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AP-42 #17

Chapter 48

Aerodynamic measurement of ammonia volatilization from urea applied to bluegrass - fescue turf (1)

R.W. SHEARD and E.G. BEAUCHAMP

ABSTRACT

Ammonia (NH_3) volatilization from 100 kg N ha^{-1} applied as urea to a closely mowed Poa pratensis - Festuca rubra turf was measured using aerodynamic procedures. A volatilization loss of 15.1% occurred where no rain occurred for 8 days after application in contrast to [illegible].7% where rain occurred in 72 hr. Strong diurnal changes in the flux of NH_3 were observed, reaching maxima near midday and minimal values during the night. High values of NH_3 volatilization measured by closed chamber techniques which have been recorded in the literature may be considered erroneous because they do not consider all the direct and interactive effects of the total environment.

Additional key words Ammonia, Volatilization,Urea, Poa pratensis, Festuca rubra

INTRODUCTION

The economic advantage of urea as a solid nitrogen source for turf is often discounted due to the incipient volatilization loss of ammonia (NH_3) following surface application. Estimates of volatilization loss range from 10% (Torillo et al., 1983) to 68% (Fenn and Kissel, 1974). The range is partially due to the experimental procedure used in measuring the NH_3 flux; the use of enclosure techniques with atypical microenvironments provided higher estimates of NH_3 loss compared with aerodynamic field measurements which do not disturb the physical environment and provide lower estimates of NH_3 loss. The micrometeorological conditions are important because temperature, humidity, wind speed and solar radiation directly or interactively influence NH_3 volatilization.

Other factors affecting the volatilization of NH_3 from urea are soil pH, cation exchange capacity, rate of urea application, type of vegetation and occurance of thatch in turf which may have 18 to 25 times greater urease activity than the underlying soil (Torello and Wehner, 1983). Maximum volatilization, therefore, may be expected to occur from heavily thatched turf, excessively fertilized with urea in warm, humid weather without subsequent irrigation or rainfall.

The current study was conducted to obtain estimates of the magnitude of NH_3 loss from urea applied to mowed bluegrass-fescue turf using a aerodynamic diffusion method.

(1) A contribution from the Department of Land Resources Science, O.A.C., University of Guelph, Ontario, N1G2W1 Canada.

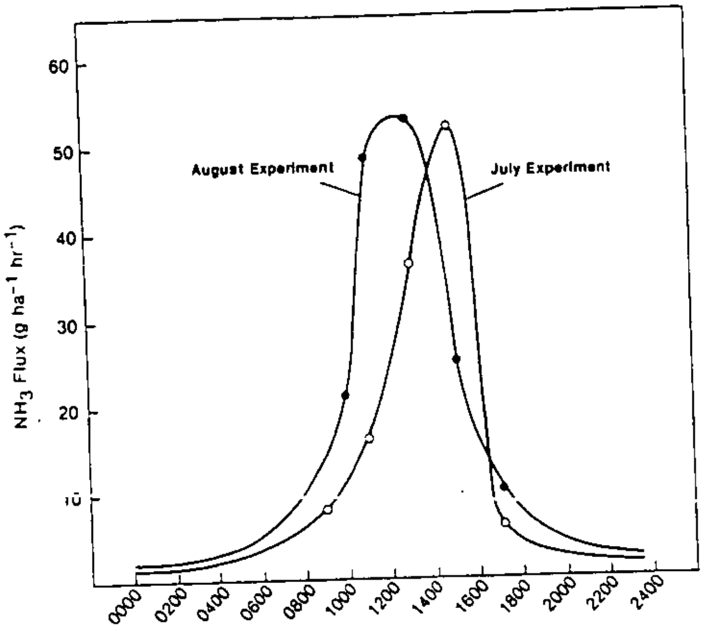

Fig. 1. Diurnal change in the background ammonia flux for the July and August experiments.

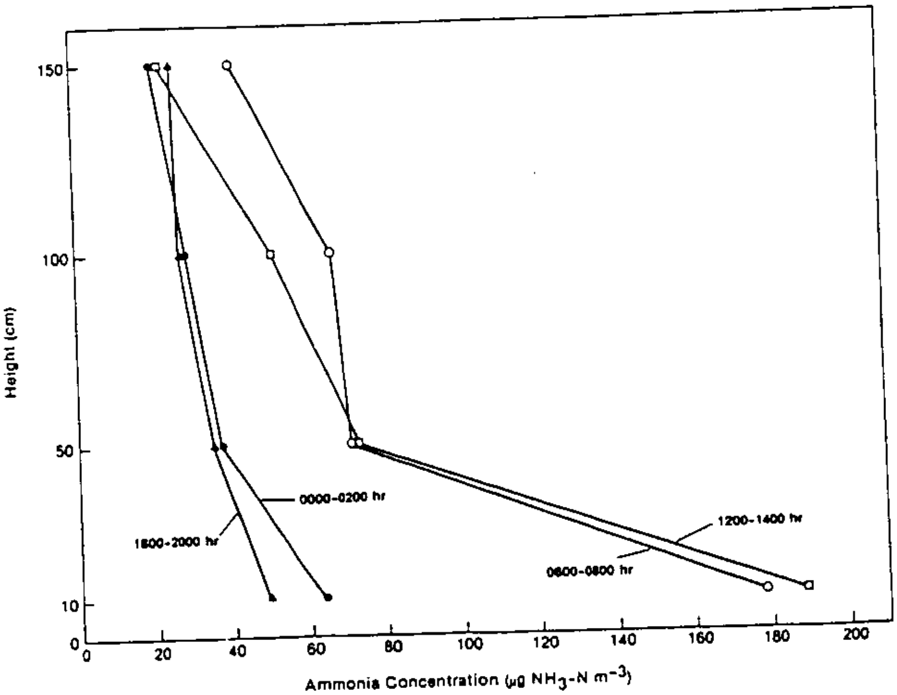

Fig. 2. The influence of time of day on the ammonia profile above turf grass.

MATERIALS AND METHODS

Ammonia flux from an application of urea to a Kentucky bluegrass (Poa pratensis L.) - creeping red fescue (Festuca rubra L.) sod, mowed at 7.5 cm, was measured by the aerodynamic procedure outlined by Beauchamp et al. (1978). Two experiments were conducted, one during the period July 11 to July 19, and the second during the period August 22 to 27.

The procedure consisted of placing a mast in the center of a circular area (0.405 ha) on to which urea had been broadcast at 100 kg N ha^{-1}. Ammonia gas collector flasks and sensitive anemometers were mounted on the mast to obtain measurements at heights of 10, 50, 100 and 150 cm above the soil surface. The gas collector flasks were 500 mL glass tubes (4.1 cm i.d., 64 cm long and tapered at one end) containing approximately 90 cm^3 of 3 mm diam glass beads and 75 mL 3% (v/v) H_3PO_4 solution. Air sampling was performed by continually drawing air through a 0.7 mm glass tube orifice and then through the gas collectors on the mast for 2-hr periods by an electromagnetic piston air pump. The air flow rate (10-20 L min^{-1}) was measured with a mass flow indicator (Model 8143, Matheson Gas Products) and a mass flow controller (Model 8163, range 0-50 SLPM, Matheson Gas Products). Multi-wire cable and plastic tubing connected the anemometers and gas collecting flasks on the mast to the pumps and air flow measurement devices in a mobile laboratory located adjacent to the experimental area. The NH_4^+-N concentration in the gas collector solution was determined colorimetrically by a Technicon AutoAnalyzer procedure having a sensitivity of 0.1 μg N mL^{-1}. The NH_3-N concentration in the air sampled at each height during a 2-hr period was calculated as:

$$\text{Atm } NH_3\text{-N concn } (\mu g\ m^{-3}) = \frac{NH_4\text{-N in } H_3PO_4 \text{ soln } (\mu g\ 2\ hr^{-1}) \times 1000\ L\ m^{-3}}{120\ min\ 2\ hr^{-1} \times \text{air flow } (L\ min^{-1})}$$

The vertical flux of NH_3 from the turf surface was assumed equal to the integrated product of wind speed x atmospheric NH_3 concentration by height to 150 cm, divided by the radius of the application area. Integration was accomplished by a planimeter estimate of the area enclosed by a graphical plot of height against the product of wind speed x atmospheric NH_3 concentration. The integral below 150 cm was multiplied by a constant factor of 1.38 to give the total integral according to the predicted model (Wilson et al., 1982, Beauchamp et al., 1978). Background measurements of NH_3 flux were made for several 2-hr periods prior to spreading the urea and were subtracted from measured flux values for the corresponding experimental period. Detail of the theory and practice of aerodynamic procedures may be found in Wilson et al. (1982) and Denmead (1983).

RESULTS

Previous studies have shown a strong diurnal shift in the NH_3 flux measured by the aerodynamic procedure (Beauchamp et al., 1978). A similar shift was considered likely to occur in background readings, therefore NH_3 fluxes were measured for several 2-hr periods prior to spreading the urea (Fig. 1). Estimates of the background flux for each 2-hr period during 24 hr were obtained from a plot of the data.

In general NH_3-N concentration profiles increased curvilinearly toward the soil surface (Fig. 2). The data for July 15 illustrate the typical profile changes which were measured during a 24-hr period, beginning with a relatively vertical profile at 0100 hr, increasing to high concentrations near the turf surface near midday, then returning to a vertical profile at 0700 hr.

In the July experiment the NH_3 flux exhibited the characteristic diurnal fluctuations, reaching a maximum value of 668 g ha^{-1} hr^{-1} at 1100 hr after an elapsed time of 118 hr following urea application (Fig. 3). Maximum fluxes of 459, 488, 226 and 419 g ha^{-1} hr^{-1} had been measured on previous days and subsequent maximum values averaged 260 g ha^{-1} hr^{-1}. During the August experiment a maximum value of 1067 g ha^{-1} hr^{-1} was attained at 1300 hr after an elapsed time of only 26 hr following urea application (Fig. 4). This high value occurred 8 hr after a 3.4 mm rain which would dissolve the urea but not move it into the dry soil surface. An 18.7 mm rainfall 6 hr after the maximum value greatly reduced further NH_3 flux. Minimal values over the five days, which occurred between 2200 and 0200 hr, averaged 32 g ha^{-1} hr^{-1}.

The accummulated total volatilization loss of NH_3-N in the July experiment for the 8-day period was 15.06 kg N ha^{-1} representing 15.1% of the urea-N applied. In contrast the total volatilization loss of NH_3-N in the August experiment for a 5 day period was 6.68 kg N ha^{-1}, representing 6.7% of the applied urea-N.

DISCUSSION

Various experiments using a similar technique have suggested uptake of NH_3 by plants from the atmosphere (Denmead et al., 1976; Porter et al., 1972; Harper et al., 1983 b; Lemon and Van Houtte, 1980). In this study, however, the NH_3 concentration profiles suggested near equilibrium to net loss situations throughout the day (Fig. 2). Any indication of plant uptake in this experiment was probably masked by the continued relatively high flux densities of greater than 100 g NH_3-N ha^{-1} hr^{-1} after application of urea in contrast to values of 50 g NH_3-N ha^{-1} hr^{-1} for background conditions. Furthermore the closely mowed turf contrasted sharply to the tall grass canopies used by Denmead et al (1976), Lemon and Van Houtte (1980) and Harper et al. (1983 a).

Diurnal cycling has been demonstrated by others (Denmead et al., 1974; Beauchamp et al., 1978; Harper et al., 1983 b). Factors believed to result in the diurnal change in flux density are the direct and interactive effects of temperature (Fenn and Kissel, 1974), windspeed and turbulent transport (Denmead et al., 1982) dew formation and evaporation (Beauchamp et al., 1982) and urease activity in the thatch; activities which reach a maximum near midday under a natural environment. During the morning hours after sunrise evaporation of dew increases the NH_3-N concentration in solution, raising the partial pressure gradient and enhances the flux of NH_3 to the air. Later in the afternoon with decreasing air temperature and a concurrent decrease in water vapour pressure deficit the evaporation rate would decrease. Urease activity increases markedly with organic matter content (McGarity and Hoult, 1971; Torello and Wehner, 1983) and temperature (Bremner and Mulvaney, 1978). Wind speed and air turbulence increase with rising daily temperature increasing the transport of NH_3 from the air-soil-plant interface, thus more rapidly depleting the concentration

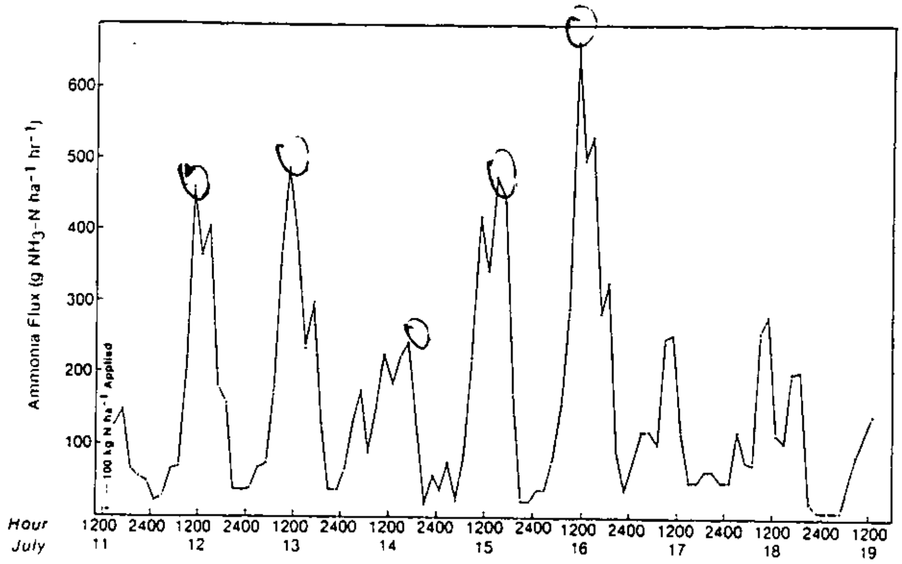

Fig. 3. The diurnal change in the net ammonia flux following an application of urea on July 11.

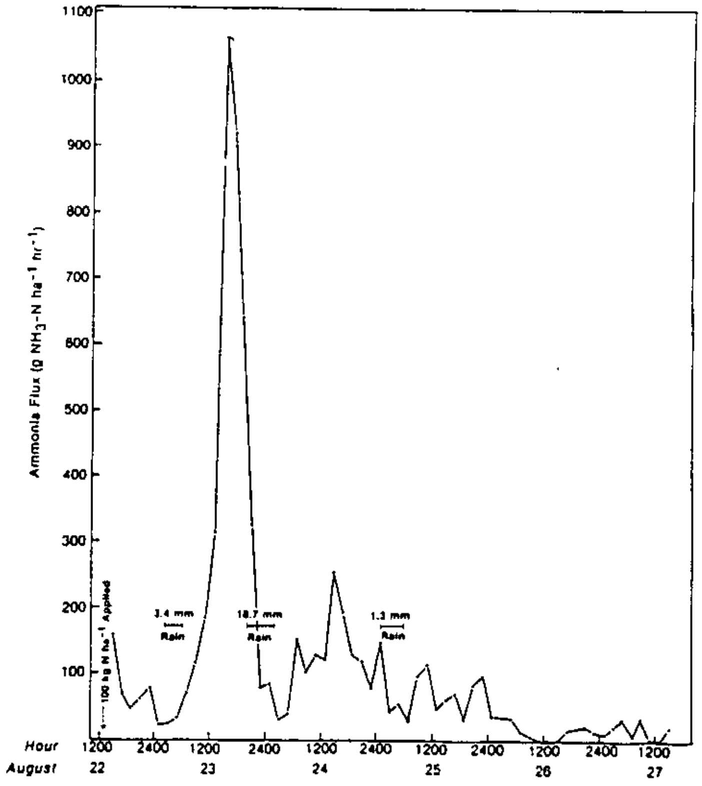

Fig. 4. The diurnal change in the net ammonia flux following an application of urea on August 22.

at the evaporative surface (Denmead et al., 1982). The diurnal cycle of NH_3-flux suggests measurements under constant laboratory conditions or single daily measurements in the field may grossly misrepresent NH_3 volatilization from urea.

Although no direct correlations between meteorological measurements and NH_3 flux were obtained it is interesting to note that during the July 11 to 19 experiment the minimum daily flux (July 14) occurred under conditions of 7.6 hr sunshine, an average 7 km hr^{-1} windspeed at 10 m and a maximum air temperature of 30.3 C. The maximum daily NH_3 flux (July 15) occurred under conditions of 14 hr sunshine, an average 12 km hr^{-1} windspeed and a maximum air temperature of 28.4 C. In contrast the maximum daily flux of the August experiment occurred on August 23 under 0.5 hr sunshine, an average 13 km hr^{-1} windspeed and a maximum air temperature of 24.8 C. These comparisons illustrate the complexity of the relationship of environmental conditions to NH_3 volatilization.

Measurements by the aerodynamic procedure of NH_3 volatilization from urea applied to grass in a tropical pasture range from 9 to 40% (Harper et al., 1983a). In this experiment the loss ranged from 6.7% where rainfall occurred within 72 hr to 15.1% where rainfall did not occur for eight days. Harper et al. (1983 b) also reported that the duration of high flux densities of NH_3 from urea-fertilized grass coincided with the number of rainless days after urea application. The use of urea in turf management, therefore, would be acceptable where irrigation is available or where rainfall may be predicted with a degree of reliability.

The loss of NH_3-N observed in this experiment is consistent with observed differences in turf quality, clipping weight and tissue nitrogen concentration where urea and ammonium nitrate have been compared on bluegrass (Sheard, R.W., Unpublished data). Where irrigation was not used urea was found to be inferior to ammonium nitrate, but never by more than 15%. Where irrigation was used they were equivalent.

ACKNOWLEDGEMENTS

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SUMMARY IN FRENCH

Mesure aérodynamique de la volatilisation ammoniacale à partir d'urée appliquée à un gazon composé de pâturin et de fétuque.

La volatilisation du gaz ammoniac (NH_3) aprés un apport de 100 Kg ha^{-1} azote sous forme d'urée à un gazon composé de Poa pratensis et de Festuca rubra a été mesuré par des procédés aérodynamiques. Une perte de 15.1% par volatilisation s'est produite, en absence de pluie, pendant 8 jours aprés l'apport tandis qu'elle se chiffrait à 6.7% dans les cas d'une pluie dans les premières 72 heures. De fortes variations journalières du flux de NH_3 furent observées, atteignant un maximum prés de midi et un minimum durant la nuit. Les valeurs élevées de volatilisation de NH_3 mesurées par de techniques de chambre close, telles que relatées dans la littérature peuvent être considérées comme erronées du fait qu'elles ne considèrent pas tous les effets directs ni les interactions avec tous les facteurs de l'environnement.

AP-42 #18

Determination of Application Losses of Anhydrous Ammonia[1]

J. H. Baker, Michael Peech, and R. B. Musgrave[2]

SYNOPSIS. Application losses of anhydrous ammonia from soils at optimum moisture content were found to be negligibly small when ammonia was applied at practical rates, even at a depth of only 4 inches below the surface, as revealed by a method described in this paper.

IN THE direct application of anhydrous ammonia to soils, ammonia is injected into the soil as a mixture of gas and liquid. The proportion of gas to liquid depends upon the tank temperature. At 70° F., about one-fifth of the ammonia is vaporized at the time of injection into the soil. The remaining liquid ammonia also vaporizes rapidly, and unless the ensuing ammonia gas is completely absorbed by the soil, appreciable losses of ammonia may occur. An application of anhydrous ammonia at the rate of 100 pounds of nitrogen per acre for a 40-inch spacing between applicator blades corresponds to about 6 liters of ammonia gas per lineal foot of row.

Laboratory studies of the losses of anhydrous ammonia upon application have been reported by Jackson and Chang (3), Stanley and Smith (6), and McDowell and Smith (4), but little attempt has been made to measure directly the losses of ammonia upon application of the anhydrous compound under field conditions. Blue and Eno (1) calculated the loss of ammonia as the difference between the amount of ammonia applied and that extracted from the soil by sodium chloride solution. Such calculations assume that the rate of injection of ammonia is uniform within the row and that there is no fixation of ammonia into nonexchangeable form. Both of these assumptions may introduce serious errors depending upon the nature of the soil and the type of equipment employed in the application of the ammonia.

This paper describes a quantitative method for measuring directly the application losses of ammonia under field conditions. In this method the ammonia escaping from the soil is caught and absorbed in standard acid. Since this work was completed, Hansen et al. (2) have reported a similar method in their studies of the application losses of ammonia. A very simple and rapid qualitative method, involving the use of pH color indicator, is also described and has been found very useful in establishing the soil conditions under which the losses of anhydrous ammonia upon application may be expected to be high.

MATERIALS AND METHODS

Application of ammonia—The anhydrous ammonia was metered through a Weatherhead Type D Ammotrol and a flowrator to a single John Blue applicator blade. The meter was calibrated by passing the ammonia into a known volume of water (5 gallons) for a specified period of time and titrating an aliquot of the resulting aqua ammonia with standard acid. A rolling coulter was mounted just ahead of the applicator blade in the application of ammonia to the soil under sod. The speed of the tractor in going over the plot was accurately measured so that the amount of ammonia applied per lineal foot of row could be calculated.

Quantitative method—Immediately following the injection of anhydrous ammonia into the soil, a pan 9 inches long, 5 inches wide, and 2½ inches deep was inverted and pressed firmly into the soil directly over the ammonia band which could be readily located by the disturbed soil or the crevice left by the applicator blade. An additional amount of loose soil was packed around the edges of the pan. The pan was provided with inlet and outlet glass tubes which were inserted through rubber stoppers into holes made in the opposite sides of the pan. The pan was connected to an acid absorption tower which, in turn, was connected to a vacuum pump. The acid absorption tower, containing 250 ml. of 0.05N H_2SO_4, consisted of a 700 ml. cylinder equipped with a fritted glass gas scrubber. A tractor-driven electric generator was used as a power source for the operation of the vacuum pump. Air was pulled through the pan at the rate of 3 liters per minute and any ammonia escaping from the soil within the pan was thus swept into the acid absorption tower. As many as 20 pans were connected simultaneously to the vacuum pump by means of rubber tubing, thus permitting measurement of losses of ammonia from different sites chosen at random or selected to represent different depths and rates of application. After the desired period of aeration (usually six hours) the amount of ammonia absorbed by the acid in the absorption tower was determined by titrating the excess acid with standardized NaOH.

The rate of flow of air through the pan (3 liters per minute) was sufficiently high to renew the air within the pan once every 30 seconds without creating a negative pressure within the pan, as was indicated by a water manometer connected to the inlet tube. This rate of flow of air was found to be effective in sweeping out the ammonia gas escaping from the soil before any appreciable amount of the ammonia could be absorbed by the surface of the soil. Preliminary trials showed that about 90% of a measured volume of ammonia gas, introduced slowly into the pan through the inlet tube, could be recovered in the absorption tower. The volume of ammonia gas introduced into the pan in these trials represented about 10% of the amount of ammonia applied to the soil area enclosed by the pan with an application rate of 85 pounds N per acre on a 14-inch spacing.

Qualitative method—In this method a neutral indicator-gypsum suspension (prepared by triturating 1 gram of phenol red with 28 ml. of 0.1N NaOH, diluting to 1 liter with water, adding 300 grams of finely divided $CaSO_4 \cdot 2H_2O$ powder, and adjusting the color of the indicator to orange) was sprayed on the cross section of the ammonia band exposed by making a vertical cut across the band with a spade. In the more compacted soils, the entire face of the crevice made by the applicator blade, extending from the point of injection to the soil surface, was also sprayed with the indicator-gypsum suspension after carefully spading and removing the opposite face of the crevice. The indicator-gypsum suspension was sprayed with a conventional household insect sprayer. The spray was applied slowly in order to prevent downward flow of any excess of the indicator-gypsum suspension that may have accumulated on the soil. The distribution of ammonia within the band and any upward movement of ammonia through the

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[1] Contribution from the Department of Agronomy, New York State College of Agriculture, Cornell University, Ithaca, N. Y., as Agronomy Paper No. 453. This work was supported by research grants from Olin Mathieson Chemical Corporation and the Sun Oil Company.

[2] Graduate Research Assistant, Professor of Soil Science, and Professor of Field Crops, respectively.

Table 1—Loss of ammonia from various soils upon application of anhydrous ammonia.

Soil type	Condition of soil			Application of NH_3		Loss of ammonia*			
	Surface	pH	Moisture	Depth	Rate†	Pan 1	Pan 2	Pan 3	Pan 4
			%	inches	lb. N/A.	% of amount applied			
Mardin silt loam	plowed	7.0	24	4	202	Nil‡	Nil	8§	Nil
				8	191	Nil	Nil	Nil	Nil
Mardin silt loam	plowed	5.1	24	4	260	Nil	Nil	Nil	0.3
Mardin silt loam	sod¶	6.6	19	4	95	Nil	Nil	Nil	Nil
				8	85	Nil	Nil	Nil	Nil
Sassafras f.s.l.	plowed	5.9	18	4	243	Nil	Nil	0.6	Nil

* After 6 hours aeration for Mardin soils and 9 hours for Sassafras soil.
† On basis of 14-inch spacing. ‡ Nil represents a loss of less than 0.1%.
§ Insufficient amount of acid in tower; loss was estimated by back titration of NH_4OH and consequently may be low. ¶ Alfalfa-grass sod.

crevice left by the applicator blade could be clearly established by the color change of the indicator as observed against the white gypsum background.

RESULTS AND DISCUSSION

Typical results showing losses of anhydrous ammonia applied to Sassafras fine sandy loam and Mardin silt loam at different rates and depths, as measured by the quantitative method, are presented in table 1. The application losses were found to be negligible even when ammonia was applied at fairly high rates to a depth of only 4 inches. The relatively large loss of ammonia (8% of that applied) observed at one of the sites on Mardin silt loam was found to be due to very shallow application of ammonia as the applicator blade was raised in going over a large stone.

In order to determine whether there was any application loss of ammonia during the short interval of time before the test pan was placed in position, one pan was mounted immediately behind the applicator blade so that it was about one inch above the soil when ammonia was applied at a depth of 4 inches. A long piece of rubber tubing connected the vacuum pump to the acid absorption tower which was mounted on the tractor. Air was pulled from the pan into the acid absorption tower at the rate of 3 liters per minute, and any ammonia escaping immediately behind the applicator blade was thus caught in the pan and swept into the absorption tower. The pertinent details of these tests and the results are given in table 2. The results show that the application losses of ammonia immediately behind the applicator blade are negligibly small.

Because of its simplicity and rapidity, the qualitative pH indicator-gypsum spray method can be used to study the distribution of applied ammonia in the soil as affected by the rate of application, soil moisture, soil reaction, and exchange capacity. Obviously, the method cannot be used to determine the magnitude of the application losses, but can be very useful in showing whether application losses occur at all by noting the color change of the indicator sprayed on the faces of the crevice left by the applicator blade.

The results of these tests would indicate that application losses of anhydrous ammonia from soils at optimum moisture content are negligibly small when ammonia is applied at all practical rates even to a depth of only 4 inches below the surface. The minimum depth of application should be determined by the radial distance of diffusion of ammonia as measured from the point of injection, and this, in turn, can be shown to be dependent upon the ammonia retention capacity, soil bulk density, and rate of application in accordance with the following equation:

$$r = 0.1\sqrt{\frac{S\,A}{C\,D}}$$

Table 2—Loss of ammonia immediately behind the applicator blade.

Soil type	Condition of soil			Application of NH_3		Ammonia lost†
	Surface	pH	Moisture content	Depth	Rate*	
			%	inches	lb. N/acre	%
Sassafras f.s.l.	plowed	5.9	18	4	257	0.001
Lima silt loam	plowed	7.2	16	4	224	0.00[illegible]
		7.2	16	4	261	0.05
Lima silt loam	alfalfa sod	6.9	13	5	261	0.01

* On basis of 14-inch spacing.
† Ammonia lost expressed as percent of the amount applied.
‡ This test covered a distance of 200 feet; the other tests covered a distance of 100 ft.

where r is the theoretical minimum depth of application in inches; S is the spacing between rows in inches; A is the nominal rate of application in pounds N per acre; D is the bulk density of the soil in grams per cubic centimeter; and C is the ammonia retention capacity of the soil in milliequivalents per 100 grams of soil. The method for determining the ammonia retention capacity of the soil has been described by Sohn and Peech (5). The ammonia retention capacity is essentially equal to the exchangeable hydrogen content of the soil as determined by the $BaCl_2$-triethanolamine method. Field observations have shown that the radial distance of diffusion of ammonia in the band in loose soils is in fairly good agreement with that given by this equation. In compacted soils, however, the crevice made by the applicator blade is not sealed sufficiently to prevent some upward diffusion of ammonia through the crevice. Under such conditions, the cross section of the ammonia band does not approach circular symmetry, and the minimum depth of application must well exceed that given by the above equation in order to prevent the escape of ammonia.

SUMMARY

A qualitative and a quantitative method for measuring directly the application losses of anhydrous ammonia under field conditions are described. In the quantitative method, the ammonia escaping from the soil is caught and absorbed in standardized acid. In the qualitative method, the exposed cross and longitudinal sections of the ammonia band are sprayed with an indicator-gypsum suspension, and the movement of ammonia within the ammonia band and through the crevice left by the applicator blade is clearly shown by the color change of the indicator. The results of these tests would indicate that application losses of anhydrous ammonia from soils at optimum moisture content are negligibly small when ammonia is applied at practical rates even at a depth of only four inches below the surface.

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