ANHYDROUS AMMONIA APPLICATION LOSSES USING SINGLE-DISC AND KNIFE FERTILIZER INJECTORS

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ABSTRACT. *Anhydrous ammonia (NH_3) is injected below the soil surface during application to limit loss to the atmosphere. Application at a shallower depth may reduce tractor power or allow greater speed, which could increase field capacity if NH_3 losses are held to acceptable levels. Losses of NH_3 during, and for 1 h after, field application were measured from a typical knife injector treatment operated at a 15-cm (6-in.) depth and 8-km/h (5-mph) travel speed and from a single-disc injector operated at shallower depths [5 and 10 cm (2 and 4 in.)] and a range of travel speeds [8, 12, and 16 km/h (5, 7.5, and 10 mph)]. NH_3 losses during application as measured with a hood over the single-disc injector were 3% to 7% in clay loam, silty clay loam, and loam soils and 21% to 52% in a coarser-textured fine sandy loam soil. Applying with a knife injector at deeper depth resulted in losses of 1% to 2% across all soil types. NH_3 losses measured during an hour after application with stationary collection over the injection trench were 1% or less for all treatments. Losses during application were 5 to 55 times greater than during the first hour after application.*

Keywords. *Anhydrous ammonia, Injector, NH_3, nitrogen, Knife, Losses, Opener.*

Nitrogen (N) losses during anhydrous ammonia (NH_3) application have detrimental environmental effects to the atmosphere and are a lost input for the crop producer. Several researchers have reported effects of application depth, soil moisture content, and soil texture on NH_3 losses. Many of these studies were conducted in the laboratory rather than the field. Stanley and Smith (1956) recommended NH_3 should be applied at a depth of 10 and 20 cm (4 and 8 in.) for heavy- and light-textured soils, respectively. They found small losses at gravimetric soil moisture contents of 15% to 18% on a silt loam soil. Losses increased with drier or wetter soil. Contrary to popular belief, Jackson and Change (1947) found application depth and soil moisture to be of minor importance in NH_3 losses. In a later study, Wagner and Smith (1958) reported NH_3 losses increased as application depth decreased from 10 cm (4 in.). Significant losses occurred despite the absence of visible white vapors. Baker et al. (1959) found negligible NH_3 losses when application was at a depth of 10 cm (4 in.) or greater and moisture content was optimum. Fenn and Kissel (1976) reported NH_3 losses from a calcareous soil increased as application depth decreased, with substantial losses (20%) at 7.5-cm (3-in.) application depth on a silty clay loam soil. Blue and Eno (1952, 1954) observed NH_3 losses as high as 75% from a coastal plain sandy soil in a laboratory study. Stanley and Smith (1956) found losses from an air-dried sandy soil to be greater than losses from silt loam or clay soils. Abo-Abda (1985) measured NH_3 losses during field application with a knife and a point injector fertilizer applicator (PIFA). Percentage NH_3 losses increased with decreasing depth and application rate, but were unaffected by speed from 4.8 to 8.0 km/h (3.0 to 5.0 mph).

Although speed effects on NH_3 loss at speeds below 8 km/h (5 mph) may be small, to pull injection knives at faster speeds [e.g. greater than 9.6 km/h (6 mph)] and depths of 15 to 20 cm (6 to 8 in.) commonly used to avoid losses requires significant horsepower. If NH_3 could be applied at a more shallow depth and at field speeds of 12 to 16 km/h (7.5 to 10 mph) without adverse consequences, equipment operators could more rapidly apply NH_3 without significantly increasing tractor horsepower requirements.

An experiment was conducted to determine NH_3 loss from the soil to the atmosphere for applications made with a prototype single-disc fertilizer injector operated at shallow depths and equal or faster speeds compared with loss from a conventional knife injector.

MATERIALS AND METHODS

TREATMENTS

Seven fertilizer injector treatments included six treatments with a single-disc fertilizer injector and one treatment with a conventional knife injector. The single-disc injector was operated at three application speeds [8, 12, and 16 km/h (5, 7.5, and 10 mph)] for two application depths [5 and 10 cm (2 and 4 in.)]. The prototype single-disc injector used a

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Figure 1. Single-disc injector with depth wheel and spring-loading closing wheel, side and rear views (actual closing wheel used was larger than shown in sketches).

spring-loaded closing wheel. Figure 1 shows drawings of the basic arrangement on the prototype of the disc opener, depth-gauging wheel, and closing wheel, which was tested in the field by mounting it on a toolbar frame. The closing wheel size used in tests was somewhat larger than shown in the sketches of figure 1. The disc opener was 46 cm (18 in.) in diameter with an adjacent 34- × 7.5-cm (13.5- × 3-in.) depth-gauging wheel. The release point for fertilizer application tube depth could be adjusted in a range of 2.5 to 10 cm (1 to 4 in.) below the soil surface. The closing wheel was 33 × 5 cm (13 × 2 in.). A 6-mm (0.25-in.) diameter fertilizer tube delivered NH_3 near the bottom edge of the disc-opener. This injector was an experimental design and has never been commercially available.

In addition, a conventional NH_3 knife with closing discs operated at 8 km/h (5 mph) and 15-cm (6-in.) application depth was used to compare with the single-disc injector treatments, representing a commonly used injector for NH_3. The knife (fig. 2; Banjo TK 10, Perry, Iowa) was 1.9 cm (0.75 in.) wide. A 6-mm (0.25-in.) diameter fertilizer tube released fertilizer at the bottom edge of the knife. The closing discs (DMI, Goodfield, Ill.) were mounted with concave sides facing the furrow. Downspring pressure kept the discs in contact with the soil surface.

Figure 2. Knife used to inject NH_3.

FIELD PLOTS AND CALIBRATION

The seven treatments were applied to 11 replicated blocks differing in locations, soils, and soil conditions (table 1). Iowa soils in replications 1 and 2 were Webster silty clay loam and Clarion loam, respectively, located at the Iowa State University Agronomy and Agricultural Engineering Research Center near Boone, Iowa. The soil in replications 7 through 11 was Hanlon fine sandy loam located near Ames, Iowa. The Texas soil, Pullman clay loam, in replications 3 through 6 was located near South Plains, Texas, at Marble Brothers Farm. Plots were 152 m (500 ft) long and 0.76 m (2.5 ft) wide.

Application rate after adjustment of the NH_3 regulator (A-3300 Nitropacer; CDS John Blue Co., Huntsville, Ala.) was determined prior to runs of that treatment by trapping NH_3 flow exiting the regulator through a hose and attached pipe inserted into water for 30 s. The amount of NH_3 was determined gravimetrically and application rate calculated from the rate of NH_3 flow and applicator field speed.

MEASUREMENTS AND APPARATUS

Measurements were made of NH_3 loss during the moment of field application and also during a roughly 1-h time period immediately after application for each treatment within each replicated block. Measurement of NH_3 loss during field application was based on a technique developed by Abo-Abda (1985). In summary, air was drawn from a hood surrounding the single fertilizer injector as it injected NH_3 into the soil. A small, known proportion of this main air flow exiting the hood was aerated through an acid solution to trap NH_3. The solution was later analyzed in the laboratory for NH_3 concentration.

Single knife and single-disc fertilizer injectors were mounted on an adjustable-height toolbar frame. Injectors did not operate in tractor-wheel tracks except for replications 1 and 2. Hoods constructed around each injector were of

Table 1. Location, soil type, previous soil condition, and application date of replications.

Replication	Location	Soil Type	Soil Condition	Date
1	Iowa	Webster silty clay loam[a]	No till[b]	10−Nov−00
2	Iowa	Clarion loam[c]	No till[b]	10−Nov−00
3	Texas	Pullman clay loam[d]	Tilled[e]	20/21−Dec−00
4	Texas	Pullman clay loam	Tilled[e]	20/21−Dec−00
5	Texas	Pullman clay loam	CRP[f]	20/21−Dec−00
6	Texas	Pullman clay loam	CRP[f]	20/21−Dec−00
7	Iowa	Hanlon fine sandy loam[g]	No till[b]	21−Jun−01
8	Iowa	Hanlon fine sandy loam	No till[b]	21−Jun−01
9	Iowa	Hanlon fine sandy loam	No till[b]	21−Jun−01
10	Iowa	Hanlon fine sandy loam	No till[b]	21−Jun−01
11	Iowa	Hanlon fine sandy loam	No till[b]	21−Jun−01

[a] Fine-loamy, mixed, mesic Typic Haplaquolls.
[b] Previous crop was soybean.
[c] Fine-loamy, mixed, mesic Typic Hapludolls.
[d] Fine, mixed, thermic, Torrertic Paleustolls.
[e] Previous crop was cotton.
[f] Soil previously in Conservation Reserve Program mixed grasses.
[g] Coarse-loamy, mixed, mesic Cumulic Hapludolls.

slightly different dimensions to accommodate injector geometry. The hood over the single-disc injector was 46 cm (18 in.) wide × 89 cm (35 in.) × 56 cm (22 in.) tall. The hood over the knife and closing discs was 46 cm (18 in.) wide × 81 cm (32 in.) long × 66 cm (26 in.) tall. Both hoods had 15-cm (6-in.) long flexible rubber-belted skirting to avoid ambient wind near the soil surface from disrupting a negative (gauge) pressure inside the hood created by the main air flow. Main air flow was exhausted from the hood by a 7.1-m^3/min (250-ft^3/min) centrifugal fan (Jabsco, model 354000, Costa Mesa, Calif.) through an 81-mm (3.19-in.) polyvinyl-chloride (PVC) schedule 40 pipe (fig. 3). Main air flow was measured before and after each test plot run with a 81-mm (3.19-in.) diameter linear-velocity vane anemometer (Davis Instruments linear velocity anemometer, Davis Inotek, Baltimore, Md.). Sample air flow for NH_3 trapping was taken from the main air flow stream through 4.8-mm (0.19-in.) diameter Tygon tube, perforated with five 3-mm (0.13-in.) diameter holes and mounted on a diameter, perpendicularly across the PVC pipe carrying the main airflow. To avoid too much initial pressure or vacuum in the air sampling tube, holes were on the lee side of the tube at a 45° angle to main air flow. The air sampling system, connected by 4.8-mm (0.19-in.) diameter Tygon tubing, consisted of a 0.5-L/min (0.018-ft^3/min) pressure-compensated sample air pump (MiDan Co., Pulse Pump III, Chino, Calif.), a rotometer to measure sample air flow, and a Pyrex #12C glass-tube-air-diffuser into a 25- × 305-mm (1- × 12-in.) cylindrical sample bottle filled with 150 mL (5.1 oz) of 0.5-N hydrochloric (HCl) acid solution. During field operation, air underneath the hood exited in the main air flow. Sample air flow was taken from the main air flow stream after it passed through the centrifugal fan during about 120 m (400 ft) of applicator travel. Sample air traveled through the rotometer and air pump, and it was bubbled through the acid solution in the sample bottle before being vented to the atmosphere (fig. 4).

Immediately after application, NH_3 loss from the soil surface of the application trench was sampled for the next hour using a stationary collection system. Chemical shelf paper sprayed with 15 mL (0.51 oz) of 0.5-N HCl solution was mounted in the bottom of a 30- × 41-cm (12- × 16-in.) aluminum pan with the plastic face of the shelf paper facing the pan. The pan was set upside-down over the application trench within approximately 3 to 5 s after application. After approximately 60 min, the paper was removed from the pan and placed in a 3.8-L (1-gal) glass jar with 1000 mL (33.8 oz) of deionized water to dissolve the NH_3. A single collection pan was used in each test plot for the first six replications (table 1) and four collection pans were used and the values averaged in each test plot for all other replications. The masses of acid and water added to the sample bottles and jars, respectively, were determined gravimetrically.

Figure 3. Top of hood over injector showing air exit from suction fan. Small tube inside air exit draws sample air used to measure NH_3 loss.

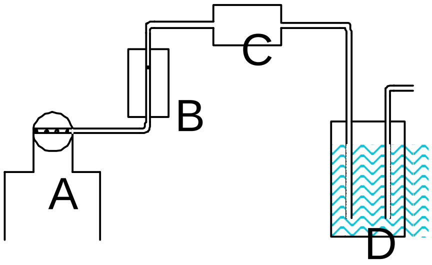

Figure 4. Schematic of NH_3 sampling flow path during application (not to scale): A – hood enclosing injector; B – rotometer; C – air pump; D – collection bottle with acid solution. Intake tube in area above A is shown in figure 3.

WET LABORATORY ANALYSIS

The pH of each sample was adjusted to 2 using either potassium hydroxide (KOH) or concentrated HCl to prepare and keep the NH_3 contained in solution for analysis. Typically less than 1 mL (0.03 oz) of HCl was needed to adjust the sample in the gallon jars to a pH of 2. An amount of KOH equivalent to that needed to adjust the pH of the sample in a bottle collecting sample air during application was added to 200 mL (6.76 oz) of high purity water. This solution was adjusted to pH 2 using concentrated HCl and analyzed for NH_3-N to determine the amount of NH_3 impurity in the KOH. Analysis was done within three weeks of field collection for replications 1 through 6 and within 5 weeks of collection for replications 7 through 11.

NH_3 analyses were accomplished using a colorimetric method to detect NH_3 concentration after a reagent was added. Analyses were performed by the salicylate modification of the automated flow injection Phenate method using a Lachat Quickchem 8000 Automated Ion Analyzer system (Loveland, Colo.). Ammonium (NH_4) was combined with an alkaline (pH 10) buffer to convert NH_4 to dissolved NH_3. The NH_3 reacted with salicylate and hypochlorite at 60°C (140°F) in the presence of nitroprusside to produce a blue indosalicylate compound whose intensity was proportional to the amount of NH_3 in the sample. Measurements were made with a colorimeter at a wavelength of 660 nm. NH_3 concentrations in samples were determined by comparing sample absorbance with those obtained from a calibration curve comprised of standards containing NH_3 concentrations (as N) of 0.025 to 5.00 mg N/L.

CALCULATIONS AND STATISTICAL ANALYSES

To determine loss during application, calculations were based on mass of NH_3 measured in the sample air flow and then adjusted to loss collected in main air flow from the hood by the ratio of main-to-sample air flow. The amount of NH_3 collected in the sample bottle during application was multiplied by the ratio of main air flow to sample air flow. This amount of NH_3 lost during application was then expressed as a percentage of that flowing through the regulator and injector during the time the sample was collected. To determine loss from the soil surface immediately after application (for the hour beginning a few seconds after injection), the amount of NH_3 collected on the acid-treated paper was divided by the amount of NH_3 applied through the injector to the soil underneath it for the time the injector was traveling through the sample area. This loss was also expressed as a percentage. Using these procedures, the lower limit of detection for N was 0.10% of that applied during and 0.01% of that applied after application.

The experiment was a randomized complete block design with all treatments applied within each replication. Two statistical analyses were done each using an analysis of variance. One was a factorial analysis of the six single-disc treatments (three speeds and two depths). A second analysis was done with all seven treatment combinations including the conventional knife application. Specific statistical contrasts were used to compare all single-disc treatments as well as discrete levels of depth and speed (main effects) of the single-disc operation with the knife treatment. Least significant differences are shown but conclusions were drawn based on significance in analysis of variance.

RESULTS AND DISCUSSION

NH_3 application rate was targeted for 168 kg N/ha (150 lb N/acre) assuming the injector would be operated with 76-cm (30-in.) spacing, a typical row width for corn production in the Midwestern United States. Measured application rates ranged from 164 to 177 kg N/ha (146 to 158 lb N/acre) except for four test runs at 12 km/h (7.5 mph) in replications one and two where the application rate was 198 kg N/ha (177 lb N/acre). Soil gravimetric moisture content was 18.7% for the silty clay loam soil, 18.2% for the loam soil, 24.1% for the clay loam soil, and 14.4% for the fine sandy loam soil at the time of application. Moisture within each replicated soil block appeared to be relatively uniform from near the surface to application depth and close to, but below field capacity.

Although it was desired to measure loss after application for exactly 60 min, 9 of 77 measurements were longer than 70 min. Initially, loss was adjusted after application to a rate basis, loss per hour. Losses during application were many times greater, however, suggesting that most losses after application probably occurred within the first few minutes or even seconds. Because analysis of loss after application adjusted to a per-hour value resulted in the same conclusions and nearly identical results, data are reported simply as total loss after application during the time NH_3 was collected.

In initial analyses pooling data from all soil types, it was noted that losses at application with the single-disc injector appeared to be considerably greater in the fine sandy loam (table 2). This agreed with Stanley and Smith's (1956) finding of greater losses in sandy than in silt loam or clay soils. In the hour after application, NH_3 loss was significantly greater in silty clay loam and loam soils than in the clay loam soils (table 2). Losses greater than 15% at the time of application were somewhat unexpected, but comparable to those observed by Fenn and Kissel (1976) on a silty clay loam at 7.5-cm (3-in.) application depth. Blue and Eno (1952, 1954) observed losses as great as 75% on a sandy soil. The combination of shallow application depth of the single-disc injector and coarse soil type probably contributed to the high losses that were measured.

Table 2. Ammonia loss by soil texture and replication as percent of applied (all treatments).

Soil Texture	Tillage	Replication	Loss at Application (%)	Loss after Application (%)
Silty clay loam	No till	1	5.3	1.0
Loam	No till	2	4.8	0.9
Clay loam	Tilled	3	4.0	0.2
Clay loam	Tilled	4	4.2	0.4
Clay loam	CRP	5	3.7	0.4
Clay loam	CRP	6	3.9	0.3
Fine sandy loam	No till	7	24.9	0.6
Fine sandy loam	No till	8	26.8	0.5
Fine sandy loam	No till	9	27.6	0.7
Fine sandy loam	No till	10	28.8	0.7
Fine sandy loam	No till	11	28.9	0.7
$LSD_{0.05}$[a]			9.5	0.5

[a] Least significant difference between treatments at a 95% level of confidence.

Another factor contributing to high losses may have been heat from the application equipment that was transferred to the NH_3 during application. In order to change sample bottles, measure main air flow, and set up equipment, the time between individual plot runs was usually at least 5 min and at times longer. Ambient air temperature during replications 7 through 11 was near 21°C (70°F). As NH_3 flowed through the regulator to only a single injector, heat energy from application equipment warming back to ambient temperature was probably able to evaporate more of the NH_3 from the liquid phase to the gas phase during flow through the applicator than would be expected in colder weather, with more injectors being supplied by the regulator, or for a longer duty-cycle during application. For example, mass flow rates of NH_3 from the tank through the regulator and manifold to an 11-injector applicator would be 11 times as great as through a single injector applicator. Abo-Abda (1985), comparing a PIFA injector operated at 13 and 18 cm (5 and 7 in.) and a conventional knife, reported losses greater than 15% at application in 9 of 78 field plots. During a mid-August application, mean losses for treatments with the PIFA injector operated at these deeper depths ranged from 7% to 12% in a medium-textured soil.

As multiple replications were nested within two major soil textures (fine and coarse) a test of the interaction of soil texture with injector type was possible. When soil type was divided between fine sandy loam (coarse-textured soil; replications 7 through 11) and those soils that were more finely textured than fine sandy loam (fine-textured soil; replications 1 through 6), there was a statistically significant interaction between these two major soil groups and injector treatments. Losses at application for the single-disc treatments averaged 27 percentage points greater in the fine sandy loam soil than for the other soils, but losses for the knife treatment were slightly lower (0.4 percentage point) in the fine sandy loam soil than for the other soils. Because of this interaction, separate statistical analyses were then done for each of the two soil textures using only data collected from that soil texture. Ratios of the error variances of the two dependent variables (loss "at" and "after" application) from these separate analyses (2.1 and 4.0) were less than ten, further confirming that earlier use of all data collected to measure a soil texture by injector interaction was valid.

Results have been analyzed and reported separately for fine-textured soils (silty clay loam, loam, and clay loam) and coarse-textured (fine sandy loam) soils.

FINE-TEXTURED SOILS

Within the factorial analysis of the single-disc injector only, NH_3 losses were not significantly affected by either depth or speed during application (table 3). After application, NH_3 losses were unaffected by speed but somewhat surprisingly were greater at the 10-cm (4-in.) depth of the prototype than at the 5-cm (2-in.) depth. Loss from the soil surface in the 3 to 5 s between passage of the applicator and initial placement of and collection by the catch container on the surface could have been significant considering that 5 to 12 times as much NH_3 was lost during passage of the injector as was lost in the subsequent hour. This unmeasured loss may have been significantly greater at the 5-cm (2-in.) depth giving rise to the unexpected results.

Comparing the single-disc injector with the conventional knife, NH_3 losses at application with the single-disc injector operated at shallower depths and the same or faster speeds were at times statistically greater than the knife (table 4). In specific statistical contrasts between the knife and main effects of speed and depth of the single-disc injector, losses at application were significantly greater if the single-disc was operated at a slower speed (8 km/h; 5 mph) or a shallower depth (5 cm; 2 in.). Losses were statistically greater (3.2 percentage points) when all single-disc treatments as a group were contrasted with the knife treatment. NH_3 losses after application were also at times statistically greater for the single-disc as compared to the knife injector. In specific statistical contrasts between the knife and main effects of the single-disc injector, losses after application were significantly greater if speed was 8 or 12 km/h (5 or 7.5 mph) or depth was 10 cm (4 in.). Also losses were statistically greater (0.6 percentage points) when all single-disc treatments were contrasted with the knife treatment. NH_3 loss during passage of the knife injector was 30 times greater than the small loss in the hour after application.

COARSE-TEXTURED SOILS

Losses at the time of application of the single-disc injector were 30 to 55 times those during the hour after application (table 5). Within the factorial analysis of the single-disc treatments, losses at application were 16 percentage points greater at an application depth of 5 cm (2 in.) than 10 cm (4 in.). Losses were 14 percentage points higher at 8 and 16 km/h (5 and 10 mph) than at 12 km/h (7.5 mph). This effect of reduced losses at an intermediate speed was unexpected. At 12-km/h (7.5-mph) speed may have been fast enough to limit the time for NH_3 to escape between passage of the injector and closing wheel, yet slow enough to minimize disruption of soil in the furrow and allow for adequate closing. Losses after application were unaffected by speed but were statistically lower (0.4 percentage point) when NH_3 was applied at a 10-cm (4-in.) depth than at a 5-cm (2-in.) depth. Lower losses at a greater application depth were also reported by Wagner and Smith (1958), Fenn and Kissel (1976), and Abo-Abda (1985), but the effect of depth was opposite of what was found in the fine-textured soil.

Comparing all treatments, losses at application were considerably greater (20 to 48 percentage points) for the single-disc injector than the knife injector (table 6). Losses at application were statistically less for the knife than any of the single-disc treatment combinations or main effects of depth and speed. Similarly, losses after application were statistically greater (average of 0.7 percentage point) for treatment combinations and main effects of the single-disc injector than for the knife (loss below the detection limit). Considering total losses by adding together loss at and after application, the single-disc injector had losses 21 to 52 percentage points greater than the knife injector (depending on depth and speed of the single-disc injector).

Table 3. NH_3 loss for single-disc fertilizer injector for fine-textured soils as percent of applied (factorial).

Treatment	Loss at Application (%)	Loss after Application (%)
Speed, km/h (mph)		
8 (5)	5.9	0.6
12 (7.5)	4.7	0.6
16 (10)	3.7	0.5
$LSD_{0.05}$[a]	NS	NS
Depth, cm (in.)		
5 (2)	5.1	0.4
10 (4)	4.4	0.8
$LSD_{0.05}$	NS	0.4

[a] Least significant difference between treatments at a 95% level of confidence.

Table 4. NH_3 loss for both fertilizer injectors for fine-textured soils as percent of that applied (seven treatments).

Configuration	Treatment		Loss at Application (%)	Loss after Application (%)
	Speed km/h (mph)	Depth cm (in.)		
Prototype	8 (5)	5 (2)	6.5	0.2
Prototype	8 (5)	10 (4)	5.4	1.1
Prototype	12 (7.5)	5 (2)	4.2	0.6
Prototype	12 (7.5)	10 (4)	5.2	0.7
Prototype	16 (10)	5 (2)	4.7	0.5
Prototype	16 (10)	10 (4)	2.7	0.5
Knife	8 (5)	15 (6)	1.6	0.1
$LSD_{0.05}$[a]			3.9	0.6

[a] Least significant difference between treatments at a 95% level of confidence.

Table 5. NH_3 loss for single-disc fertilizer injector for coarse-textured soils as percent of applied (factorial).

Treatment	Loss at Application (%)	Loss after Application (%)
Speed, km/h (mph)		
8 (5)	36.3	0.7
12 (7.5)	22.6	0.7
16 (10)	36.4	0.8
$LSD_{0.05}$[a]	4.7	NS
Depth, cm (in.)		
5 (2)	39.6	0.9
10 (4)	23.9	0.5
$LSD_{0.05}$	3.8	0.2

[a] Least significant difference between treatments at a 95% level of confidence.

Table 6. NH_3 loss for both fertilizer injectors for coarse-textured soils as percent applied (seven treatments).

Configuration	Treatment		Loss at Application (%)	Loss after Application (%)
	Speed km/h (mph)	Depth cm (in.)		
Prototype	8 (5)	5 (2)	44.3	0.9
Prototype	8 (5)	10 (4)	28.2	0.4
Prototype	12 (7.5)	5 (2)	22.9	0.9
Prototype	12 (7.5)	10 (4)	22.3	0.5
Prototype	16 (10)	5 (2)	51.6	1.0
Prototype	16 (10)	10 (4)	21.2	0.7
Knife	8 (5)	15 (6)	1.4	ND[a]
$LSD_{0.05}$[b]			6.3	0.3

[a] ND indicates that NH_3 level was below the detection limit (non-detectible).

[b] Least significant difference between treatments at a 95% level of confidence.

SUMMARY

Within the range of test conditions [application rates targeted for 168 kg N/ha (150 lb N/acre)], the following findings are supported:

- NH_3 losses during application with the single-disc injector as a percentage of that applied were greater in the fine sandy loam (coarse-textured) soil, ranging from 21% to 52%, than in finer textured soils (clay loam, silty clay loam, loam) where losses ranged from 3% to 7%. Losses at application for the knife injector, 1% to 2%, were similar between soils.

Fine-textured soils:

- About 5 to 30 times as much NH_3 was lost at application during passage of the injector as during the first hour after application. Losses at application were statistically greater when all single-disc treatments were compared to a knife injector. Losses were statistically greater than the knife injector when single-disc treatments were applied at shallow depth [5 cm (2 in.)] or slower speed [8 km/h (5 mph)].
- Losses after application were statistically greater (0.6 percentage points) when all single-disc treatments were compared to a knife injector and were statistically greater if speed was 8 or 12 km/h (5 or 7.5 mph) or depth was 10 cm (4 in.).

Coarse-textured soils:

- About 30 to 55 times as much NH_3 was lost during passage of the injector as during the first hour after application. Total losses at and after application were considerably greater for single-disc treatments than the knife. Total losses ranged from 21 to 52 percentage points greater for single-disc injector treatments (combinations of 8, 12, and 16 km/h speeds and 5- and 10-cm depths (5-, 7.5-, and 10-mph speeds and 2- and 4-in. depths)] than for the knife treatment [8 km/h and 15-cm depth (5 mph and 6-in. depth)].
- For the single-disc injector, losses at application were observed to be about 16 percentage points greater during application at a 5-cm (2-in.) depth than a 10-cm (4-in.) depth. At an intermediate application speed of 12 km/h (7.5 mph) loss during application was 14 percentage points less than at speeds of 8 or 16 km/h (5 or 10 mph).
- For the single-disc injector, losses after application were unaffected by speed but were 0.4 percentage points less at an application depth of 10 cm (4 in.) rather than 5 cm (2 in.).

Greater losses of NH_3 to the atmosphere, particularly in coarse soils, from a single-disc prototype injector operated at shallower depths and greater speeds as compared to conventional application with a knife indicate that caution should be used with alternative techniques until improved sealing procedures are verified.

REFERENCES

Abo-Abda, A. E. 1985. Field losses of anhydrous ammonia using a point injector fertilizer applicator. Unpublished M. S. thesis. Ames, Iowa: Iowa State University.

Baker, J. H., M. Peech, and R. B. Musgrave. 1959. Determination of application losses of anhydrous ammonia. *Agron. J.* 51(6): 361-362.

Blue, W. B., and E. F. Eno. 1952. Some aspects of the use of anhydrous ammonia on sandy soils. *Soil Sci. Proc. of Florida* 12(1): 4-12.

Blue, W. B., and E. F. Eno. 1954. Distribution and retention of anhydrous ammonia in sandy soils. *Soil Sci. Soc. Am. Proc.* 18(4): 420-424.

Fenn, L. B., and D. E. Kissel. 1976. The influence of cation exchange capacity and depth of incorporation on ammonia volatilization from ammonium compounds applied to calcareous soils. *Soil Sci. Soc. Am. J.* 40(3): 394-398.

Jackson, M. L., and S. C. Change. 1947. Anhydrous ammonia retention by soils as influenced by depth of application, soil texture, moisture content, pH value, and tilth*. J. Am. Soc. Agron.* 39(7): 623-633.

Stanley, F. A., and G. E. Smith. 1956. Effect of soil moisture and depth of application on retention of anhydrous ammonia. *Soil Sci. Soc. Am. Proc.* 20(4): 557-561.

Wagner, G. H., and G. E. Smith. 1958. Nitrogen losses from soils fertilized with different nitrogen carriers. *Soil Sci.* 85(3): 125-129.