

ORIGINAL RESEARCH ARTICLE

Agrosystems

Ammonia volatilization from fertilizer sources on a loam soil in Idaho

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Assigned to Associate Editor Chase Straw.

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Abstract

Optimizing crop N uptake while minimizing NH₃ volatilization from N fertilizer sources is a critical part of agricultural best management practices. Urea is the most widely used N fertilizer but is also one of the most susceptible to losses as NH₃. Fertilizer sources and additives can be used to reduce NH₃ volatilization. Specifically, urease inhibitors [e.g., *N*-(*n*-butyl) thiophosphoric triamide (NBPT)] can reduce NH₃ volatilization from urea. A novel fused ammonium sulfate nitrate (ASN) product has recently been developed as another potential alternative N fertilizer source but has not been studied widely. A field study was performed to quantify NH₃ volatilization from the newly available ASN fertilizer as compared with various N fertilizers (ammonium sulfate [AS] and urea) including urea treated with the urease inhibitor NBPT in an alkaline calcareous loam soil in Idaho. Further, we assessed NH₃ volatilization from surface applied and incorporated N fertilizers from these various N sources. Untreated surface-applied urea volatilized the highest amount of NH₃, whereas incorporation of N fertilizers was effective in reducing volatilization as compared with untreated surface-applied urea. Our study indicated that the N fertilizer sources (AS, ASN, and urea+NBPT) were equally effective in reducing NH₃ volatilization when compared with surface-applied urea. Our study will help refine N fertilizer management under multiple field situations and traditional management practices of crop producers in the western United States. Further, site-years and study locations would be needed to provide evidence of the effectiveness of ASN in reducing NH₃ volatilization under a wider range of soil and environmental conditions.

Abbreviations: AM, application method; AN, ammonium nitrate; AS, ammonium sulfate; ASN, ammonium sulfate nitrate; DAA, days after application; NBPT, *N*-(*n*-butyl) thiophosphoric triamide; RH, relative humidity.

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1 | INTRODUCTION

Urea fertilizer is the most widely used source of N for agricultural production globally (Cantarella et al., 2018; Hu et al., 2020; Pan et al., 2016), as well as in the United States (Woodley et al., 2020). Urea usage is widespread due to its low cost, high N content (46% N), and ease of transport as a stable dry-granular substance. Although there are many positives of urea fertilizer, it is well reported that urea is highly susceptible to NH_3 volatilization losses when left on the soil surface (Goos & Guertal, 2019; Pan et al., 2016; Rochette et al., 2013). These NH_3 volatilization losses affect crop yields, fertilizer N use efficiency, environmental and health issues, and indirectly N_2O emissions (Panday et al., 2020). The magnitude of NH_3 volatilization is greatly affected by soil pH, soil texture, and environmental conditions. Ammonia gas is preferentially formed as pH increases into the alkaline range, where added urea dissolves, hydrolyzes to form NH_4 or NH_3 , and increases pH due to the nature of the chemical reaction (Panday et al., 2020). High pH alkaline calcareous and loamy agricultural soils in the western United States (e.g., Idaho) can be more conducive to NH_3 volatilization (Dari, Rogers, & Walsh, 2019). Therefore, sustainable management of N fertilizer is warranted to ensure better crop production, reduce the environmental footprint of N emissions from soils, and improve the overall farm economy.

The most common mitigation measure for controlling NH_3 volatilization losses includes choosing the “right source of N” as well as the “right placement of N” as a part of best N management practices (i.e., 4R N management; Rochette et al., 2013). Alternative sources of N fertilizer include ammonium sulfate (AS) and ammonium nitrate (AN). These sources exhibit reduced potential for NH_3 volatilization losses due to a lack of pH increase as well as a reduced amount of N in the NH_4 form for AN (Ti et al., 2019; Woodley et al., 2020). However, AS and AN are typically more expensive (USDA-NRCS, 1999), less accessible, and may even be restricted (e.g., AN) (Panday et al., 2020). Larger quantities of AS fertilizer are needed for comparable N application as compared with urea due to the lower percentage of N (21%). Ammonium nitrate has a higher N content (34%) than AS, but lower than urea with an approximate 50/50 split between the NH_4 form. However, despite having many positive characteristics, the potential for AN to be used in the manufacture of explosives has resulted in greater regulations, oversight, and storage and handling requirements that have reduced availability and desirability for many agricultural producers (Shea et al., 2013). To avoid the issues associated with using AN as an explosive, a nonexplosive fused AN/AS product ammonium sulfate nitrate (ASN) was developed (26% N) with about 70% as a 2:1 molar ratio AN/AS double salt and 30% as free AS in granular form (Chien et al., 2013). Limited research is available comparing ASN to other known N fertilizer sources. We are

Core Ideas

- Source and method of N fertilizer were assessed for NH_3 volatilization.
- Greatest NH_3 volatilization was from untreated surface applied urea.
- Incorporation of N fertilizer was effective for reducing NH_3 volatilization.
- AS, ASN, and urea-NBPT were comparable in reducing NH_3 volatilization compared with urea.

unaware of fertilizer N-source field NH_3 volatilization studies performed on alkaline calcareous and loamy soils in southern Idaho.

Reduction of NH_3 volatilization from urea can be made through the modification of urea fertilizer formulations. For example, slow or controlled-release fertilizers and additives to urea (e.g., NBPT) that temporarily block the soil urease enzymes can prevent urea hydrolysis (Chien et al., 2009) and reduce NH_3 volatilization. Multiple sources investigated the benefits of using the urease inhibitor NBPT in controlling NH_3 volatilization losses from urea (Griggs et al., 2007; Nascimento et al., 2013; Silva et al., 2017; Woodley, 2020). Approximately, a 52–54% reduction in NH_3 volatilization losses by using NBPT inhibitors as compared with untreated urea was reported in a global meta-analysis that included 45 studies (Cantarella et al., 2018). However, the reports are limited from high pH (soil pH > 7.5) alkaline calcareous agricultural soils common in the western United States.

Based on a global review, it was reported that the selection of appropriate N fertilizer application methods (i.e., incorporated or deep placement as opposed to near-surface application of N-fertilizer) tends to reduce the volatilization losses by up to 48% (Ti, 2019). Over a 60% reduction was noted by (Drury et al., 2017) when using both alternative N sources (UAN) and incorporating into the soil. Despite the positives, incorporation of N fertilizers is associated with large and specialized mechanical equipment to move the fertilizer into the soil. Thus, surface application is a widely practiced method of N fertilizer application despite the high risk of NH_3 volatilization losses under specific production scenarios.

The use of an appropriate source of N fertilizer including inhibitors and their proper placement can be challenging in soils with high pH (e.g., alkaline calcareous loamy soils) common throughout the western United States. Selection of urease inhibitors or other sources of N fertilizers and their mode of application in soils (surface application vs. incorporated) determine the efficacy of applied N fertilizer especially in alkaline calcareous soils for better crop production and environmental management. Rogers and Loomis (2021) reported

TABLE 1 Selected soil chemical properties of research performed on a Declo loam (coarse-loamy, mixed, superactive mesic Xeric Haplocalcids) soil at the Aberdeen Research and Extension Center, Aberdeen, ID

Depth	Sand	Silt	Clay	Soil pH	OC	Lime	NH ₄ -N	NO ₃ -N	Olsen-P	SO ₄ -S
cm	mg kg ⁻¹				g kg ⁻¹		mg kg ⁻¹			
0–30	480	320	200	8.0	4.7	23	2.2	4	17	9
30–60	340	430	230	8.0	3.7	43	1.3	7	–	22

over a 10% difference in fertilizer N use efficiency between surface and incorporated treatments using stable isotope tracers in barley production (*Hordeum vulgare* L.) in southern Idaho on an alkaline loamy soil.

Thus, a field experiment was carried out in a loamy soil in southern Idaho to quantify the losses of N by NH₃ volatilization. The main objective of this study was to investigate NH₃ volatilization from the newly available ASN as compared with various sources of N fertilizers including the urease inhibitor NBPT from an alkaline calcareous loamy soil in Idaho. In addition to fertilizer source, we also assessed NH₃ volatilization from surface applied and incorporated N fertilizers. This study sought to refine fertilize N management under multiple scenarios that are routinely used by growers in the region.

2 | MATERIALS AND METHODS

2.1 | Characterization and description of study site

A field research study was conducted on a Declo loam soil (coarse-loamy, mixed, superactive mesic Xeric Haplocalcids) at the University of Idaho Aberdeen Research and Extension center in Aberdeen, ID, in the spring of 2015. To characterize the study location, soil from the top 0-to-30-cm and 30-to-60-cm depth representative of the depths used for fertilizer recommendations for a range of crops (Robertson & Stark, 2003; Walsh et al., 2019) was collected and analyzed for initial nutrient status of the soil (Table 1). Four N sources were investigated: ammonium sulfate (AS), ASN (FUSN, J.R. Simplot Company, a fused ASN fertilizer), untreated urea, and urea + NBPT at 0.08% w/w (Eclipse-N [26.7% NBPT], J.R. Simplot Company). Ammonia volatilization was measured at a fertilizer rate of 135 kg N ha⁻¹ for the four N sources (AS, ASN, urea, and urea+NBPT) where additional control chambers with 0 kg N ha⁻¹ were measured as well. The N fertilizer was either surface applied or incorporated. To exacerbate loss mechanisms and provide an indication of the efficacy of the individual N sources under suboptimal conditions, 15 mm of irrigation water was applied prior to surface N applications. For incorporated N treatments, the fertilizers were placed to an approximately 5-cm depth prior to irrigation application.

TABLE 2 ANOVA results for the analysis of application method (AM), N source, and days after fertilizer application (DAA) effects on cumulative NH₃ losses for research conducted at the Aberdeen Research and Extension Center, Aberdeen, ID

Source of variation	P value
AM	<.001
N source	<.001
AM × N source	<.001
DAA	<.001
AM × DAA	<.001
N source × DAA	<.001
AM × N source × DAA	<.001

This scenario would provide evidence of loss under preplant conditions (i.e., incorporated) as well as provide evidence of N source differences under a maximum surface loss situation for all N sources.

2.2 | Description of ammonia volatilization study

Ammonia volatilization was determined using semi-open static chambers constructed of 14-cm diameter by 60-cm chambers inserted 15 cm into the soil (Griggs et al., 2007; Rogers et al., 2015). Polyurethane foam sorbers (14 cm by 2.5 cm tall) were impregnated with 20 ml of a 0.73 mol L⁻¹ H₃PO₄ 33% glycerol solution (Griggs et al., 2007; Rogers et al., 2015). Sorbers were collected 1, 4, 7, 10, 15, and 20 d after N fertilizer applications. Chambers had a top and bottom sorber, where the top sorber was situated level with the top of the chamber and was used to capture atmospheric NH₃, and the bottom was placed 15 cm below the top of the chamber to trap NH₃ lost from the fertilizer. Foam sorbers were extracted with 2 M KCL solution and NH₄-N was measured spectrophotometrically (Massey et al., 2011). Throughout the study, relative humidity (RH, %) and temperature (°C) within the chambers and outside were recorded using data loggers (HOBO U23-001; Onset Computer Corporation). The ambient RH and temperature were measured using data loggers positioned 10 cm from the soil surface outside the chambers.

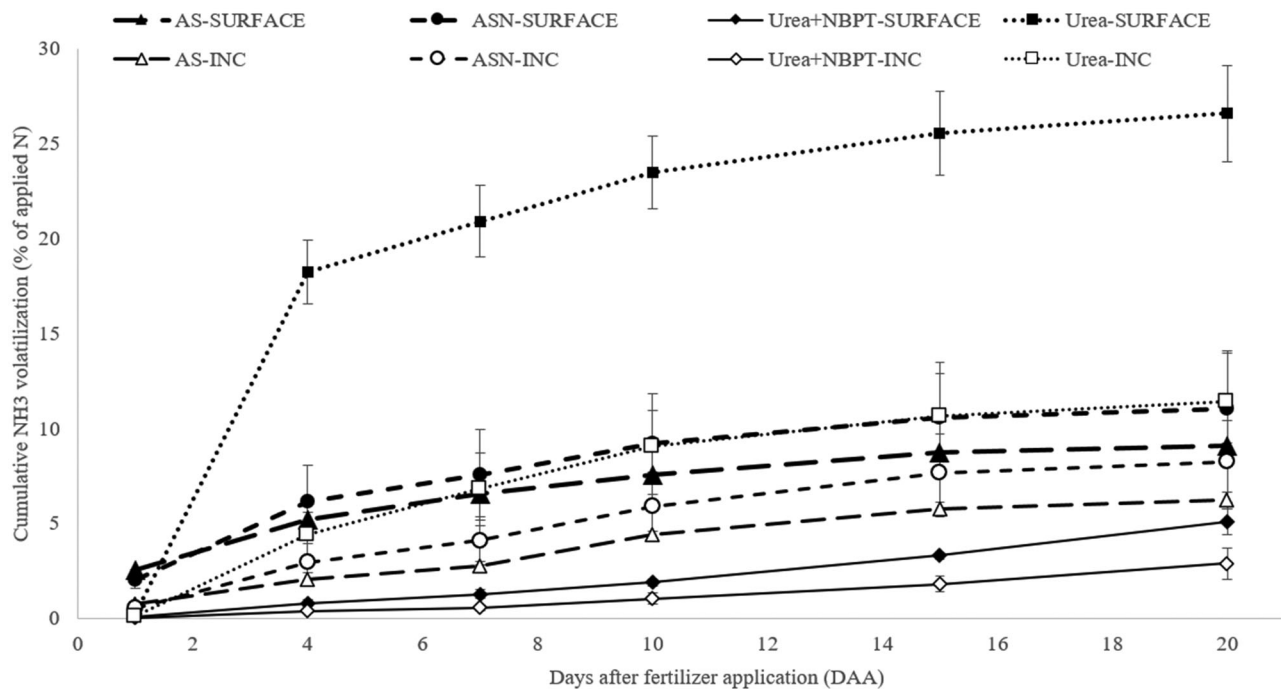


FIGURE 1 Mean ammonia volatilization and standard error from four N sources and two application methods on a moist loam soil over a 20-d period during spring 2016 at the Aberdeen Research and Extension Center, Aberdeen, ID. AS, ammonium sulfate; ASN, ammonium sulfate nitrate; NBPT, *N*-(*n*-butyl) thiophosphoric triamide; INC, incorporated; SURFACE, surface applied

2.3 | Statistical analysis

The study design was a factorial arranged as a randomized complete block with fertilizer source (AS, ASN, urea, and urea+NBPT) and application method (AM, surface applied and incorporated) with four replications of each treatment and four 0-N check plots. Time of sampling was treated as a repeated measure and block was included as a random factor during the analysis. Cumulative NH₃ volatilization was analyzed by ANOVA using the MIXED procedure in SAS 9.4 (SAS Institute) and post-hoc multiple comparison analysis at the $P < .05$ level. #agg220192-fig-0002.fig was conducted using Fisher's protected LSD.

3 | RESULTS AND DISCUSSION

3.1 | Soil characterization

The top 0-to-30-cm and lower 30-to-60-cm soil samples were representative of commonly found loamy soils with low organic C in the region indicating the usefulness of the data for a large percentage of hectares in southern Idaho under irrigated production (Dari, Rogers, Leytem, & Schroeder, 2019; Rogers et al., 2018). The 0-to-30- and 30-to-60-cm depths soil texture was confirmed as a loam soil with relatively low inorganic C content and alkaline pH. As is common in the area, NH₄-N content in the top depth was low with slightly greater

NO₃-N. On the other hand, greater NH₄-N and NO₃-N concentrations were found in the lower depth, as is common for many soils in the region when sampled prior to planting of spring crops.

3.2 | Ammonia volatilization among various sources and methods of N fertilizer application

Results of the ANOVA of application method (AM), N source, and days after application (DAA) indicated a significant three-way interaction of AM, N source, and DAA. All the main effects as well as all other interactions were significant at a $P < .001$ (Table 2).

Untreated surface applied urea had greater N loss than all other treatments from Day 4 until the termination of the study on Day 20 after fertilizer application (Figure 1). Surface applied urea lost 18% of the applied N by 4 d after fertilizer application with losses of 26% by 15 d after fertilizer application and total losses of 27% on 20 d after fertilizer application. On 15 and 20 d after fertilizer application there was no difference indicating that the rate of loss was beginning to plateau by 15 d after fertilizer application. These results indicated that growers have less than 4 d from the time fertilizer is applied to incorporate surface applied untreated urea into the soil in southern Idaho if conditions are conducive to NH₃ volatilization to avoid substantial volatilization losses from untreated urea (Figure 1). Ammonia volatilization losses 20 d after

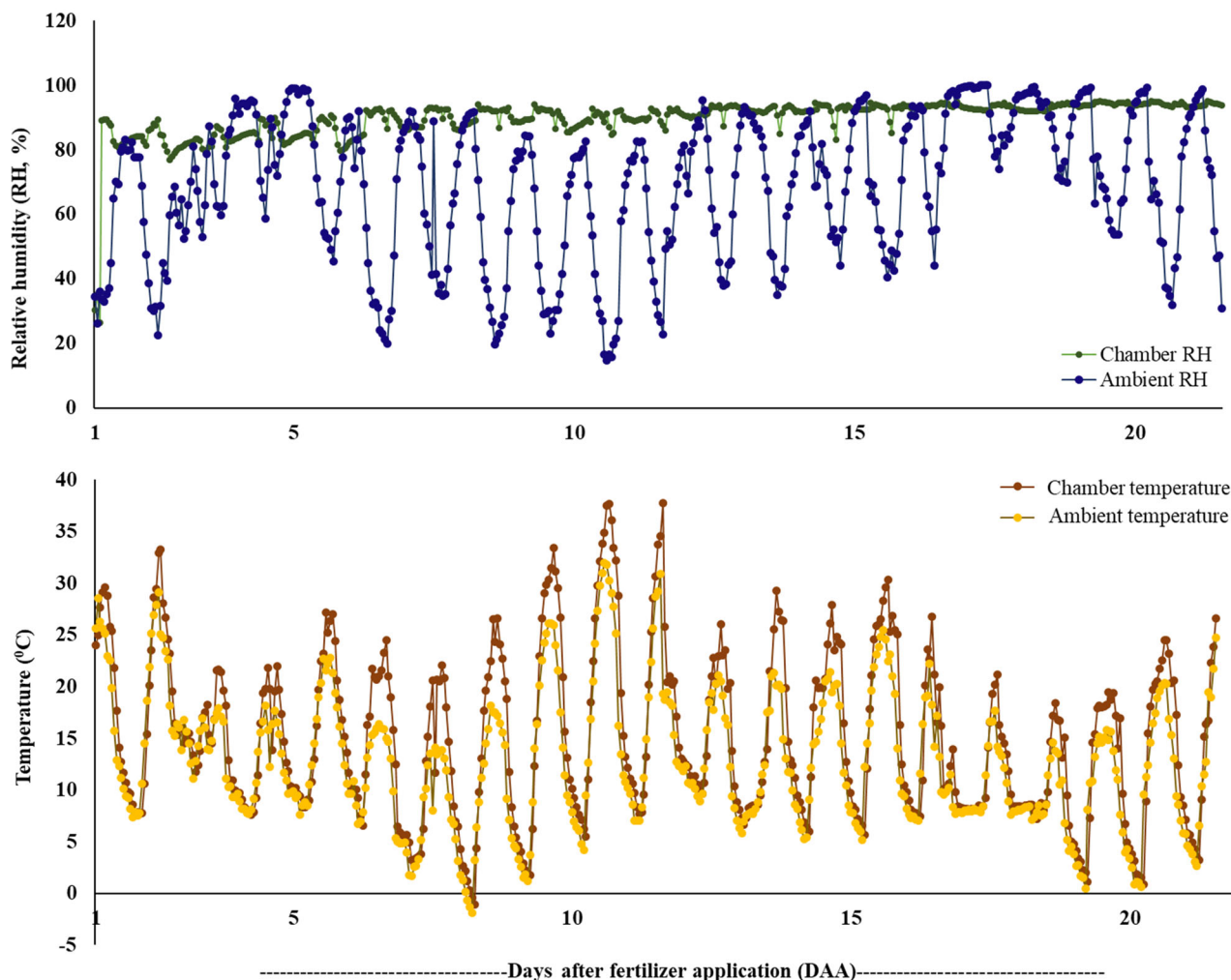


FIGURE 2 (a) Relative humidity (%) and (b) air temperature ($^{\circ}\text{C}$) during 20-d NH_3 volatilization study during spring 2016 in Aberdeen Research and Extension Center, Aberdeen, ID

fertilizer application ranged from 3 to 11% where no differences were measured between incorporated untreated urea, surface applied ASN, surface applied AS, incorporated ASN, and surface applied NBPT.

Incorporated urea-NBPT resulted in less loss (3%) than incorporated untreated urea (11%) and surface applied ASN (11%) on 20 d after fertilizer application (Figure 1). Results indicated that surface application of ASN, AS, and NBPT treated urea were all comparable in the current study and can be considered as effective mechanisms to reduce NH_3 volatilization. Thus, AS, ASN, and urea+NBPT were effective at reducing NH_3 volatilization as compared with surface applied urea.

The susceptibility of urea to losses via NH_3 volatilization is well established in the scientific literature (Cantarella, 2018; Rochette et al., 2013; Silva et al., 2017), but continued efforts on novel fertilizer and inhibitor formulations in regions across the United States is important. These studies will ensure we provide the most current information to growers for

maximizing their farm agronomic productivity alongside optimizing environmental stewardship (Silva et al., 2017) reported in a meta-analysis that the average N lost for surface-applied urea-N was 31% compared with 15% for urea+NBPT. In our study, the magnitude is similar for the surface applied untreated urea, but the urea+NBPT was substantially lower at 5.1% loss in the current study (Figures 1 and 2). Additionally, the time for 50% of the total loss of the untreated surface applied urea was determined as 4.8 d by Silva et al. (2017) where nearly 70% of the total was lost by 4 DAA much higher amounts than were determined in the current study using semi-open static chambers.

Ammonia volatilization of AS was reported at 1.6% from acidic soils in Arkansas (Griggs et al., 2007). In northern Idaho, soil incubations indicated that surface applied urea lost 21% where incorporated urea, AS, and AN did not differ and ranged from 1 to 3% (Hamid & Mahler, 1994). These losses from AS and AN in previous studies are less than the 12 and 9% loss from ASN surface applied and AS surface applied in

the current study, respectively (Figure 1). The greater magnitude of losses in the current study is likely related to the elevated pH of the loamy soil (Table 1) resulting in increased volatilization from the NH_4 in both AS and ASN as compared with the previous studies. Research by Chien et al. (2013) reported reduced NH_3 volatilization from ASN as compared with urea but made no comparisons with other fertilizers or inhibitors.

Similar to Rogers et al. (2015) we observed a difference in RH and temperature between the chamber and ambient conditions using the semi-open static chambers described in the study. The chamber RH and temperature were consistently higher as compared with ambient conditions throughout the study duration (Figure 2), which would likely increase NH_3 volatilization irrespective of the N fertilizer sources and method of applications. However, the chamber does not necessarily mimic real conditions (e.g., no wind occurs within the chamber, a mechanism that influences NH_3 volatilization), and thus the rate of NH_3 volatilization is not expected to represent exact field situations (Rogers et al., 2015). The RH and temperature would likely increase the rate of volatilization as compared to the field, whereas the lack of wind would decrease within the actual field conditions as compared with the chamber conditions. However, these semi-open static chambers can be considered as a cost-effective and easy-to-use way to compare fertilizer N source effectiveness at reducing NH_3 volatilization, when a large number of replications are needed in a confined area, or when micrometeorological field measurements are not feasible due to other factors.

4 | CONCLUSIONS

Alternatives to surface-applied urea must be based on the needs of the grower and their ability to manage applied N in their own fields. Results provide evidence that incorporation of N fertilizer was effective for all sources as a means to reduce NH_3 volatilization losses. Where surface applications are the only option, AS, ASN, and NBPT-treated urea were all shown to be effective and comparable in reducing NH_3 volatilization losses as compared with surface-applied untreated urea, and thus should be considered as a sound management strategy to minimize environmental impacts. Continued work focused on crop response will be critical for determining the agronomic importance of these fertilizer sources in southern Idaho's irrigated agriculture production systems.

ACKNOWLEDGMENTS

The authors would like to thank J.R Simplot Company for partial support of the project and Scott Pristupa, Irene Shackelford, and Grant Loomis for field and laboratory assistance.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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How to cite this article: Dari B, Rogers CW. Ammonia volatilization from fertilizer sources on a loam soil in Idaho. *Agrosyst Geosci Environ*. 2021;4:e20192. <https://doi.org/10.1002/agg2.20192>