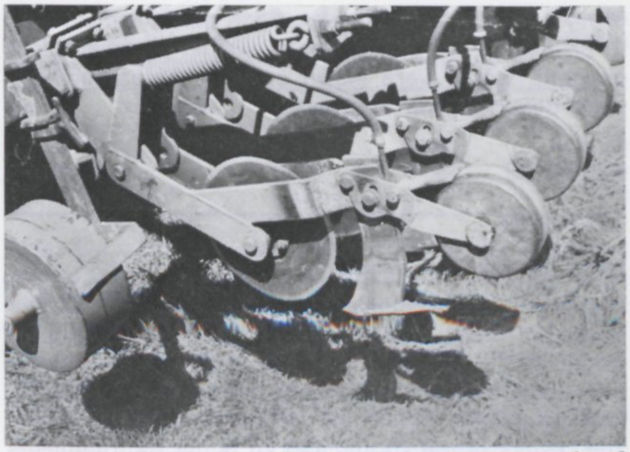


plate 3

plate 4

considerably more effective than the latter [2]. On the other hand trials in England on two-year-old leys [4] and on leys in Denmark [7] revealed that considerably lower yields were obtained with ammonia than with sulphate of ammonia, nitrochalk or calcium nitrate. It was also shown in an extensive investigation carried out as early as 1950 and 1951 on permanent pasture in the Netherlands that ammonia was less effective than conventional solid fertilizers [6].

However, experimentation was recommenced in 1963, firstly because great technical advances had taken place during the previous 15 years and the effectiveness of ammonia depends to a large degree on the injection equipment, and secondly because our acquaintance with all the possibilities for using NH_3 still appeared to be inadequate.

Experimental investigations

For the purposes of this trial an injector (plate 1 and 2) specially developed by Ets. Fenet (France) for use on grassland was imported.

An ammonia injection implement consists basically of (a) a high-pressure tank, (b) a metering device, and (c) injection tines. An injection tine resembles the knife-coulter on a plough. A small tube attached behind the tine delivers the ammonia into the soil. The problems involved in ammonia injection into grassland are, of course, entirely different from those associated with arable land. The injection tines need to be as thin as possible. Attached in front of each tine is a disc coulter which makes a preliminary slice into the sward and thereby reduces the amount of tractive effort required. A small foot attached to the base of the tine loosens a quantity of soil above the ammonia in order to prevent nitrogen being lost through the gas escaping; a press-wheel running behind the tine seals off the completed furrow. (plate 3 and 4).

Trials, about 10 in number, were carried out in 1963 and 1964 on various soil types (see table 1).

Tabel 1. **Soil analysis data**

exp. no	soil type	pH KCl	% org. matter	% silt $<16\mu$
IB 738	sand	5.2	3.2	2
IB 739	peat	5.9	60.3	7
IB 741	clay	6.3	14.2	41
IB 824	sand		as IB 738	
IB 825	clay		as IB 741	
IB 852	clay	5.9	15.3	39
IB 853	peat	5.3	68.1	3
IB 854	sand	5.5	7.6	9
IB 906	peat	5.3	58.6	9

Experimental layout 1963

The following problems were studied in 1963:

a. How do annual yields with nitrolime and NH_3 compare with each other with regular top-dressing/injection after each cut.

b. How do annual yields with nitrolime and NH_3 compare with each other when these fertilizer materials are applied in large amounts as a single spring treatment.

c. What effect does the slicing action have on the sward.

d. At what depth does NH_3 have to be injected in order to prevent nitrogen being lost through the ammonia escaping.

e. How far apart may the injector tines be spaced without obtaining an irregular crop stand.

The experimental layout is summarized in table 2. All treatments were replicated 3 times. The item

Table 2. **Experimental set-up of the experiments in 1963**

N kg/ha	N-fertilizer	frequency of fertilization or injection	depth adjustment of the injector, cm 0 = no injector (see text)
0	none	for each cut	0 - 5 - 10 - 15
70	nitrolime	for each cut	0 - 5 - 10 - 15
70	NH_3	for each cut	5 - 10 - 15
140	nitrolime	for each cut	0 - 5 - 10 - 15
140	NH_3	for each cut	5 - 10 - 15
250	nitrolime	in spring only	0
250	NH_3	in spring only	10
500	nitrolime	in spring only	0
500	NH_3	in spring only	10

'5, 10 and 15 cm' in the last column of this table refering to 0, 70 and 140 kg N per ha (nitrolime) treatments signifies that these plots were worked with the injector but without any NH_3 being introduced. The item '0 cm' signifies that the plots concerned were not worked with the injector. This enables the effect of 'slicing' the sward to various depths to be determined *per se*. A separate system of mowing was employed for each nitrogen level (0, 70, 140, and 250 and 500 kg N per ha). An attempt was made to mow the plots whenever their average yield approached the grazing stage (2000 kg dry matter per hectare). This was by no means always achieved. It is therefore not possible to make a comparison of annual yields at the various nitrogen levels.

Experimental layout 1964

Three fresh trials were laid down in 1964. The layout of the experiments is shown in table 3. All treatments were given at least 6 replications. The depth of injection was about 9 cm, the distance between injector tines 25 cm. The trial plots were mown according to a fixed harvest schedule, viz. every 4 to 5 weeks.
In order to gain an impression of the practical prospects of NH_3 a further trial on a farm scale was carried out on a field of grassland on peat soil. On 4 March 1964 half of the field was injected with NH_3 at the rate of 600 kg N per hectare. On the non-injected half nitrolime was applied after each cut

Table 3. **Experimental set-up of the experiments in 1964**

N-fertilizer	kg N/ha to cut						kg N/ha total
	1	2	3	4	5	6	
nitrolime	46	23	23	23	23	12	150
nitrolime	92	46	46	46	46	23	299
nitrolime	138	92	138	92	92	46	598
NH_3	300	0	0	0	0	0	300
NH_3	600	0	0	0	0	0	600
NH_3 + nitrolime (46 N)	346	0	0	0	0	0	346

using a centrifugal spreader. Each time the field was to be utilized by the farmer a number of small plots on both halves were mown one day beforehand for yield determination purposes.

RESULTS

1963 trials

Effect of 'slicing' the sward

When injecting ammonia cuts have to be made in the sward. In order to determine how effectively the nitrogen in the ammonia acts we ought to know in advance whether these incisions have any adverse effect on yield.
The results of the 70 and 140 kg N per ha treatments are summarized in table 4. Slicing the sward with the injection equipment is clearly shown to have an adverse effect on yield.

Table 4. **Effect of 'slicing' the sward with the injector on the annual dry matter yield. Nitrogen was applied as nitrolime, average of 70 and 140 kg N per ha to each cut. With the available horse-power it was not possible on the clay-soil to 'slice' more than 10 cm.**

Exp. no	Soil type	no of cuts	depth of slicing, cm: 0	5	10	15
			yield without injector damage 100 kg dm/ha	yield increase due to injector damage 100 kg dm/ha		
IB 738	sand	4	90.7	—1.6	—4.3	—4.8
IB 739	peat	4	74.2	—3.6	—5.0	—6.9
IB 741	clay	4	113.7	—9.4	—20.4	—

The depression in yield is generally greater the deeper the incision. This is strongly in evidence mainly on the clay soil, especially when rainfall after injection is low and the incisions made with the injector form broad furrows through which severe drying-out takes place (plate 5 and 6). If rainfall is heavy after injection then the damage to the sward has little or no effect on yield, as figure 1 shows.

Annual yield from top-dressing/injection after each cut

Yields from treatment 'nitrolime 0 cm' (i.e. conventional dressing with nitrolime) and from the best NH_3 treatment are shown in table 5. They indicate clearly that considerably higher yields are obtained from nitrolime than from NH_3. The poor effectiveness of NH_3 is only partially attributable to the so-called slicing effect. From a combined glance at tables 5 and 4 the obvious conclusion is that for equal depths of incision the comparison works out in favour of nitro-

Table 5. **Annual dry matter production (100 kg per ha) with nitrolime and NH_3. Average of 70 and 140 kg N per ha, applied to each cut. Between brackets depth of injection.**

exp. no	no of cuts	soil type	nitrolime	NH_3
IB 738	4	sand	90.7	49.2 (10)
IB 739	4	peat	74.2	60.1 (10)
IB 741	4	clay	113.7	79.7 (5)

lime. On peat and clay about 30% of the observed poorer effectiveness of ammonia may be blamed on the slicing of the sward, while on sandy soil only 10% of it may be ascribed to this cause.

Depth of injection

When injecting ammonia we should strive to keep nitrogen losses due to escape of ammonia to a minimum.

It is therefore important to know what the shallowest depth of incision ought to be, since it has already been shown in table 4 that sward damage decreases the shallower the incisions are. The risk of the gas escaping will, however, be greater. Furthermore, the depth of injection also has its consequences from a practical standpoint. The shallower the injection can be carried out the less is the tractive effort needed per tine, the more tines can be used and the greater therefore the working width. Under normal circumstances, with an injection depth of 10 cm, a working width of 1.5-1.75 metres (6 or 7 tines each 25 cm

Fig 1

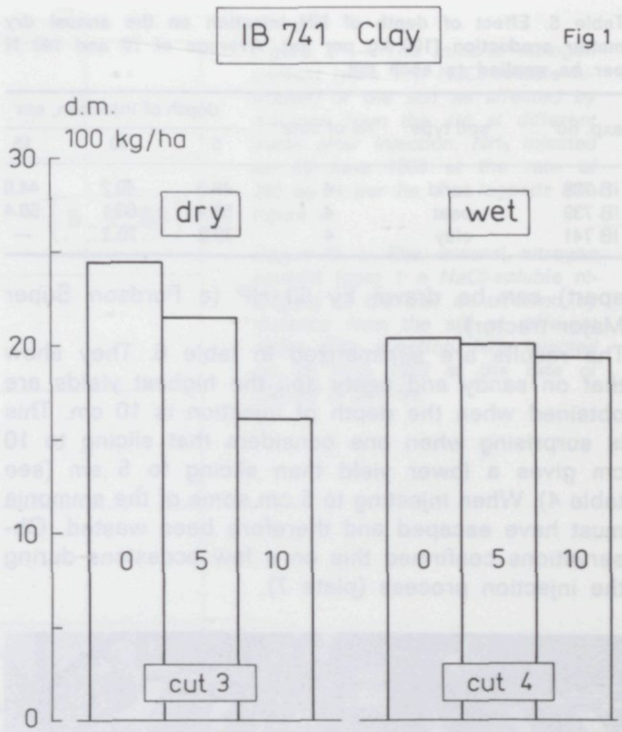


Figure 1 — Effect of rainfall on the damage caused by 'slicing' the sward with the injector. Dry: 34 mm rain in first two weeks after injection. Wet 74 mm rain in first two weeks after injection.

plate 5

plate 6

Table 6. **Effect of depth of NH_3-injection on the annual dry matter production (100 kg per ha). Average of 70 and 140 N per ha applied to each cut.**

exp. no	soil type	no of cuts	depth of injection, cm 5	10	15
IB 738	sand	4	48.3	49.2	44.8
IB 739	peat	4	58.4	60.1	56.4
IB 741	clay	4	79.6	70.7	—

apart) can be drawn by 50 HP (a Fordson Super Major tractor).

The results are summarized in table 6. They show that on sandy and peaty soil the highest yields are obtained when the depth of injection is 10 cm. This is surprising when one considers that slicing to 10 cm gives a lower yield than slicing to 5 cm (see table 4). When injecting to 5 cm some of the ammonia must have escaped and therefore been wasted. Observations confirmed this on a few occasions during the injection process (plate 7).

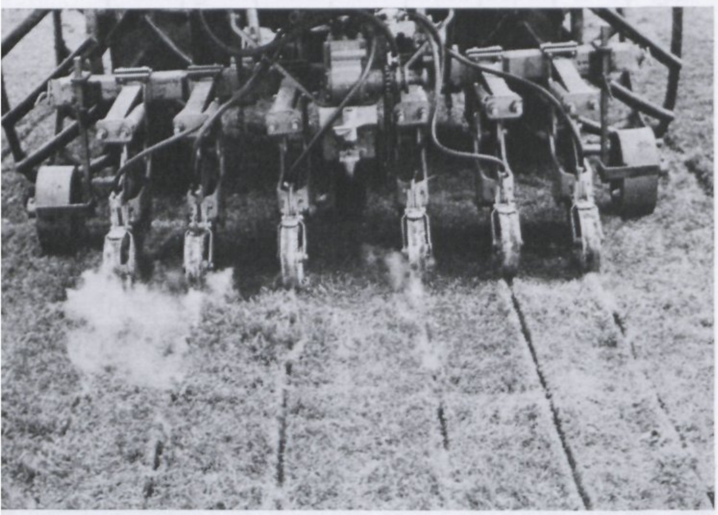


plate 7

The table also indicates that injecting at 15 cm gives a stronger yield depression than might be expected from reference to table 4. The possibilty exists that nitrogen placed at such depth is less readily available to the grass. It was, for example, observed that the grass greened more rapidly the shallower the injection depth.

Annual yield from a top-dressing/injection in spring only

The results are summarized in table 7. The application method which was used is known to be extremely unfavourable for good utilization efficiency of nitrogen from nitrolime. However, the total annual yield was slightly in favour of the ammonia on the peat soil only. On sandy soil, even nitrolime gave a much higher yield than ammonia did. In every instance, especially at the first cut, yields from ammonia were well below those from nitrolime. Except on the sandy soil, ammonia had a greater residual effect than nitrolime had. This is in complete accord with the results obtained by Mulder [6].

Table 7. **Annual dry matter production (100 kg per ha) with nitrolime and NH_3. Average of 250 and 500 kg N per ha applied as a single dressing in spring.**

cut	IB 738, sand nitro-lime	IB 738, sand NH_3	IB 739, peat nitro-lime	IB 739, peat NH_3	IB 741, clay nitro-lime	IB 741, clay NH_3
1	15.9	8.8	23.8	10.2	26.9	15.7
2	29.6	21.5	22.6	30.3	36.0	44.2
3	16.8	16.1	15.4	20.4	11.7	12.6
4	5.4	6.2	15.7	18.8	15.8	16.3
5	—	—	4.4	4.7	9.9	10.8
total	67.7	52.6	81.9	84.4	100.3	99.6

Spacing between the injector tines

Sideways diffusion of NH_3 away from the site of injection is not great [2]. It was, however, not known how far apart the injector tines ought to be spaced for use on permanent grassland. The greater the spacing between the tines the greater the permissible working width for a given number of tines (i.e. a given tractive effort).

In order to gain an impression of the permissible spacing between tines, instead of using one fixed spacing between tines in the trials discussed above the following variant was employed: spacing between tine 1 and tine 2, 25 cm; between tines 2 and 3, 30 cm; between tines 3 and 4, 40 cm; between tines 4 and 5 and between tines 5 and 6 respectively, 30 and 25 cm again (see also plate 7). It became apparent that with a spacing of 40 cm between tines a strip about 7 cm broad, on which the grass showed clear signs of nitrogen deficiency, was developed mid-way between the incisions. Where the tines were 30 cm apart there was no visible sign of this.

In the summer of 1963 two further independent trials were laid down on sandy and on clay soil to enable sideways diffusion of ammonia to be studied further. For this purpose soil and crop samples were taken at various distances from the incision. Soil samples were analysed for NaCl-soluble mineral nitrogen.

The results of the soil analysis are shown in figures 2 and 3. It may be concluded from these data that in both sandy and clay soil the ammonia has certainly

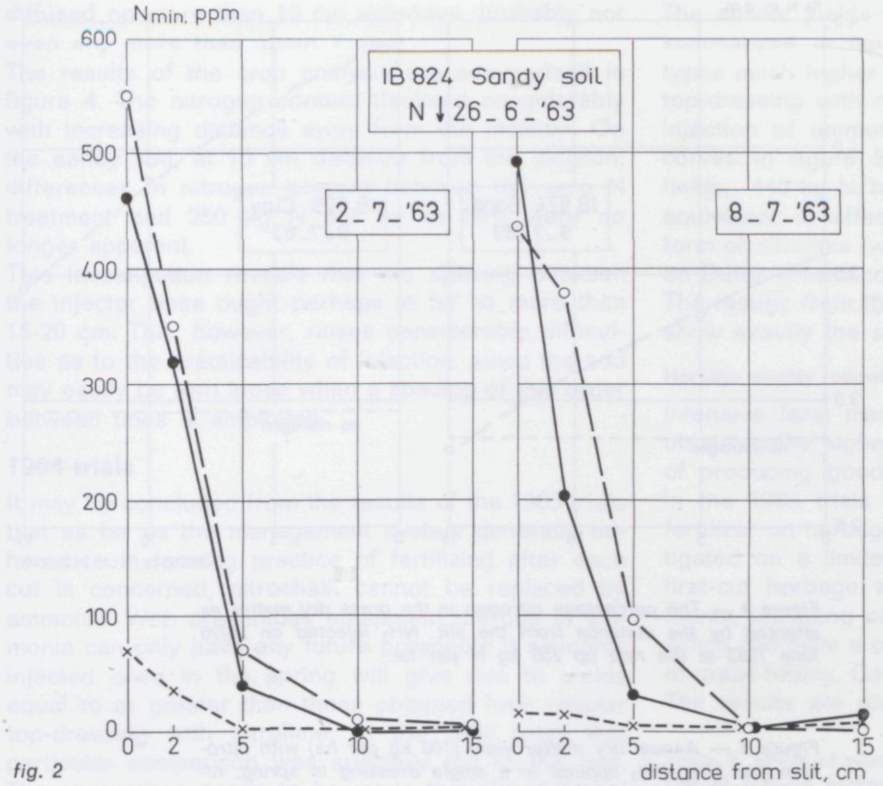


fig. 2

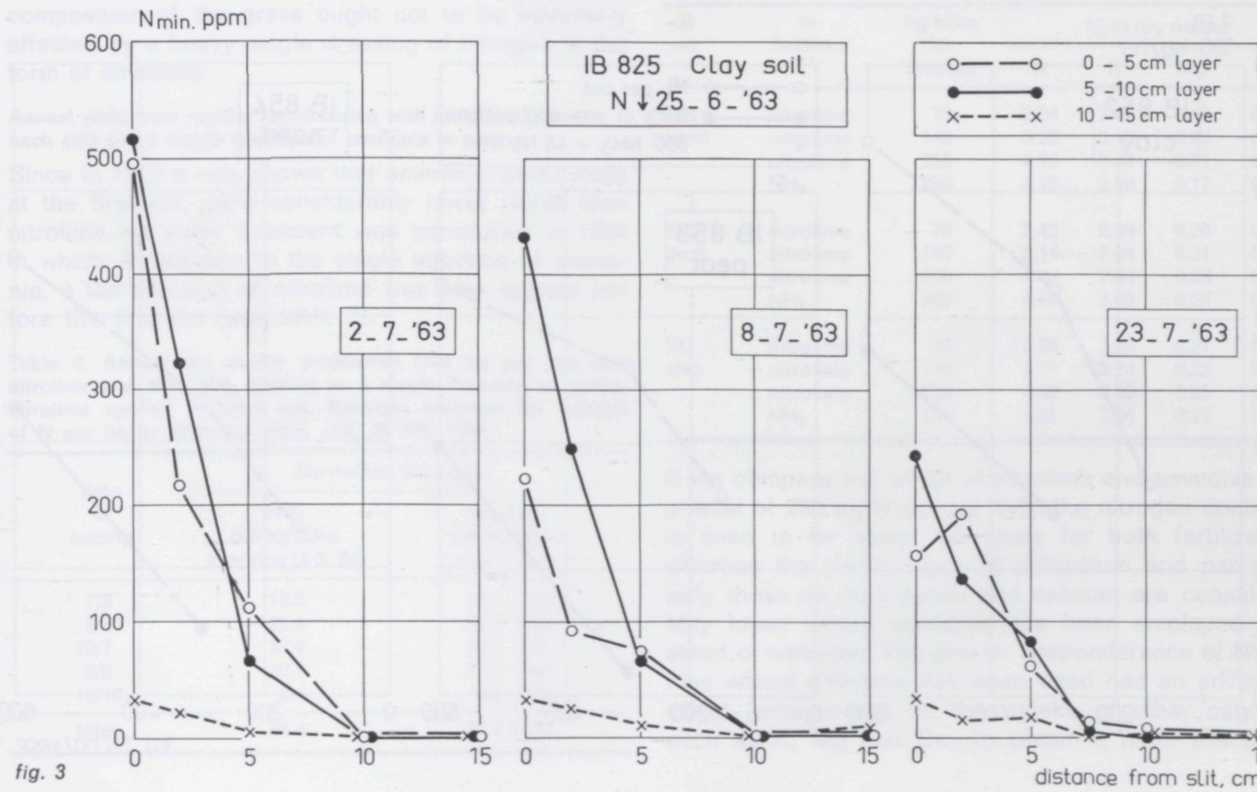


fig. 3

Figure 2 — The mineral nitrogen content (ppm 1 n NaCl-soluble nitrogen) of the soil as affected by distance from the slit at different dates after injection. NH_3 injected on 26 June 1963 at the rate of 250 kg N per ha. For legends see figure 3.

Figure 3 — The mineral nitrogen content (ppm 1 n NaCl-soluble nitrogen) of the soil as affected by distance from the slit at different dates after injection. NH_3 injected on 25 June 1963 at the rate of 250 kg N per ha.

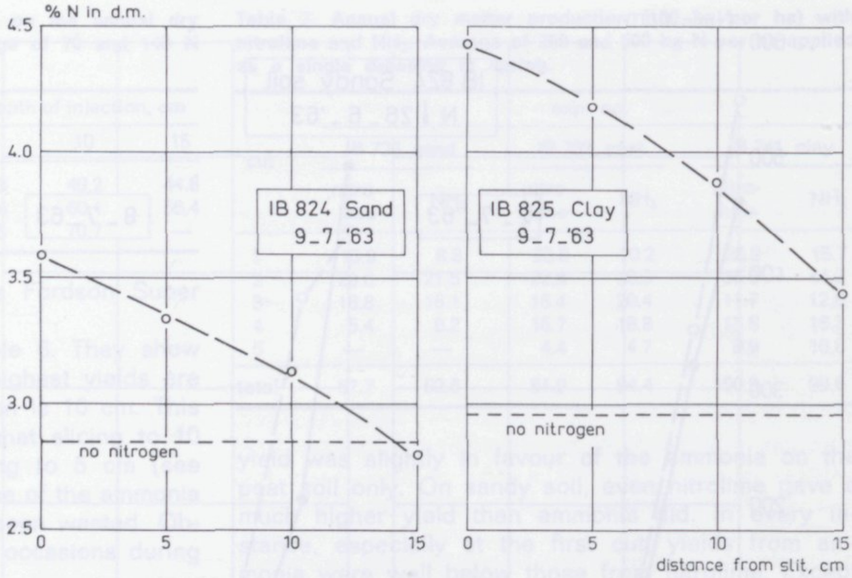
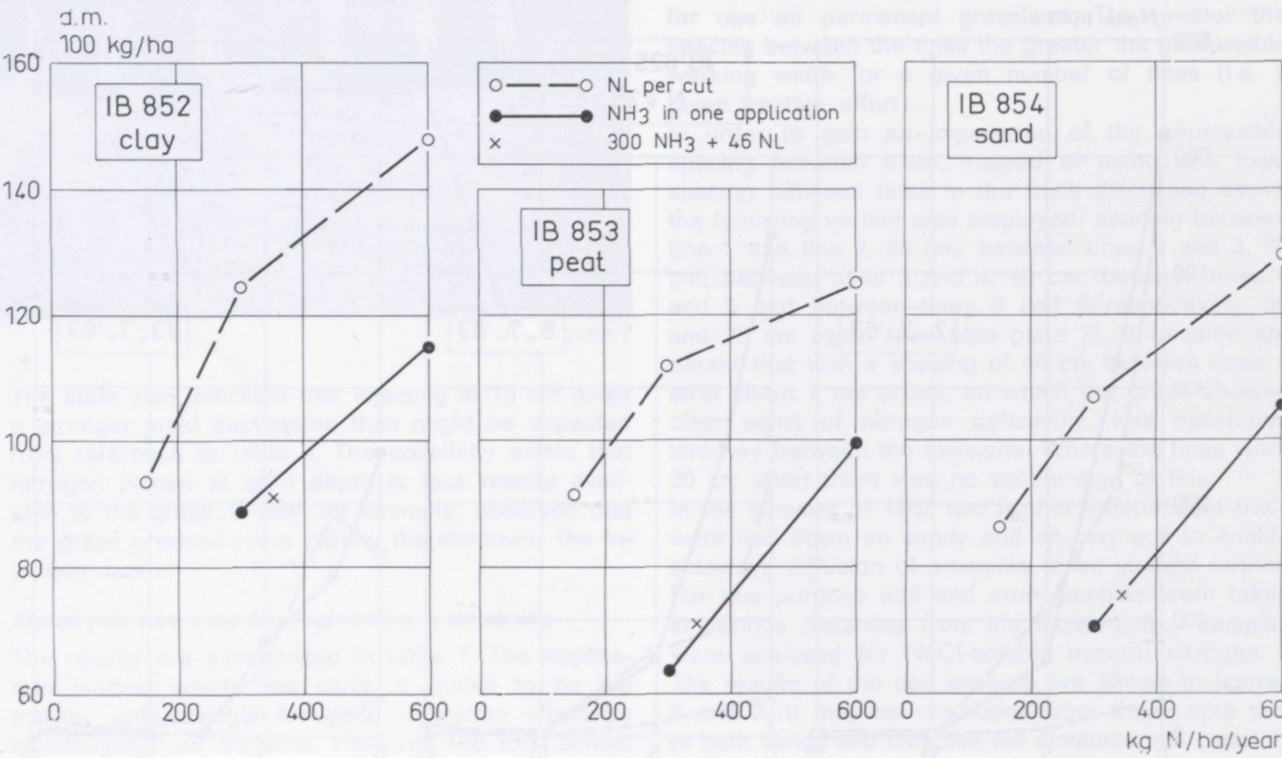


Figure 4 — The percentage nitrogen in the grass dry matter as affected by the distance from the slit. NH_3 injected on 26/25 June 1963 at the rate op 250 kg N per ha.

Figure 5 — Annual dry matter yield (100 kg per ha) with nitrolime and NH_3. NH_3 applied in a single dressing in spring, nitrolime applied after each cut.



diffused no more than 10 cm sideways, probably not even any more than about 7 cm.

The results of the crop analysis are summarized in figure 4. The nitrogen content declined considerably with increasing distance away from the incision. On the sandy soil, at 15 cm distance from the incision, differences in nitrogen content between the zero N treatment and 250 kg N per ha as NH_3 were no longer apparent.

This investigation reveals that the spacing between the injector tines ought perhaps to be no more than 15-20 cm. This, however, raises considerable difficulties as to the practicability of injection, since the sod may easily be torn loose when a spacing of this order between tines is employed.

1964 trials

It may be concluded from the results of the 1963 trials that as far as the management system generally adhered to in farming practice of fertilizing after each cut is concerned, nitrochalk cannot be replaced by ammonia. With presentday equipment the use of ammonia can only have any future prospects if ammonia injected once in the spring will give rise to yields equal to or greater than those obtained from regular top-dressing with nitrolime. In the 1964 trials this particular comparison was specially put to the test. The reservation needs to be made that the chemical composition of the grass ought not to be adversely affected by a heavy single dressing of nitrogen in the form of ammonia.

Annual yield from regular top-dressing with nitrolime (after each cut) and a single injection of ammonia in spring

Since in 1963 it was shown that ammonia, particularly at the first cut, gave considerably lower yields than nitrolime, an extra treatment was introduced in 1964 in which, in addition to the single injection of ammonia, a top-dressing of nitrolime was also applied before the first cut (see table 3).

Table 8. **Annual dry matter production (100 kg per ha) with nitrolime and NH_3. NH_3 applied as a single dressing in spring, nitrolime applied to each cut. Between brackets the amount of N per ha as nitrolime. Peat soil, *IB 906*, 1964**

date of cutting	dry matter, 100 kg/ha	
	NH_3 600 kg N/ha in spring (4-3-'64)	nitrolime 235 kg N/ha over 5 cuts
7/5	13.5	10.7 (54)
8/6	22.4	24.5 (60)
29/7	32.4	32.0 (60)
8/9	19.7	22.5 (46)
16/10	6.4	8.2 (15)
total	94.4	97.9 (235)

The annual yields (from a total of 5 to 6 cuts) are summarized in figure 5. It is clear that on all soil types much higher yields were obtained from regular top-dressing with nitrolime than from a single spring injection of ammonia. It may be deduced from the curves in figure 5 that, averaged over the 3 trial fields, 440 kg N/ha in the form of ammonia is about equivalent in effectiveness to 150 kg N/ha in the form of nitrolime (which is the average nitrogen usage on Dutch grassland), a ratio of 3 to 1.

The results from the farm-scale trial, given in table 8, show exactly the same trends.

Herbage quality following a single injection of ammonia

Intensive farm management is not only a matter of obtaining the highest possible yield of grass, but also of producing good quality herbage.

In the 1963 trials the effect of type of nitrogenous fertilizer on herbage chemical composition was investigated on a limited scale. A number of samples of first-cut herbage were analysed for various constituents, including nitrogen, potassium and magnesium which can have a considerable effect on the incidence of grass tetany. Calcium content was also determined. The results are given in table 9.

Table 9. **Effect of nitrolime and NH_3 on the chemical composition of first-cut herbage.**

IB no.	N-fertiliser	kg N/ha for first cut	% in dry matter			
			N	K	Mg	Ca
738	nitrolime	70	2.04	2.58	0.18	0.54
sand	nitrolime	140	3.28	3.18	0.20	0.61
	nitrolime	250	4.28	3.33	0.21	0.63
	NH_3	250	4.10	3.08	0.17	0.49
739	nitrolime	70	2.43	2.36	0.20	0.72
peat	nitrolime	140	3.14	2.84	0.21	0.73
	nitrolime	250	4.33	2.63	0.23	0.80
	NH_3	250	4.25	2.55	0.20	0.68
741	nitrolime	70	2.25	2.86	0.21	0.84
clay	nitrolime	140	3.71	3.14	0.23	0.89
	nitrolime	250	4.89	3.30	0.25	0.92
	NH_3	250	4.81	2.96	0.21	0.85

If we compare the effect of nitrolime and ammonia at a level of 250 kg N per ha, then the nitrogen content is seen to be about the same for both fertilizers, whereas the percentages of potassium and particularly those of magnesium and calcium are considerably lower where ammonia has been employed instead of nitrolime. The greater preponderance of NH_4-ions where ammonia has been used has an adverse effect (antagonism) on the uptake of other cations such as K, Mg and Ca. To obtain a more practical assessment, however, the effect of 250 kg N per ha as ammonia (single injection) ought to be compared with that of, say, 70 kg N per ha in the form of nitrolime (a more or less normal top-dressing for the first spring cut). It may be seen from this sort of comparison that higher nitrogen and potassium contents are obtained with ammonia than with nitrolime, whereas with both fertilizers the magnesium remains at about the same level. Even though the magnesium content does not show a decrease, the alteration in the mineral composition is still not to be regarded as a favourable one.

From the standpoint of grass tetany control, an increase in the contents of nitrogen and potassium and no change in the magnesium content always means a decline in the quality of the herbage [5].

REFERENCES

1. ADAMS, J. R., M. S. ANDERSON and W. C. HULBURT, Liquid nitrogen fertilisers for direct use. U.S.D.A. Agric Handboak 198, 1961, pp. 44.
2. ANDREWS, W. B., Anhydrous ammonia as a nitrogenous fertiliser. Advances in Agronomy 8, 1956, pp. 61-125.
3. BURG, P. F. J. VAN en G. D. VAN BRAKEL, De bemestingswaarde van ammoniak. Stikstof 4, 1964, pp. 260-274.
4. JAMESON, H. R., Liquid nitrogenous fertilisers. J. Agric. Sci. 53, 1959, pp. 333-338.
5. KEMP, A., Hypomagnesaemia in milking cows: the response of serum magnesium to alterations in herbage composition resulting from potash and nitrogen dressings on pasture. Neth. J. Agric. Sci 8, 1960, pp. 281-304.
6. MULDER, E. G., Investigations on the agricultural value of nitrophosphate and anhydrous ammonia. Fert. Soc. Proc. no. 25, 1953, pp. 50.
7. OLESEN, Joh., Oversigt over resultaterne of markforsøg i landboforeningere i Jylland 1964, pp. 663-783.