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Dr. John L. Malcolm
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Washington, D.C. 20523

Dear John:

Enclosed please find the final report for our Indo-U.S. Science and Technology AID Grant No. DAN-1406-G-SS-4088.

I am looking forward to getting back together when funding comes in for the continuation of this valuable cooperative research program.

Sincerely,

Richard H. Fox
Professor of Soil Science

RHF/se

Enclosure

An Equal Opportunity University

Nitrogen Fertilizer - Estimating Losses and Improving Efficiency

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The Pennsylvania State University

During the last two years the primary goal of our research with the Indo-U.S. Science and Technology project has been to determine which factors are important in controlling NH_3 volatilization loss from surface applied urea-containing fertilizers and to develop means to reduce these losses. We have recently initiated research to determine the quantity of clay interlayer fixed NH_4^+ in our agricultural soils and to estimate what fraction of this fixed NH_4^+ is available for crop uptake. We are also developing a soil N availability index that can be used to predict N fertilizer needs for maize and wheat. We are also conducting several experiments designed to estimate NO_3^- leaching losses as a function of N rate and the use of manure.

NH_3 Volatilization from Surface Applied Urea-Containing Fertilizer

Rainfall Effects

Several investigators have noted that rainfall in the first few days following urea application reduces NH_3 volatilization losses (Forster and Lippold, 1975; Fox and Hoffman, 1981; Catchpoole et al., 1983; Murdock and Fry, 1985). The amount of rainfall during the 48 hr following urea application that appeared to prevent NH_3 volatilization loss ranged from 2.5 mm (Murdock and Fry, 1987) to 10 mm (Fox and Hoffman, 1981; Forster and Lippold, 1975). Recent work with simulated rainfall and plexiglas flow-through systems placed in the field have shown that maximum reduction in NH_3 volatilization occurred when the rainfall event was within the first 3 hr following urea application (Black et al., 1987). Four mm of simulated rainfall was sufficient to lower loss significantly but greater reductions occurred with 16 mm. Simulated rainfall 24 hr after urea application still reduced volatilization, but was much less effective than earlier H_2O applications.

In a recent experiment we estimated the effect of rainfall quantity and time of rainfall after fertilizer application on NH_3 volatilization losses by the ^{15}N recovery method using ^{15}N-labeled urea applied to microplots in the field. The methodology used was that developed in previous research supported by this project (Burch and Fox, 1989). The ^{15}N content of soil samples was determined by the new USDA/ARS-Univ. of Nebraska ^{15}N analysis facility. Simulated rainfall treatments were 2.5, 5, and 10 mm of H_2O applied either 1 or 3 days following application of urea at a rate of 200 kg ha^{-1} of N. Two soil moisture levels were used: -0.1 bar (22% H_2O) and -2.0 bar (15%H_2O).

Surprisingly high ^{15}N losses were observed in this experiment with more than 65% of the fertilizer N disappearing by day 5 from all treatments in the wetter soil and up to 63% by day 5 in the drier soil. Since natural rainfall was not allowed to fall on these plots, leaching was unlikely to have been a loss pathway. Analyzing the surface layers for urea, NH_4^+, and NO_3^- content at the time samples were taken for ^{15}N analysis and subtracting the amount present in unfertilized check treatments (N balance method) showed that losses

estimated by this method were very similar to those from the ^{15}N method (Fig. 1). Some denitrification may have occurred in the wetter soil but this loss pathway was unlikely in the drier soil. We believe that most of the ^{15}N lost was due to NH_3 volatilization. The weather was warm and humid during the time of the experiments. These nearly ideal conditions for NH_3 volatilization loss from surface applied urea may have been the cause for the large N losses in this experiment. With the wetter (-0.1 bar) soil, rainfall treatments had no significant effect on total NH_3 loss. In the drier, -2 bar moisture potential soil, the 10 and 5 mm H_2O applications one day after application of urea both significantly lowered NH_3 loss (Fig. 2), with the 10 mm treatment being the more effective. Apparently, the urea had hydrolyzed by day 3, and the rainfall treatments did not leach the NH_4^+ produced by this hydrolysis to a sufficient depth to reduce volatilization loss. It is also apparent that 2.5 mm on day 1 was not enough H_2O to reduce volatilization loss.

A laboratory flow-through experiment was also conducted with the same treatments as the field experiment. Ammonia volatilization loss was measured by capturing evolved NH_3 in boric acid. rather than measuring ^{15}N loss. Previous research in our lab and by others (Ferguson and Kissel, 1986) has shown that the moisture content of the flow-through air has a great influence on NH_3 volatilization loss making it very difficult to simulate NH_3 volatilization losses in the field with flow-through systems (Burch and Fox, 1989). In an attempt to more closely simulate field conditions, the flow-through air was humidified by passing it through a water bath resulting in air with 98% relative humidity (RH) for 12 hr at night and by using unhumidified air during the 12 hr day period (RH approximately 60%). With the drier (-2.0 bar) soil, all rainfall treatments except the 10 mm applications either 1 or 3 days after fertilizer application increased loss compared to the check (Fig 3). The NH_3 volatilization loss with the 10 mm treatments was not significantly different from the check. This illustrates the danger of using laboratory flow-through systems to try to estimate the effect of environmental factors on NH_3 volatilization loss from urea in the field.

Comparison of Estimates of NH_3 Volatilization Loss in the Field by the Sponge Trap and ^{15}N Recovery Methods.

Because of our (Burch and Fox, 1989) and other (Ferguson and Kissel, 1986) research showing how important initial soil moisture potential and the rate of H_2O loss are on NH_3 volatilization loss from urea, we were concerned that the sponge-trap method proposed by our Indian collaborators as a method to estimate NH_3 volatilization loss in the field would give erroneous results. The lack of air movement above soil covered by sponge boxes would also contribute to lower NH_3 volatilization losses. During my visit to India in December, 1986 it was agreed that I would compare estimates of NH_3 volatilization losses made by the ^{15}N recovery method and the sponge method used in India. If possible, the Indian scientists would do similar experiments in India.

Three smaller versions of sponge-trap boxes based on the Indian design were constructed and NH_3 volatilization losses from urea applied at the rate of 200 kg ha^{-1} N was estimated by the sponge-trap and ^{15}N recovery methods. The experiment was initiated one day after a saturating rain. Surface soil moisture content at the time of urea application was 26.5% under the sponge-traps. Soil moisture in the ^{15}N microplots was 22%, so initial moisture conditions were not identical.

The two methods gave very different estimates of total volatilization loss for the 10-day experiment (Fig. 4). The estimated total N loss in 10 days was 68.3% by the ^{15}N recovery method and 22.5% by the sponge method. There is the possibility that some of the ^{15}N was lost by denitrification, but as mentioned above, since ^{15}N loss in the field microplots was even greater in a drier soil where denitrification was unlikely, it is probably a safe assumption that most of the ^{15}N disappearance was due to NH_3 volatilization. The lack of air movement and non-drying conditions under the sponges were the probable causes for lower losses measured by this method. The surface soil moisture was still 26.5% at the end of the 10-day trial indicating that almost no drying had occurred. The soil in the ^{15}N recovery micro-plots had dropped from an initial moisture content of 22% to 19%. Research (Burch and Fox, 1989; Ferguson and Kissel, 1986; Kern, 1987) has shown that if there is enough soil moisture for complete urea hydrolysis, drying conditions increase NH_3 volatilization loss because of: a) higher concentrations of aqueous NH_3 in the soil solution (Henry's law), and b) the upward movement of H_2O through the soil during drying brings ammoniacal N to the surface that had leached to depths where volatilization would have been unlikely.

Results from this experiment confirm that the sponge-trap method should not be used to estimate NH_3 volatilization losses in the field because it produces results that do not reflect what occurs under conditions where the soil surface is left exposed to the environment. We are not sure that the ^{15}N recovery method gives completely accurate estimates of loss, but because the soil environment is more similar to that under natural field conditions, it is probably one of the best methods for estimating NH_3 volatilization losses in the field. Using the micro-meteorological method to determine volatilization losses is technically difficult and expensive. It is also difficult to compare treatment effects using the micro-meteorological method because of the difficulty in studying more than one replicate of one treatment at a time.

Urease Inhibitors

One of the proposed methods for reducing NH_3 volatilization losses from surface applied, urea-containing fertilizers is to use urease inhibitors with the urea fertilizer. No NH_3 volatilization loss occurs from urea until it hydrolyzes to ammonium bicarbonate. An effective urease inhibitor that prevents urea hydrolysis for at least several days would increase the probability for rainfall to leach the urea into the soil before ammonium bicarbonate is formed and thereby prevent or reduce volatilization loss.

The effectiveness of several urease inhibitors (phenylphosphorodiamidate [PPD], N-butyl-phosphorothioic triamide [NBPT], thiophosphoryl triamide [TPTA], and ammonium thiosulfate [ATS]) on reducing NH_3 volatilization loss were compared using our flow-through apparatus. The urea was in a urea-ammonium nitrate solution (UAN) because that is the main source of N fertilizer used in Pennsylvania. The UAN was applied on maize residue on a moist soil rather than on the soil surface because NH_3 volatilization losses are greater from UAN applied on plant residue than on bare soil, and unincorporated surface applications of UAN are generally made on no-till maize where approximately 75% of the surface is covered by maize residue. The inhibitors were applied at rates of 0.66% by weight of UAN for NBPT and TPTA, 1.29% by weight for PPD, and at a 95:5 UAN:ATS solution ratio for ATS.

In agreement with other recent research (Chai and Bremner, 1985), the most effective inhibitor for reducing and delaying NH_3 volatilization loss was NBPT in both trials (e.g. Fig. 5). The primary drawback with NBPT is that it is very expensive and difficult to manufacture. A commercial firm is attempting to determine if it can be manufactured at a cost that will allow its use by farmers.

Clay Interlayer Fixed Ammonium

This research has just recently started, but initial findings indicate that soils in our research plots at the Penn State Agronomy Research Farm contain from 100 to 200 ppm fixed NH_4^+-N. Concentration of fixed NH_4^+ increased with soil depth and the use of manure. We have not yet determined whether this fixed NH_4^+ is released to the crop or whether it plays any other role in controlling soil N availability to crop plants.

Soil N Availability Tests

Our research over the last several years has shown that both young stalk and soil nitrate concentration can be used to predict soil N availability to maize that has received manure or is in a rotation where a forage legume has been grown within the two previous years (Iversen et al., 1985; Fox et al., 1987). The stalk test seems to be best correlated with soil N availability under uniform environmental conditions, but it appears that maize stalk nitrate concentration is too greatly affected by solar radiation during the three days prior to sampling and soil moisture to allow for the stalk test to be used on a routine basis (Durst, 1985; Bamka, 1988). The pre-sidedress soil nitrate test proposed by Magdoff et al. (1984) appears to be less sensitive to these environmental variables and shows promise as a test to predict the need for N fertilizer in these manured and legume rotation maize fields (Fig 6). A soil NO_3^- quick-test using nitrate sensitive paper strips and a reflectometer designed to measure color density of these strips was developed. This will allow farmers and consultants to make quick and easy determinations of soil nitrate concentration to facilitate the use of the test for making sidedress N application recommendations (Jemison and Fox, 1988).

Roth (1987; Roth et al., 1989) found that determining the total N concentration of young wheat plants (Feekes stage 5) was a more effective predictor of soil N availability to winter wheat than were stalk nitrate or total N uptake tests.

Nitrate Leaching

Soil cores have been taken to a depth of 120 cm after harvest and the following spring in a number of N fertilizer rate experiments with maize. Results indicate that at the economic optimum N rate, NO_3^--N concentration in soil solution at field capacity were approximately 23 ppm. We have established a new field experiment using relatively large (61 x 72 cm) zero-tension lysimeters placed at a depth of 120 cm in an attempt to better estimate actual NO_3^- leaching losses under optimally fertilized maize fields. Both unmanured and cattle manured soils will be studied.

LITERATURE CITED

Bamka, W. J. 1988. Environmental influences on corn stalk nitrate levels used for tissue testing. M. S. Thesis, Penn State Univ.

Black, A. S., R. R. Sherlock, and N. P. Smith. 1987. Effect of timing of simulated rainfall on ammonia volatilization from urea applied to soil of varying moisture content. J. Soil Sci. 38:679-688.

Burch, J. A. and R. H. Fox. 1989. The effect of temperature and initial soil moisture content on the volatilization of ammonia from surface-applied urea. Soil Sci. 147:311-318.

Catchpoole, V. R., D. J. Oxenham, and L. A. Harper. 1983. Transformation and recovery of urea applied to a grass pasture in south-eastern Queensland. Aust. J. Expt. Agric. Anim. Husb. 23:80-86.

Chai, H. S. and J. M. Bremner. 1985. Evaluation of some phosphoroamides as soil urease inhibitors. 1985 Agron. Abstracts, p. 154. Amer. Soc. Agron., Madison, WI.

Durst, P. T. 1985. Corn stalk nitrate as an indicator of soil nitrogen availability and sidedress nitrogen requirement. M. S. Thesis, Penn State Univ.

Forster, I., and H. Lippold. 1975. Ammonia losses from urea fertilizers. II. Determining ammonia losses under field conditions as affected by the weather (In German). Arch. Acker-Pflanzenbau Bodonkund. 19:631-639.

Fox, R. H. and L. D. Hoffman. 1981. The effect of N fertilizer source on grain yield, N uptake, soil pH, and lime requiremnet in no-till corn. Agron. J. 73:891-895.

Fox, R. H., K. V. Iversen, G. W. Roth, and W. P. Piekielek. 1987. Predicting sidedress N fertilizer needs for corn with stalk and soil nitrate tests. 1987 Agron. Abstracts, p. 202. Amer. Soc. Agron., Madison, WI.

Iversen, K. V., R. H. Fox, and W. P. Piekielek. 1985. The relationships of nitrate concentrations in young corn stalks to soil nitrogen availability and grain yields. Agron. J. 77:927-932.

Jemison, J. M. and R. H. Fox. 1988. A quick-test procedure for soil and plant tissue nitrates using test strips and a hand-held reflectometer. Commun. Soil Sci. Plant Anal. (In Press).

Kern, J. M. 1987. The effect of initial soil moisture content and soil drying on the susceptibility of ammonia volatilization loss from surface-applied urea. M. S. Thesis, Penn State Univ.

Magdoff, F. R., D. Ross, and J. Amadon. 1984. A soil test for nitrogen availability to corn. Soil Sci. Soc. Am. J. 48:1301-1304.

Murdock, L. W. and W. W. Frye. 1985. Comparison of urea and urea-ammonium polyphosphate with ammonium nitrate in production of tall fescue. Agron. J. 77:630-633.

Roth, G. W. 1987. Evaluation of plant tissue and soil tests for predicting nitrogen fertilizer requirements of winter wheat. Ph.D. Thesis, Penn State Univ.

Roth, G. W., R. H. Fox, and H. G. Marshall. 1989. Plant tissues tests for predicting nitrogen fertilizer requirements of winter wheat. Agron. J. 81:502-507.