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Experiments on the use of anhydrous ammonia for grass

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SUMMARY

A hand injector was used to inject ammonia into soils in pots in which ryegrass was subsequently grown and under grass in the field; the spacing was varied.

Injecting ammonia or applying ammonium nitrate at one point or three points in the middle of a clay-loam and a sandy-loam soil in pots did not affect the growth of grass or its uptake of N. Grass with ammonium nitrate grew slightly better than with ammonia on the sandy loam and slightly worse on the clay loam.

Best yields of dry matter and most uptake of N were obtained from grass swards having ammonia injected in lines 23 and 30 cm apart and the injection points from one-quarter to one-half of the distance between rows. Increasing the distance between lines from 30 to 45 cm diminished total yield and uptake because the strip 15·2 to 22·8 cm from the line of injection grew less than grass nearer to the line of injection.

With grass grown in rows 12·1 cm apart, yields were greatest with the lines of injection perpendicular to the rows of grass and least with the ammonia injected along and into the rows. The yield of dry matter of the row with ammonia injected into it was usually less than of the adjacent row and the percentage N in the grass was usually more, so that the weight of N in the grass sometimes increased and sometimes decreased with distance from the line of injection depending on the relative changes in yield of dry matter and of percentage N.

INTRODUCTION

Anhydrous ammonia injected into the soil as a gas, a liquid under pressure or usually a mixture of both, has often increased yields of grass less than other forms of fertilizer-N (van Burg, van Brakel & Schepers, 1967). The reasons are not clear, but some workers have suggested that the injectors may damage the sward or ammonia may be lost through the slit made by the injector. Using a hand injector fitted with a hollow-needle for injection avoids damage to the sward and loss of ammonia during injection; also the amount applied can be more accurately measured than with existing field machinery. Our work used this method to investigate how the pattern of injection affected the gross yield of herbage and the way yield varied between lines of injection; we also compared effects on grass grown in pots of injected ammonia and placed ammonium nitrate.

EXPERIMENTAL

Sample preparation and analytical methods

All plant samples were weighed fresh; either the whole or a subsample was dried overnight at 80 °C and reweighed to calculate yields of dry matter. Per cent N in the dry matter was measured by a macro-Kjeldahl method and weights of N in crops calculated. pH of soils was measured using a soil: water ratio of 1:2·5, using a pH meter with a glass electrode and calomel reference electrode. Total-N in soils was measured by the standard Kjeldahl method of Bremner (1960). Organic-C in soils was measured by dichromate oxidation (Walkley and Black) (Bremner & Jenkinson, 1960) using a correction factor of 1·3.

Materials and methods used in pot experiment

Ryegrass was grown in 15·2 cm diameter polythene pots filled with either (i) a clay-loam soil from Geescroft, Rothamsted (derived from Clay-with-Flints [Batcombe series]) with pH 5·7 and containing 0·154 % total-N and 1·58 % organic-C, or (ii) a sandy-loam soil from Lansome Piece, Woburn Experimental Station (derived from Lower Greensand [Cottenham series]) with pH 6·3 and containing 0·061 % total-N and 0·58 % organic-C. The pots contained the same volume of each soil, requiring 2100 g of Rothamsted and 2500 g of Woburn soil. Anhydrous ammonia or ammonium nitrate supplied 0, 0·25, 0·50, 0·75 or 1·00 g N/pot and was applied either at a single point in the centre of the pot or as three equal portions in the

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horizontal plane at the mid-height of the pot. The experiment tested all combinations of five amounts of fertilizer-N supplied as ammonium nitrate or anhydrous ammonia applied at one or three points to the two soils and required 40 pots for each block. There were three blocks giving a total of 120 pots. Each pot had a basal PK dressing of 1 g KH_2PO_4 + 0·5 g K_2SO_4.

1000 g Rothamsted or 1200 g Woburn soil was weighed into each pot and firmed, and in the pots given ammonium nitrate, this was placed at one or three points on the surface of this portion of soil. The basal PK was mixed with 1000 g Rothamsted or 1200 g Woburn soil, which was then put in the pot. Water was added to the saucer to bring the soil to 40 % water-holding capacity (W.H.C.) (Gasser, 1961). Ammonia was injected with a hand injector either into the centre of the pot or at three points in the mid-plane, and the three replicates of each treatment were placed in a polythene bag with a beaker containing sulphuric acid. The acid was changed four times during a period of 10 days and an aliquot was tested with Nessler's reagent for absorbed ammonia. Perennial ryegrass (*Lolium perenne* S. 23) was sown at 0·75 g seed/pot on the soil surface and covered with 100 g of dry soil. Water was added to the saucers to bring the soil to 50 % W.H.C. and the surface was lightly sprayed. The pots were covered until plants emerged. Grass was sown on 5 May 1969 and cut on 3, 25 June, 22 July and 10 September.

Field experiment I, 1968

The experiment was with old permanent grassland on Parklands, Rothamsted. The soil is Batcombe series. Ammonia supplying 224 or 448 kg N/ha was injected 10 cm deep, with an area per injection of 232 cm², in three patterns: (i) at 15·2 cm × 15·2 cm centres; (ii) 7·6 cm apart in rows 30·5 cm apart; (iii) 5·1 cm apart in rows 45·7 cm apart. For patterns (ii) and (iii), the grass was cut in strips as shown in Fig. 3, to estimate yields in 7·6 cm strips from the line of injection. Plots with the three patterns of injection at the two amounts of N, together with two plots without N, were randomized in a block. The experiment had four blocks containing a total of 32 plots.

Ammonia was injected on 25 March and the grass was cut with shears three times on 15 May, on 1 July and on 19 August.

Field experiment II, 1969

The experiment was with a long ley in Appletree field, Rothamsted. The soil is Batcombe series. Ammonia supplying 224 or 448 kg N/ha was injected 10 cm deep in rows 15·2, 22·9 and 30·4 cm apart so that the distance within the row did not exceed the distance between the row with the area occupied by each injection of 116, 232, 464 or 929 cm². The nine treatment combinations at two rates of N, together with two plots without N, were randomized in a block and the whole experiment had three blocks. Plot sizes were 152 cm × 305 cm for block I and 152 cm × 183 cm for blocks II and III. Eight rows were injected for plots with 15·2 cm rows, six rows with 22·9 cm rows and five rows with 30·4 cm rows. The centre 91·4 cm of each plot was harvested, a length of 274 cm was taken from block I and 152 cm from blocks II and III. All plots were given 1000 kg/ha of a compound fertilizer containing 6·1 % P and 23·2 % K. Plots in block I were injected on 1, 2, 9, 10 April, block II on 10 April and block III on 11 April. (The delay was caused by a breakdown of the injector.) The grass was cut by a self-propelled scythe on 6 June, 23 July and 17 October and sampled as described.

Field experiment III, 1970

Ryegrass was sown in rows 12·1 cm apart on Stackyard field, Woburn. The soil, a sandy-loam derived from Lower Greensand (Cottenham series), had pH 5·5 and contained 0·078 % total-N and 0·69 % organic-C. Ryegrass (*Lolium perenne* S. 24) was sown on 11 September 1969, at 56 kg/ha; 750 kg/ha of a compound fertilizer, containing 6 % N:6·5 % P:12·5 % K supplying 45 kg N/ha, 49 kg P/ha and 94 kg K/ha was combine-drilled with the seed. The grass was cut with a rotary mower on 10 April 1970; ammonia supplying 448 kg N/ha was injected 10 cm deep on 16 or 17 April, and 'Nitro-Chalk' supplying 224 or 448 kg N/ha was applied on 17 April. The plots given 224 kg N/ha on 17 April were given 112 kg N/ha after each of the first and second cuts.

The eight plots with N, and two without, were randomized in a block. The whole experiment had four blocks, totalling 40 plots. Individual plots were 12 rows (144·8 cm) wide and 305 cm long. Ammonia was injected either *into* the rows of grass or *between* the rows of grass, every row, alternate rows or every third row. The area per injection was constant at 276 cm² and the injections were 22·9 cm apart for every row, 11·4 cm for alternate rows and 7·6 cm for every third row. 274 cm of the centre six rows of each plot were cut using hand-shears after removing 15·2 cm from each end of each plot with a rotary mower. From plots with ammonia injected in alternate rows, two adjacent rows were harvested separately and the remaining four together; from plots with ammonia injected every third row, three adjacent rows were harvested separately and the remaining three together. Grass was cut 13 May, 15 June, 29 July and 24 September. The fresh grass was weighed, samples were dried to measure percentage dry matter and total-N.

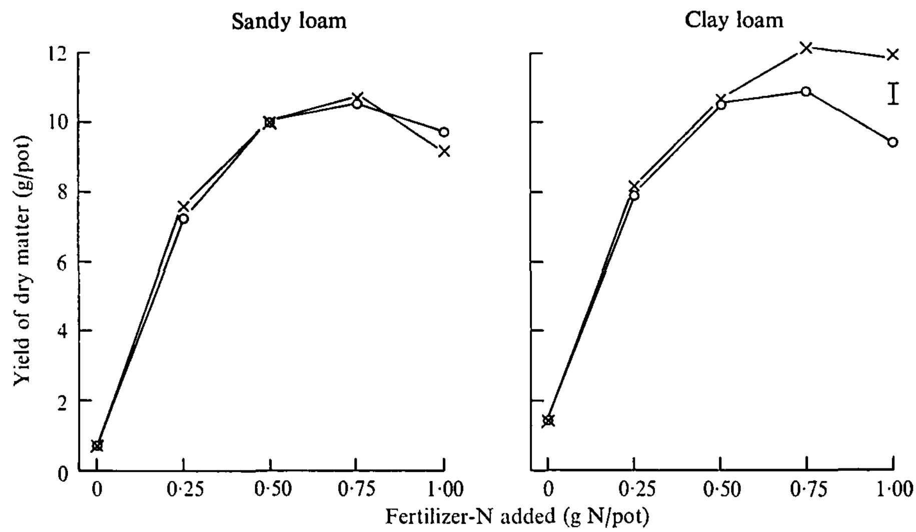

Fig. 1. Effects of fertilizer-N as ammonia and ammonium nitrate applied to two soils on the yield of ryegrass at the first cut. ●, No fertilizer-N; ×, fertilizer-N applied as ammonia; ○, as ammonium nitrate. I = least significant difference $P = 0{\cdot}05$.

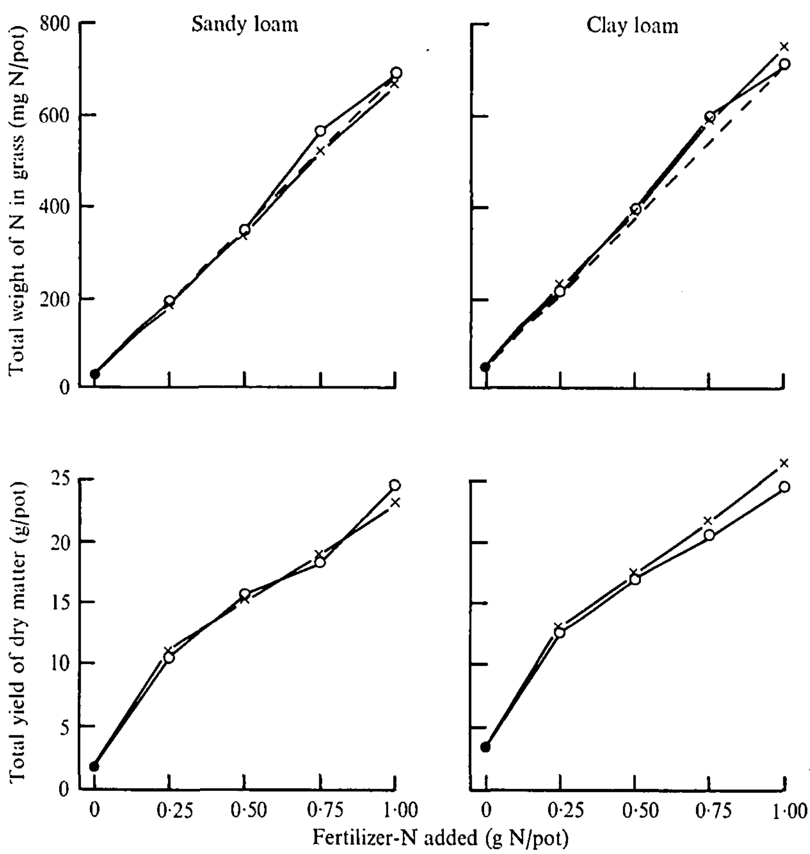

Fig. 2. Total yields of dry matter of grass and its uptake of N from two soils without added-N and with fertilizer-N as ammonia and ammonium nitrate. ●, No fertilizer-N; ×, fertilizer-N applied as ammonia; ○, as ammonium nitrate; ---, line of 2/3 recovery of fertilizer-N.

RESULTS

Pot experiment

Ammonia was evolved during incubation only from the most ammonia given to the sandy-loam soil, and was less than 0·01 % of the amount applied. The smallest amount of ammonium nitrate slightly delayed germination of the grass and with the two largest amounts the centre 5–8 cm of the pot remained without seedlings for 15–20 days. Anhydrous ammonia did not delay germination but the largest amount applied retarded growth, more on the light than the heavy soil, and Fig. 1 shows these adverse effects were reflected in the yields at the first cut. With the most N applied, both forms affected yields equally on the sandy soil and ammonium nitrate more on the clay loam. Fig. 2 shows the total dry matter produced by the grass and the N taken up from the two soils. Slightly more dry matter was produced with ammonia than with ammonium nitrate on the heavy soil, but it did not consistently contain more N; conversely, dry matter produced on the light soil varied between forms with the amount applied, but the grass given ammonium nitrate always contained slightly more N. As the following average values show, ammonium nitrate increased yields of dry matter and uptake of N more than did ammonia on the sandy soil and less on the clay soil (Table 1).

Field experiment I, 1968

Table 2 gives the monthly rainfall and amounts between cuts. February and March were drier than average; rainfall was near average until July, when the weather was much wetter. Table 3 gives the whole plot yields and N uptake for each cut and the total for three cuts. At the first cut, the widest spacing produced least dry matter containing least nitrogen, whereas at the third cut the reverse was true, the widest spacing produced most dry matter containing most N. With the smaller amount of nitrogen, ammonia injected in rows 30·5 cm apart produced most grass containing most N. With 448 kg N/ha, yields differed less, but grass contained least N with ammonia injected in rows 45·7 cm apart.

Table 4 shows that, with ammonia injected in rows 30·5 cm apart, the first two cuts of grass 7·6–15·2 cm from the line of injection yielded slightly less and contained less N than grass adjoining the line of injection. The longer-term residual value measured in the third cut was very similar for both strips with 224 kg N/ha, but was greater in the 7·6–15·2 cm strip with 448 kg N/ha. With

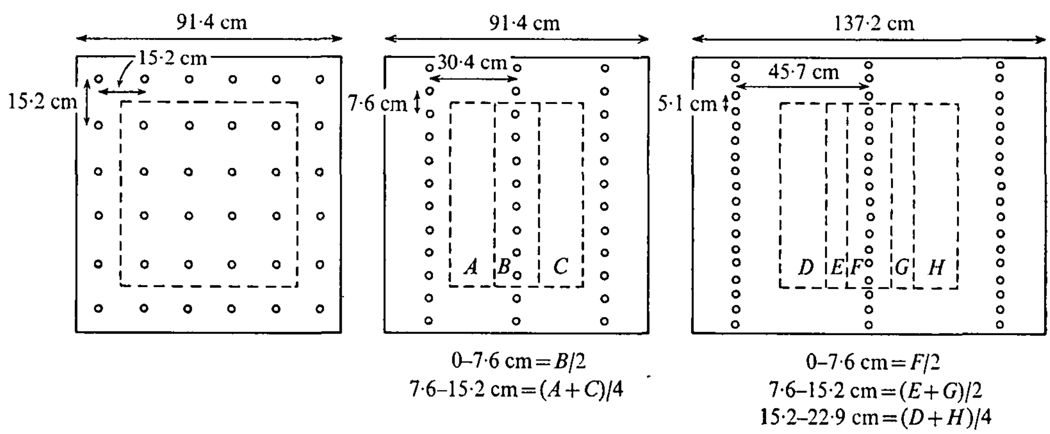

Fig. 3. Plot sizes and patterns of injecting ammonia with areas harvested to allow estimation of yields in strips 7·6 cm wide from the line of injection. ○, Injection point. ---, boundary of harvested strip or area.

Table 1

Soil	Fertilizer-N applied as: Ammonium nitrate	Anhydrous ammonia	Ammonium nitrate	Anhydrous ammonia
	Dry matter (g/pot)		N uptake (g N/pot)	
Sandy loam	15·4	15·2	0·42	0·40
Clay loam	15·3	16·2	0·44	0·45

ammonia injected in rows 45·7 cm apart, yield and N uptake were always less in the 15·2–22·9 cm strip than in the 0–7·6 cm strip with both amounts applied. With the smaller amount, the 7·6–15·2 cm strip yielded the same as the 0–7·6 cm strip at the first cut, and more at the second and third cuts; N uptake was less at the first cut. With 448 kg N/ha yields and uptakes in the 0–7·6 cm and 7·6–15·2 cm strips differed less but followed the same pattern as with 224 kg N/ha.

Field experiment II, 1969

April was drier than average but weather was very wet in May, and the first cut was delayed by about 10 days (Table 2). Growth was restricted by drought through the rest of the season, especially

Table 2. *Monthly totals of rainfall (mm) at Rothamsted and Woburn during the experiments and the long-term averages*

	Rothamsted			Woburn	
Month	1968	1969	Long-term average	1970	Long-term average
J.	66	73	64	56	53
F.	24	65	48	57	40
M.	27	48	48	45	42
A.	65	38	75	71	45
M.	54	81	54	7	55
J.	58	37	56	32	50
J.	85	52	65	42	56
A.	75	46	66	64	62
S.	139	10	61	37	52
O.	54	6	75	18	57
N.	49	89	71	131	63
D.	78	66	67	38	54

Rainfall (mm) between injection and first cut and between cuts.

	Rothamsted				Woburn	
	1968		1969		1970	
Injection–cut 1	26 Mar. –16 May	113	11 Apr. –6 June	117	16 Apr. –13 May	38
Cut 1–cut 2	17 May –2 July	67	7 June –23 July	58	14 May –15 June	5
Cut 2–cut 3	3 July –20 Aug.	150	24 July –17 Oct.	83	16 June–29 July	71
Cut 3–cut 4	—	—	—	—	30 July –24 Sept.	101

Table 3. *Yield of dry matter of grass and its uptake of N without fertilizer-N and with ammonia supplying 224 or 448 kg N/ha injected at three spacings*

		Anhydrous ammonia injected at spacing					
		15·2 cm × 15·2 cm		30·5 cm × 7·6 cm		45·7 cm × 5·1 cm	
		Supplying kg N/ha					
	No added fertilizer-N	224	448	224	448	224	448
		(*a*) Yield of dry matter (kg/ha)					
Cut 1	2 230	3210	3680	3460	3300	3000	2990
2	2 410	3300	3800	4100	4180	3630	3890
3	1 960	2160	2800	2390	2950	2480	2990
Total	6 600	8660	10280	9950	10430	9110	9870
		(*b*) Uptake of N (kg N/ha)					
Cut 1	50	116	146	114	126	98	96
2	44	76	121	100	127	94	115
3	45	52	81	57	87	63	97
Total	139	244	348	. 271	339	254	307

Table 4. *Effects of distance from line of injecting ammonia on yield of dry matter and N uptakes of grass*

	Distance between lines of injection (cm)				
	30·4		45·7		
	Distance of strip from line of injection (cm)				
	0–7·6	7·6–15·2	0–7·6	7·6–15·2	15·2–22·9
	Yields of dry matter as % of 0–7·6 cm strip				
224 kg N/ha					
Cut 1	100	87	100	100	70
2	100	86	100	120	83
3	100	101	100	123	94
448 kg N/ha					
Cut 1	100	92	100	95	88
2	100	91	100	110	88
3	100	113	100	104	88
	N uptakes as % of 0–7·6 cm strip				
224 kg N/ha					
Cut 1	100	84	100	82	49
2	100	85	100	110	71
3	100	97	100	119	93
448 kg N/ha					
Cut 1	100	80	100	86	68
2	100	94	100	104	73
3	100	111	100	102	84

in September after the second cut. At cuts 1 and 2, yields and N uptakes did not differ significantly between treatments (Table 5), but at cut 3 they were larger at intermediate than at either the extreme spacings or square spacings, except that the 30·5 × 3·8 cm spacing was good because of poor yields at cuts 1 and 2. Total yields and uptakes do not show great differences between spacings, and, for grass with 448 kg N/ha, Table 6 suggests that yields and uptakes are similar over considerable ranges of spacing. They tend to decrease (i) at widest and closest spacing, and (ii) with injections in rows 22·9 and 30·5 cm apart when the spacing within the row is similar to the distance between the rows, i.e. with square or nearly square spacing.

Field experiment III, 1970

After applying the fertilizers little rain fell and by the first cut in mid-May, growth of the grass was restricted by drought (Table 2); less than 6 mm of rain fell between mid-May and mid-June. July and September each had about three-quarters as much rainfall as average.

Table 7 gives the yields of dry matter and N uptake by the grass at each cut and the total for 1970. At the first cut grass yields were greatest with 'Nitro-Chalk' (production did not differ significantly between the single, 448 kg N/ha, and divided, 224 kg N/ha, dressing), and least with ammonia injected *into* alternate rows and *into* every third row. At the second cut, most dry matter was produced by ammonia previously injected *into* every row and least by the single dressing of 'Nitro-Chalk'. At the fourth cut ammonia injected *between* every third row gave the greatest yield and least was from the single dressing of 'Nitro-Chalk'. Over the whole season most grass was produced by injecting ammonia *into* every row of grass and least from ammonia injected *into* alternate rows or *into* every third row and the single dressing of 'Nitro-Chalk'.

Although grass with the divided dressing of 'Nitro-Chalk' contained least weight of N at the second cut, it contained most N when all four cuts were totalled. Similarly although the single dressing of 'Nitro-Chalk' did not persist as long as the ammonia, more total-N was removed in grass with 'Nitro-Chalk' than with ammonia. Least N was recovered from ammonia injected *into* alternate rows or every third row of grass. Recoveries of fertilizer-N in 1970 ranged from 68% from the divided broadcast dressing of 'Nitro-Chalk' to 51% from ammonia injected *between* alternate rows of grass.

To see whether the fertilizer-N had any residual effects the experiment was continued into 1971.

Table 5. *Yields of dry matter of grass and its uptake of N without fertilizer-N and with ammonia supplying* 224 *or* 448 *kg N/ha injected in*

	Yield of dry matter (kg/ha)				N uptake (kg N/ha)			
	Cut 1	Cut 2	Cut 3	Total	Cut 1	Cut 2	Cut 3	Total
No fertilizer-N ...	3220	1450	560	5230	48	23	10	81
Spacing of injections (cm × cm)								
With anhydrous ammonia supplying 224 kg N/ha								
15·2 × 7·6	6320	2210	490	9020	143	44	9	196
22·9 × 5·1	6400	3060	670	10140	161	67	12	240
30·5 × 3·8	6370	2790	620	9780	143	51	11	206
15·2 × 15·2	6170	2550	570	9300	132	48	11	191
22·9 × 10·2	5410	2180	720	8320	150	43	14	207
30·5 × 7·6	5780	2360	580	8730	159	56	11	215
22·9 × 20·3	5840	2350	720	8910	151	43	13	208
30·5 × 15·2	5900	2510	590	9000	135	47	11	193
30·5 × 30·5	6250	3190	660	10100	149	63	12	219
With anhydrous ammonia supplying 448 kg N/ha								
15·2 × 7·6	6720	3060	1230	11010	180	72	27	280
22·9 × 5·1	6150	3410	1800	11370	179	92	38	309
30·5 × 3·8	5830	3050	1830	10710	162	84	45	290
15·2 × 15·2	7060	3110	1420	11590	192	80	31	303
22·9 × 10·2	6520	3390	1530	11430	184	90	36	310
30·5 × 7·6	5900	3340	2060	11300	171	90	53	313
22·9 × 20·3	6290	3570	930	10780	168	89	18	275
30·5 × 15·2	6320	3300	1700	11320	192	89	38	319
30·5 × 30·5	5780	3920	1420	11320	154	96	33	287
	± 324	± 275	± 148	± 447	± 8·8	± 6·6	± 4·3	± 12·8

Table 6. *Total fertilizer-N recovered from* 448 *kg N/ha injected in various patterns*

Distance between rows (cm)	Area of injection (cm^2)			
	116	232	464	929
	Fertilizer-N recovered (kg N/ha)			
15·2	199	222	*	*
22·9	228	229	194	*
30·5	209	232	238	206

* Pattern not used.

Each plot was given 630 kg/ha of a compound fertilizer containing 6·1 % P and 23·2 % K on 17 March. The grass was cut on 3 May by harvesting 274 cm of the centre six rows of each plot with a rotary mower, after removing 15·2 cm from each end. Individual rows were not cut. Table 7 shows that all fertilizer-N applied in 1970 increased yields of dry matter and weight of N in the crop in 1971, most by ammonia injected *into* every third row and least by the single dressing of 'Nitro-Chalk'. Total yield of dry matter in 1970 + 1971 was greater with ammonia injected every row or every third row than with 'Nitro-Chalk', but the grass contained less fertilizer-N (Table 8). Most fertilizer-N (71 %) was recovered from the divided dressings of 'Nitro-Chalk' and least (55 %) from ammonia injected under alternate rows of grass (on average of *into* and *between* rows).

Table 8 shows the yields from individual rows for ammonia injected *into* and *between* alternate rows and every third row, expressed as percentages of those of grass with ammonia injected every row averaging *into* and *between* rows. For ammonia injected *between* alternate rows the rows are similar. The results, averages of both rows, show that this spacing was less good than injecting in rows across

Table 7. *Yield of dry matter of grass and its uptake of N without fertilizer-N and with ammonia or Nitro-Chalk supplying* 448 *kg N/ha*

		1970						1970+1971
		Cut 1	Cut 2	Cut 3	Cut 4	Total	1971	total
		Yield of dry matter (kg/ha)						
	No nitrogen ...	2500	710	490	590	4280	640	4920
	Ammonia injected							
Every row	Between rows	3420	3000	3100	2990	12510	1950	14460
	Within rows	3410	2770	3050	2920	12150	1980	14130
Alternate rows	Between rows	3600	2220	2560	2640	11020	1950	12970
	Within rows	3120	2500	2670	3030	11320	1660	12980
Every third row	Between rows	3290	2450	2620	3490	11850	2410	14260
	Within rows	3060	2500	2710	3000	11260	3280	14540
	'Nitro-Chalk'							
Single dressing		4220	2020	2470	2590	11310	1250	12560
Divided dressing		4270	1340	2840	3180	11630	1750	13380
Standard error		±113	±277	±165	±165	±432	±258	±385
		N uptake by grass (kg N/ha)						
	No nitrogen ...	35	10	6	8	59	9	68
	Ammonia injected							
Every row	Between rows	100	81	72	65	319	28	347
	Within rows	101	75	81	63	320	29	349
Alternate rows	Between rows	103	64	61	58	286	28	314
	Within rows	92	67	68	67	294	24	318
Every third row	Between rows	87	66	68	82	303	36	339
	Within rows	81	64	70	74	290	47	337
	'Nitro-Chalk'							
Single dressing		168	60	64	54	345	19	364
Divided dressing		157	32	89	82	362	15	387
Standard error		±4·1	±6·0	±5·7	±4·7	±10·0	±4·0	±10·3

the grass at cuts 2, 3 and 4 and for the total in 1970. Injecting ammonia *into* alternate rows or every third row lessened yields and uptake of N by that row; the adjacent rows obtained sufficient N to make slightly better growth than with the rows of injection across the rows of grass, i.e. injected every row. With ammonia injected *between* every third row, the two rows adjacent to the line of injection grew better than with injection across the rows, but the third row more distant from the injection failed to obtain enough N for maximum growth. N uptake followed a similar pattern.

DISCUSSION

As the grass in pots showed, where ammonia was not lost and growth was not damaged it was as good a source of fertilizer-N as ammonium nitrate. Therefore the inferior performance of ammonia in the field was due to other causes including damage to the grass.

Increases in yield and N uptake by grass were independent of spacing of injections at discrete points over wide ranges. Square spacing was less good than in rows 22·9–30·5 cm apart with spacing within the row from one-quarter to one-half of the distance between rows, giving an approximately continuous line of treated soil. With grass grown in rows, injecting ammonia along and *into* the row damages the grass; in established swards this damage is masked by the more uniform distribution of plants. Experiments with grass cut in strips suggest that the loss of total yield may be as much as 10%. When ammonia was injected in rows 45·7 cm apart, yield and N uptake by grass in the strip 15·2–22·9 cm from the line of injection were always least, suggesting the distance was too great. This was confirmed when ammonia was injected *between* every third row of grass sown in rows 12·1 cm apart; the row more distant from the injection (18·1 cm) yielded only half as much as the adjacent rows.

Table 8. *Effect of ammonia injected into or between alternate rows or every third row of grass on the yields of individual rows and their N contents compared with ammonia injected every row (on average of within and between rows)*

	Weight of N in grass with ammonia injected every row (kg N/ha)	Ammonia injected									
		Alternate rows				Every third row					
		Between		Within		Between			Within		
		Row 1	Row 2	Row 1	Row 2	Row 1	Row 2	Row 3	Row 1	Row 2	Row 3
		↓ (between Row 1 and Row 2)			↓		↓ (between Row 2 and Row 3)			↓	
		Weight of N in grass as % of that injected every row									
Cut 1	100	102	102	82	82	54	103	103	75	91	75
Cut 2	78	82	82	99	72	57	99	99	97	53	97
Cut 3	76	80	80	95	82	53	106	106	99	78	99
Cut 4	64	91	91	115	94	78	156	156	130	92	130
Total	319	90	90	99	85	59	113	113	97	78	97

	Yield of grass with ammonia injected every row (t/ha)	Ammonia injected									
		Alternate rows				Every third row					
		Between		Within		Between			Within		
		Row 1	Row 2	Row 1	Row 2	Row 1	Row 2	Row 3	Row 1	Row	Row 3
		↓ (between Row 1 and Row 2)			↓		↓ (between Row 2 and Row 3)			↓	
		Yield of grass as % of that injected every row									
Cut 1	3·42	105	105	95	88	78	105	105	94	81	94
Cut 2	2·88	77	77	102	71	61	97	97	104	50	104
Cut 3	3·08	83	83	97	76	58	99	99	104	56	104
Cut 4	2·96	89	89	117	88	78	138	138	119	66	119
Total	12·33	89	89	102	81	69	110	110	105	64	105

Notes: ↓ indicates point of injection. Some pairs of rows are equivalent: 1 and 2 for alternate rows between rows. 2 and 3 for every third row between rows. 1 and 3 for every third row within rows.

The better performance of ammonia injected in rows compared with square or nearly square spacing suggests a complex ammonia-soil-plant interaction which cannot be quantified from these results but which warrants further investigation.

The use of ammonia as an N-fertilizer for grass poses a dilemma. Injecting the ammonia in rows is the most efficient way of applying it, but the concentration of ammonia in the usual spacing (30·5 cm apart) and supplying enough N (200–400 kg N/ha) to give good yields of grass, damages the grass along the line of injection (irrespective of any mechanical damage by the injector) thereby diminishing yields.

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