Improved N application methods and N sources for corn in Southwestern Ontario

Project # CAN-4RC02 (Bridge Funding) - Final Report
April 17, 2015

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Summary

In Canada, there were 5.26 million tonnes of N fertilizer products sold in 2013 at a cost of over \$4.4 billion with urea and UAN representing 74.1% of all of the N fertilizer sales. A field study was conducted in 2014 to evaluate the effect N fertilizer sources and additives (i.e. with/without a urease inhibitor or with/without a urease and nitrification inhibitor) and N application methods (broadcasting, streaming or injection) on ammonia volatilization, nitrous oxide emissions, plant N uptake and corn grain yield. Broadcasting urea resulted in the greatest ammonia volatilization losses followed by streaming and injection following the sidedress application of 130 kg N ha^{-1} when the corn was at the 6-8 leaf stage. When regular N fertilizers were used without any inhibitors, broadcast urea resulted in 35.9 kg N ha^{-1} ammonia volatilization loss, followed by streaming at 11.4 kg N ha^{-1} with injection having the lowest loss at 8.4 kg N ha^{-1}. The addition of urease inhibitors decreased ammonium volatilization losses by 76% with broadcast urea (8.52 kg N ha^{-1}), 52% with streaming (5.48 kg N ha^{-1}) and by 97% with injection (0.27 kg N ha^{-1}). Injecting UAN+UI+NI was found to increase N uptake (112 kg N ha^{-1}) and yields (10.1 t ha^{-1}) compared to all streaming and broadcast treatments (88.9-98.9 kg N ha^{-1} and 4.61–9.41 t ha$^{-1,}$ respectively) as well as the control. Hence improved N application methods and sources contributed to yield increases and reductions in environmental losses from ammonia volatilization and nitrous oxide emissions.

Introduction:

Nitrogen (N) is an essential plant nutrient required for all non-legume intensive cropping systems in Canada including corn, cereal crops, tomatoes, potatoes, etc. However, nitrogen is subject to many chemical (e.g. urea hydrolysis), physical (e.g. solute transport) and biological (e.g. nitrification, denitrification, mineralization, immobilization) processes which can result in losses of inorganic N from the soil via ammonia volatilization, nitrous oxide emissions, nitrate leaching and N losses in runoff. These processes have both negative environmental and economic impacts as they may represent losses of an expensive and essential crop input.

There were about 5.26 million tonnes of N fertilizers sold in Canada in 2013 with urea (2.74 million tonnes) and UAN (1.15 million tonnes) accounting for 74.1% of these nitrogen fertilizers. With increased application of urea-based fertilizers and UAN solutions to field crops, ammonia volatilization losses from just these two forms may exceed 186,000 t N in Canada (assuming 25% of applied urea and UAN is lost to volatilization) at a cost of \$259 million/yr.

There have been several technological advancements in reducing nitrogen losses from agricultural soils over the last 5 to 10 years. In particular, conservation tillage systems including zone tillage and no-tillage, applying nitrogen in a shallow band and splitting nitrogen applications have been found to reduce nitrous oxide emissions from soils (Drury et al., 2006, 2012). Using polymer coated urea as a slow release fertilizer (SRF) was only effective in conservation tillage systems when there were considerable amounts of precipitation shortly after fertilizer application (Drury et al., 2012). Ziadi et al. (2011) showed that 150 kg N ha^{-1} of slow released fertilizers produced similar yield to 200 kg N ha^{-1} of calcium ammonium nitrate fertilizer under rain fed potato crop on sandy soil. However, management practice may decrease one type of N loss but increase another; for example, deep injection of manure reliably decreases N loss through ammonia volatilization, but also tends to increase N loss via nitrous oxide emissions (Drury and Lauzon, unpublished data). Hence, a holistic and comprehensive approach is required to decrease total losses of applied N and thereby enhance the environmental and economic performance of field crop production.

Increasing farm sizes exerts a great deal of pressure on producers to apply the N fertilizer quickly, and so many have switched to applying UAN (urea ammonium nitrate) solution to their crops using wide-boom stream applicators. Although UAN only contains 50% urea, liquid application to the soil surface may be prone to high N losses through volatilization, especially when the soil surface is warm (. After urea is hydrolyzed, the ammonium remaining in the soil nitrifies to nitrate within 3 weeks of application when the soil temperature is about 15 °C (Drury et al., 1991), and a significant amount of N can be lost as N_2O during the nitrification and denitrification processes.

Ammonia volatilization losses occur when materials containing urea (livestock urine or urea fertilizer) or ammonia (livestock manure or anhydrous ammonia) are applied to the soil. The problem is exacerbated when the material is left on the soil surface especially under warm and windy conditions. During urea hydrolysis, the soil pH surrounding the urea granule can increase (become more basic) and ammonia can be formed and volatilize. The greater the N application rate, the greater the amount of ammonia volatilization losses. For this reason, incorporating manure or urea into the soil can help reduce ammonia volatilization and increase the amount of available N in the soil. However, in a recent study in Quebec, injecting urea into the soil at 5 cm depth still resulted in up to 12% ammonia volatilization loss at the higher N rates (200 kg N ha-1) (Rochette et al., 2012).

Urea applied as urea granules or in solution as UAN is especially problematic in conservation tillage systems where incorporation options are limited. There is no option for incorporation for cereal crops such as winter wheat where urea granules are often broadcast on the soil surface of the growing crop in the spring. The inability to incorporate urea in no-till systems is also problematic as producers may have to over-fertilize to ensure that enough nitrogen remains in their soils for their crops after ammonia has volatilized. Sheppard et al. (2010) estimated that in 2006 a total of about 100,000 tonnes ammonia was lost via annual emissions when fertilizer was applied to agricultural land in 12 ecoregions across Canada. Ammonia emissions were greatest with broadcast fertilizer application, intermediate for shallow injected fertilizer, and least for deep injected fertilizer. They did not consider ammonia losses by stream application of UAN, as this is a relatively recent practice.

When soils become anaerobic such as after a rain event, nitrous oxide may be emitted during the denitrification process. There are several approaches that could be used to reduce these losses, such as shallow soil incorporation to avoid wet and anaerobic conditions associated with deeper incorporation (Drury et al., 2006), or use of a conservation tillage system such as zone tillage which produces lower penetration resistance values, lower bulk densities, and improved aeration in the shallow root zone (Drury et al. 2006, 2012). Using coated urea, a slow release formulation, can delay nitrate formation and N_2O emissions but this product was only found to be effective in reducing total growing season losses 1 year out of 3 on a clay loam soil in Ontario (Drury et al., 2012). The other 2 years, N_2O emissions were simply delayed to later in the growing season

This research study examines mechanical fertilizer application methods (streaming, injection, broadcast application), as well as enhanced products that delay urea hydrolysis and nitrification to enable the fertilizer to move into the soil and be utilized by the crops more effectively. Hence the overall objective of this field experiment is to address the new production and environmental challenges that producers are facing in the Lower Great Lakes region. Management practices (methods and sources) for intensive production systems will be evaluated, and protocols that are most effective for reducing nitrogen losses from agricultural soils will be identified and recommended to producers and soil and crops consultants. The specific objectives of this study are to determine if: 1) improved N application methods (streaming, banding versus broadcast N application) and/or different N sources (regular vs. enhanced urea formulations) could be used to reduce ammonia volatilization, nitrous oxide emissions while enhancing fertilizer N utilization by crops.

Materials and Methods:

The field site chosen for this study was located at the Eugene Whalen experimental farm, in Woodslee Ontario. The soil is a Brookston clay loam soil which is the dominant soil type in SW Ontario. Corn (NK N49J-3000GT) was planted on May 26, 2014 in 30 inch (76.2 cm) rows at a population of 79,700 plants ha^{-1} with a Kinze planter. A starter fertilizer (20-20-10) at 142 kg ha^{-1} was applied to all treatments including the control at planting while the side-dress N source and management treatments were applied on June 30, 2014 at 130 kg N ha^{-1} when the corn was at the 6-8 leaf stage. Herbicides were applied (Integrity at 735 g ai ha^{-1} at planting and Roundup at 1.4 a.i. kg ha^{-1}, and Atrazine at 1.0 kg ai ha^{-1} on July 11, 2014) to control weeds.

Corn population counts were determined in each of the harvest rows shortly before combining. Grain corn was harvested on November 21, 2014 with an International Harvester combine. Corn grain moisture content was determined using a Dickey-John moisture meter. Corn grain samples were dried, ground and analyzed on a Leco 2000 CN analyzer for N concentrations.

There were 10 treatments chosen for this study and these involved side-dress N applications. We evaluated 3 application methods (broadcasting, streaming and banding N fertilizers) and 3 different N sources (the regular N source [urea for broadcast and UAN for streaming and banding], the regular N source with a urease inhibitor and the regular N source with a urease and a nitrification inhibitor). A control N treatment (0 kg N ha^{-1}) was also included for comparison.

Ammonia volatilization measurements were obtained daily using 18 wind tunnels (3 wind tunnels each for 6 of the 10 treatments) over the first 28 days following sidedress N application. On a daily basis, 100 ml of weak phosphoric acid solution (0.005 M) was put into the 2 acid traps per tunnel with one trap connected to a Teflon tube drawing air samples through a pump from the entrance of each tunnel and a second Teflon tube drawing samples of air from a port at the exit of each tunnel. These solutions were replaced on a daily basis including weekends over a 28 day period. In addition to collecting the samples containing the trapped ammonium (ammonia gas is converted to soluble ammonium in the trap), daily cumulative flow volumes were recorded using a digital flow meter.

Weekly measurements of N_2O emissions were obtained throughout the growing season (May 1st until October 31st) from each of the 40 plots. When N_2O emissions were determined, a lid is placed over the collar and fastened into place. Air samples (18 ml) are collected from each chamber after 0, 10, 20 and 30 minutes and then injected into a pre-evacuated exetainer. These 160 exetainers from each sampling campaign were transported to the lab. The samples and standards were then analyzed on a Varian gas chromatograph fitted with a Combipal autosampler and an ECD and TCD detector which are used to analyze for N_2O and CO_2 emissions. Soil temperature and moisture measurements were also collected on the same day as the gas sampling. Seasonal N_2O fluxes were then determined using the trapezoid rule.

Every three weeks following corn emergence, soil samples and 5 plant samples were taken from each treatment (4 replicates) to examine the amount of inorganic N remaining in the soil and the plant biomass and plant N uptake. Soil samples were extracted with 2 M KCl shaken for 1 hr and filtered. The extracts were analyzed for nitrate using a cadmium reduction column and for ammonium using the brucite method using a TRAACS 2000 analyzer (Tel and Heseltine, 1990). Soil samples were also analyzed for gravimetric water contents and the soil inorganic N results were expressed on a dry weight basis. Plant samples were ground and analyzed for N concentration as previously described.

Results and Discussion:

1. Corn grain yields and N uptake:

Nitrogen application significantly increased corn grain yields compared to the control (0 kg N ha^{-1}) treatment (Table 1). In particular all treatments had dramatically greater corn grain yields (8.74 to 10.2 t ha^{-1}) compared to the control treatment at 4.61 t ha^{-1}. Hence N was clearly a limiting nutrient. There were significant corn grain yield differences between N application methods and sources. The greatest yields were obtained when UAN was injected into the soil in combination with either UI or UI+NI. Yield decreases were observed with broadcast urea (with/without UI) or with all 3 streaming treatments (regular UAN, UAN+UI and UAN+UI+NI) compared to the injected UAN treatments (Table 1). It was however interesting to note that the corn yields with broadcast urea with UI+NI (i.e. Super U^{TM}) were not significantly different from the injected UAN treatments (regular UAN, UAN+UI, UAN+UI+NI).

Plant grain N uptake was also found to be significantly affected by treatments with all N methods and N sources having significantly greater quantity of N uptake in corn grain (88.9 – 112 kg N ha^{-1}) compared to the 0N treatment (46.7 kg N ha^{-1}). Since all treatments received the same quantity of starter fertilizer, we found that between 32.5% of N from the broadcast urea was taken up in the grain as compared to 50.2% with the injected UAN+UI+NI treatment.

There were significant differences amongst N source and application method treatments. The greatest N uptake (112 kg N ha^{-1}) was observed with the injected UAN+UI+NI treatment and it was significantly greater than all other application methods and sources except for the injected UAN+UI treatment (107 kg N ha^{-1}). Injected UAN+UI+NI was found to have 13.2% more N uptake in corn grain than the injected UAN treatment without any inhibitors (98.9 kg N ha^{-1}) and about 26% greater N uptake than broadcast urea (88.9 kg N ha^{-1}).

2. Nitrogen losses from ammonia volatilization and nitrous oxide emissions:

The summer of 2014 tended to be cooler and drier than previous years and as a result urea hydrolysis and ammonia volatilization was spread out over the 4 week collection period (Figure 1) compared to data from 2013 (unpublished data). Because of instrumentation costs, only 6 treatments were monitored (3 replicates) for ammonia volatilization loss. For all 3 application methods (broadcasting, streaming and injection) the regular N treatments (urea or UAN) with a urease inhibitor had greater ammonia volatilization losses as compared to the corresponding treatment with UI+NI inhibitors (Super U or UAN+UI+NI). Amongst the 3 application methods, the greatest ammonia volatilization losses occurred for broadcast urea and the peak emission occurred about 2 weeks after application (Fig. 1).

Cumulative ammonia volatilization losses were related to both application method and N source (Fig. 2). Between 0.21% (injected UAN+UI+NI) and 27.6% (broadcast urea) was lost (volatilized) from the soil within the first 28 days after application. Ammonia volatilization losses were compared across the N application method treatments. When no inhibitors were co-applied with the fertilizers, broadcast urea (35.8 kg N ha^{-1}) had 3.1 times greater ammonia loss than streaming UAN (11.4 kg N ha^{-1}) and 4.2 times greater losses than injected UAN (8.43 kg N ha^{-1}). When urease inhibitor was added with the broadcast N fertilizer (Super U, urea +UI+NI), ammonia volatilization decreased by 76% to 8.52 kg N ha^{-1} compared to broadcast urea (35.8 kg N ha^{-1}). Ammonia volatilized was reduced by 97% when UAN+UI+NI was added (0.27 kg N ha^{-1}) compared to injected UAN (8.44 kg N ha^{-1}) and volatilization was reduced by 52% when streaming UAN+UI+NI (5.48 kg N ha^{-1}) was compared to streaming UAN (11.4 kg N ha^{-1}).

Nitrous oxide emissions varied by application method, N source and rainfall event (Fig. 3). The largest nitrous oxide emissions occurred following rain events after sidedress N was applied. The two largest N_2O emission peaks occurred following 2 rain events in late July (50.8 mm on July 27, 2014) and early August (35.8 mm on August 11, 2014). The largest N_2O emissions were associated with the injected treatment. It was interesting to note that for the broadcast treatments urea+UI and for the injected treatments UAN+UI had larger N_2O emissions than the corresponding treatments without the inhibitors. This could be explained in part by the lower ammonia volatilization losses which results in more inorganic N remaining in the soils.

However when both the urease and nitrification inhibitors were included, the N_2O emissions were reduced compared to when just a urease inhibitor was co-applied.

The cumulative N_2O emissions over the growing season ranged from a low of 221 g N ha^{-1} for the control treatment to a maximum of 2095 g N ha^{-1} with the injected UAN treatment (Fig. 4). There were fairly dramatic differences between N sources and application methods that were intimately linked with the ammonia volatilization losses with these treatments. In general when a treatment had higher volatilization losses, then there was less N left in the soil and subject to denitrification losses. For this reason, for all 3 methods there were greater N_2O emissions when urease inhibitors were applied than compared to regular N application. For example injected UAN+UI had N_2O emissions of 2,095 g N ha^{-1} whereas injected UAN had 869 g ha^{-1} N_2O loss (Fig. 4). Similarly, Broadcast UAN+UI resulted in N_2O emissions of 1197 g N ha^{-1} compared to 587 g N ha^{-1} with broadcast urea. This is a good illustration of pollution swapping whereby reductions in ammonia emissions with the use of a urease inhibitor resulted in greater soil inorganic N contents and greater N_2O emissions. However, when both a urease and a nitrification inhibitor were used the N_2O losses were lower than when the urea +UI treatment was used and similar to the regular N treatment. For example Broadcast SuperU^{TM} (UI+NI) had N_2O emissions of 609 g N ha^{-1} which was similar to broadcast urea at 587 g N ha^{-1}. Similairly, Injected UAN +UI+NI had an N_2O emission value of 898 g N ha^{-1} which was similar to injected UAN at 869 g N ha^{-1}.

Summary:

Dramatic differences were obtained between N application methods and N sources in ammonia volatilization losses. In general, the broadcast urea resulted in the greatest ammonia volatilization losses (35.8 kg N ha^{-1}) and when a urease inhibitor was included with the urea (8.5 kg N ha^{-1}) or the N was injected into the soil (8.4 kg N ha^{-1}), the ammonia losses were significantly reduced. The combination of injected urea with UI+NI resulted in negligible ammonia loss (0.27 g N ha^{-1}). When ammonia loss was reduced, then more inorganic N remained in the soil which in turn increased N_2O emissions. However the combination of urease and nitrification inhibitors reduced both ammonia volatilization and nitrous oxide emissions. When the crop yields were also considered, the treatments with the greatest yields and highest N uptake values was the injected UAN with the urease and nitrification inhibitor. The injected UAN+UI+NI treatment had yields that were 15.6 % greater and N uptake values that were 20.6% greater than the broadcast urea treatment. Hence using a combination of better N application methods and N sources could result in more environmentally friendly practices and significantly greater crop yields and N recoveries. However, these results are based upon only 1 year of field measurements and additional research is required to see how some of these treatments respond over varying soil and weather conditions.

Next steps:

The effectiveness of various N application methods and N sources has been demonstrated in this bridging project. There are however many other questions that have to be addressed to improve N management even further as even with the best management practice, only about 50% of the applied N was captured in the corn grain. Not only will other treatments have to be investigated, but these transformations have to be examined under varying climatic conditions to ensure that a recommended practice will work under a range of soil and weather conditions.

Acknowledgements:

We would like to express appreciation to the Canadian Fertilizer Institute and AAFC for providing the funding for this study and to Rigas Karamanos for providing the Super U^{TM} used in one of the treatments we evaluated.

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Table 1. Corn grain yields (2014) and N uptake as a function of varying N sources and application methods.

Treatment	N Source	Corn grain yield t ha^{-1}	Corn N uptake kg N ha^{-1}
Control		4 61 (0.28) c	46.7 (2.8) d
Broadcast	Urea	8.74 (0.26) b	88.9 (3.3) c
	Urea + UI	9.10 (0.27) b	93.2 (2.8) c
	Urea + UI + NI	9.41 (0.41) ab	98.6 (3.8) bc
Streaming	UAN	9.09 (0.51) b	93.1 (5.4) c
	UAN + UI	9.01 (0.42) b	96.9 (4.5) bc
	UAN + UI + NI	9.11 (0.42) b	95.3 (3.4) c
Injection	UAN	9.67 (0.21) ab	98.9 (2.2) bc
	UAN + UI	10.2 (0.65) a	107 (6.8) ab
	UAN + UI + NI	10.1 (0.39) a	112 (4.0) a

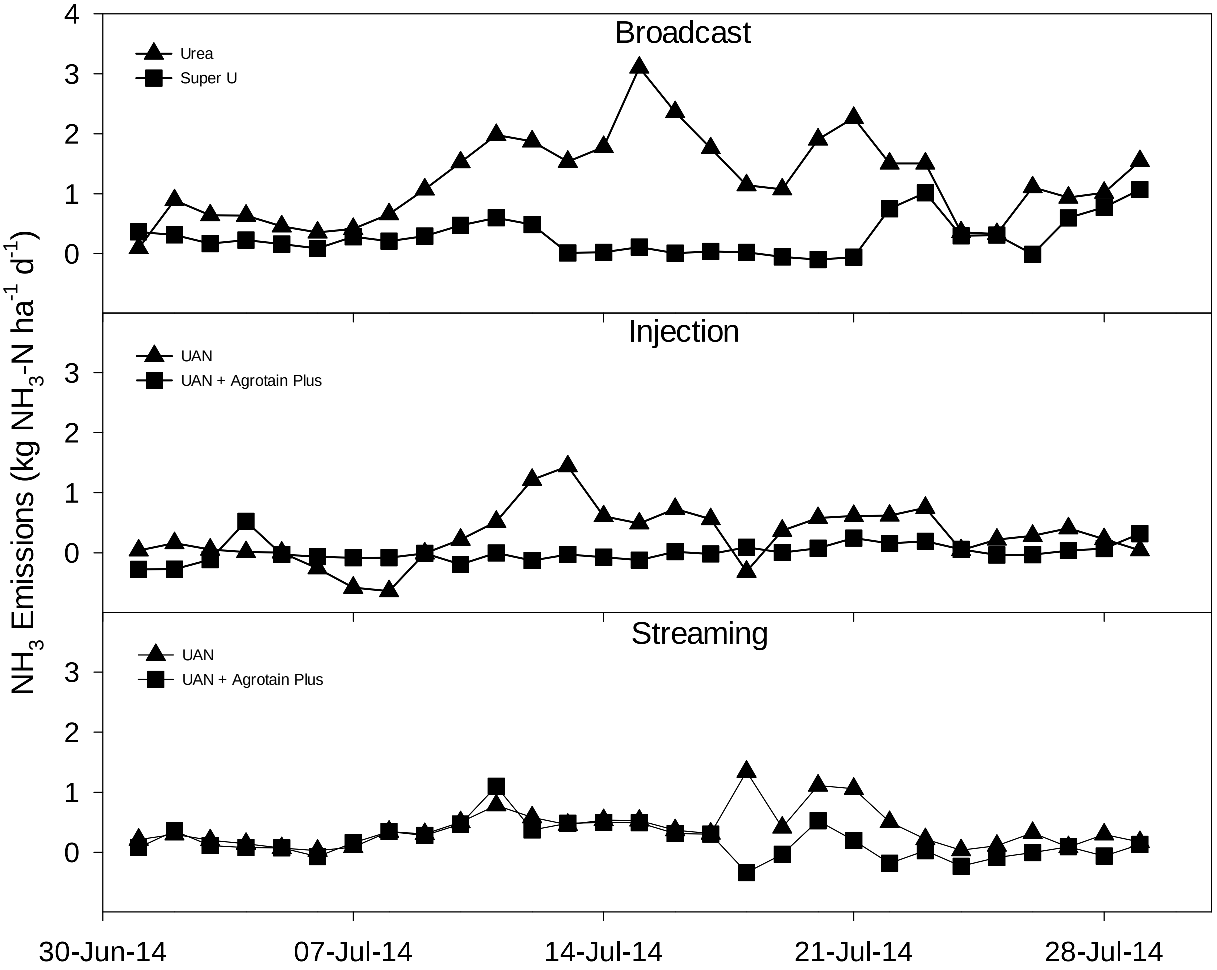

Figure 1. Daily ammonia volatilization losses associated with the N application methods and N sources following side-dress N application.

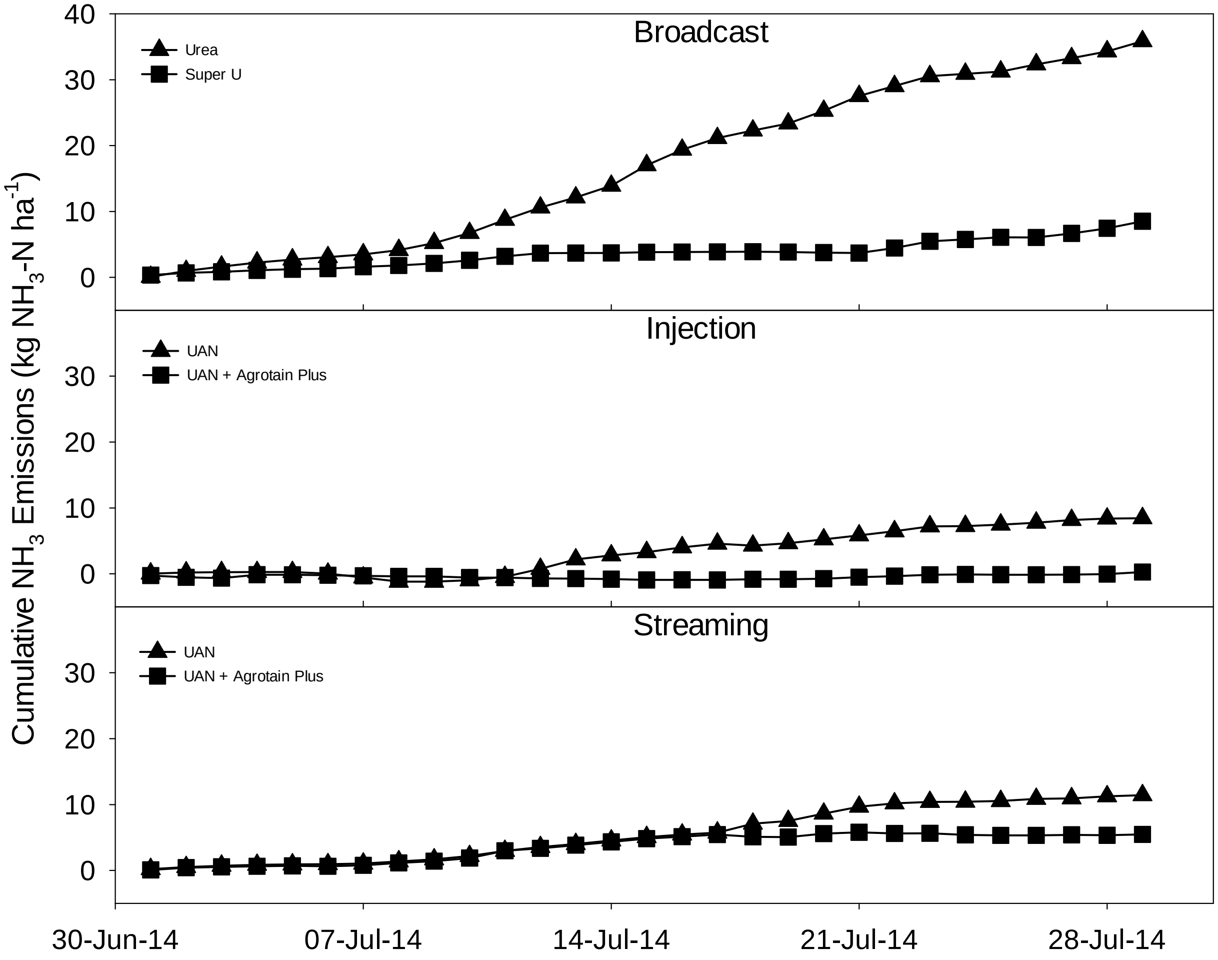

Figure 2. Cumulative ammonia volatilization losses associated with the N application methods and N sources following side-dress N application.

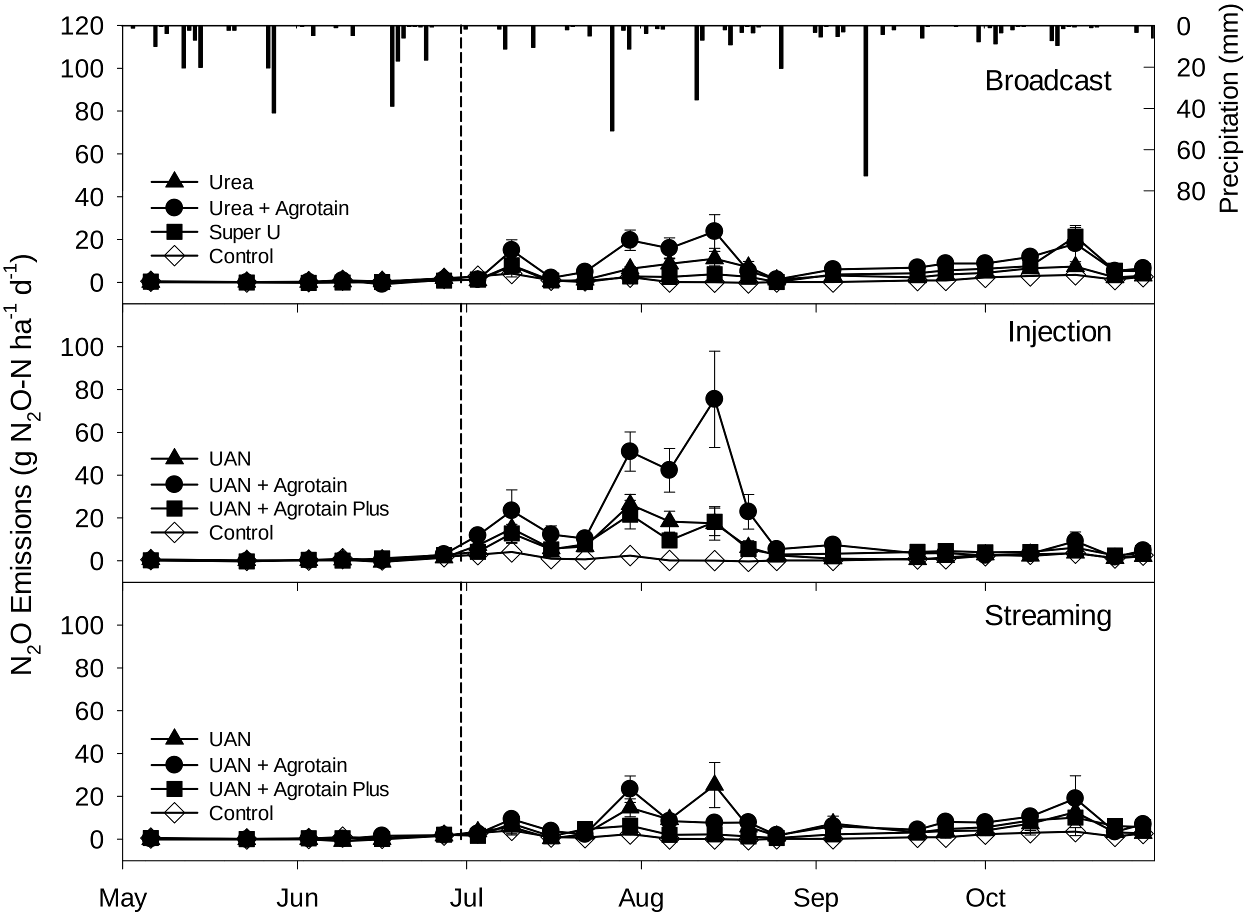

Fig. 3. Nitrous oxide emissions associated with the N application methods and N sources over the 2014 growing season.

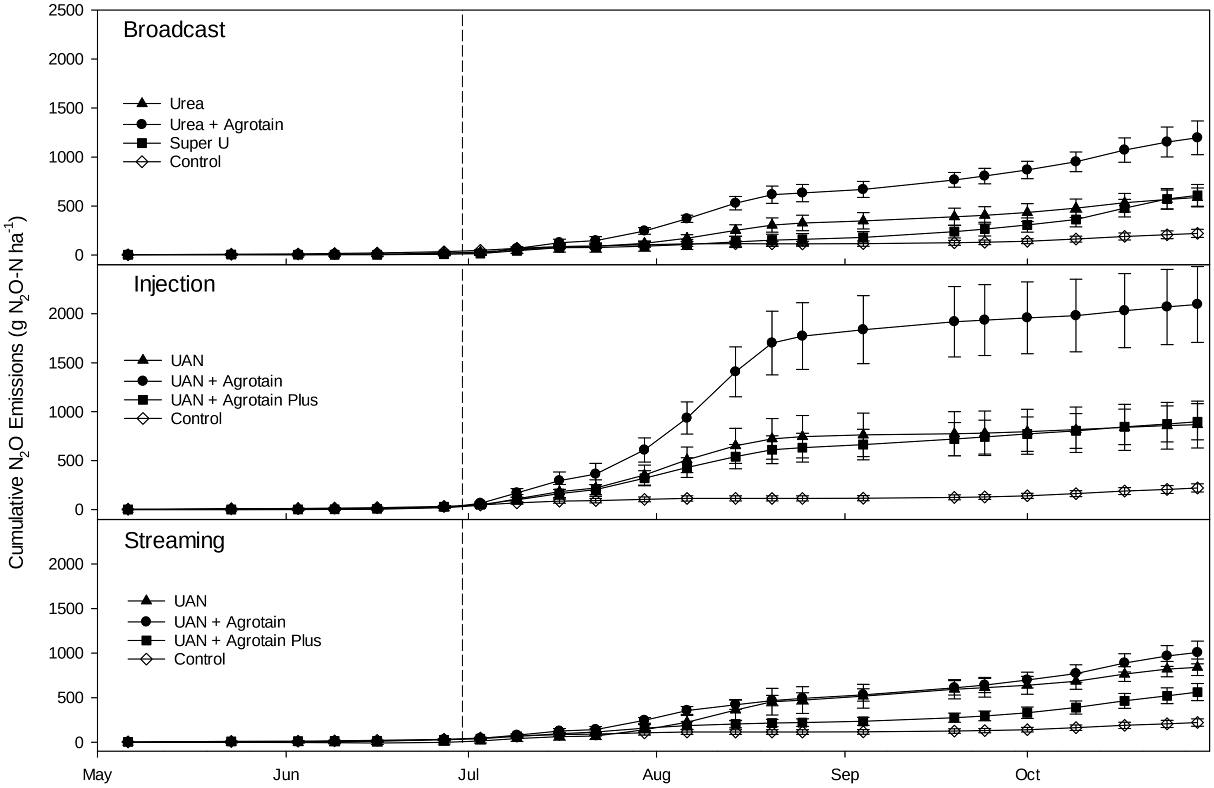

Fig. 4. Cumulative nitrous oxide emissions associated with the N application methods and N sources over the 2014 growing season.