Nitrogen Source Effects on Soil Nitrous Oxide Emissions

N selection can be a mitigation practice for reducing N_2O emissions in irrigated corn.

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***Summary:** Nitrogen (N) application to crops generally results in increased nitrous oxide (N_2O) emissions. Commercially available enhanced-efficiency N fertilizers were evaluated for their potential to reduce N_2O emissions from a clay loam soil compared with conventionally used granular urea and urea-ammonium nitrate (UAN) fertilizers in an irrigated strip-till (ST) corn production system. All other N sources had significantly lower growing season N_2O emissions than granular urea, with UAN + AgrotainPlus and UAN + Nfusion having lower emissions than UAN. Similar trends were observed when expressing N_2O emissions on a grain yield and N uptake basis. Loss of N_2O-N per kilogram of N applied was <0.8% for urea and <0.5% for all other N sources. Corn grain yields were not different among N sources but greater than treatments with no N applied.*

Nitrous oxide has a global warming potential (GWP) approximately 298 times greater than that of CO_2, thus the importance of developing methods to reduce N_2O emissions in agricultural systems. Nitrogen fertilization has been essential for optimizing crop yield and economic returns in irrigated cropping system in the U.S. Central Great Plains. Data available for analyzing impacts of N_2O emissions on net GWP in irrigated crop production systems are limited, however. More research on enhanced-efficiency N fertilizers is needed to thoroughly evaluate their agronomic impact and effects on N_2O losses.

The main objectives of this study were:

- Study the effects of the following enhanced-efficiency N fertilizers (1) controlled release polymer-coated urea (ESN), (2) stabilized granular urea (SuperU), (3) stabilized UAN (UAN + AgrotainPlus), and (4) slow-release UAN (UAN + Nfusion) on growing season N2O emissions compared with those from conventionally-used granular urea and liquid UAN applications within an irrigated strip-till (ST) continuous corn production system
- Evaluate the possible agronomic benefits of the enhanced-efficiency N fertilizers on grain yield and N uptake, and relate N_2O emissions from each N source on a grain yield and N uptake basis.

Results/Discussion

Environmental. Air and soil temperatures at each greenhouse gas emission (GHG) sampling date in 2009 and 2010 are shown in Figure 1. Both years, soil temperatures were cooler during May and early June (DOY 121 – 160) than the main part of the growing season, with cooler soil temperatures during May 2010 than during May 2009, but warmer temperatures, starting in June through most of the growing season, in 2010 than in 2009. With crop canopy closure in late June, soil temperature rose to ~20o C and then declined starting in September. Soil temperatures, during the December 2009 through February 2010 sampling period, were generally <0°C, with an increase in soil temperature starting in early March. Air temperatures in early May were generally cooler in 2010 than in 2009.

Precipitation and irrigation amounts in 2009 and 2010 are shown in Figure 2. Total 2009 yearly precipitation was 341 mm, with the May through October corn growing season totaling 259 mm. In 2009, 397 mm of irrigation water was applied to the corn crop with a growing season total (precipitation + irrigation) of 656 mm. Annual precipitation totaled 273 mm in 2010, with a May through October corn growing season total of 129 mm. In 2010, the corn received 396 mm of irrigation water, with a growing season total (precipitation + irrigation) of 525 mm.

Water-filled pore space (WFPS) ranged from ~65 to 80% from early May to mid-June in 2009 (Figure 3). In 2010, WFPS ranged from ~72 to ~82% in May, then declined to a low of ~50% during June and stabilized between 60 and 70% during the rest of the growing season. During the winter months, WFPS declined to a low of ~35% in December 2009 to February 2010. The WFPS tended to increase following precipitation and irrigation events (Figure 2) and averaged 67.8 and 65.1% during the 2009 and 2010 growing seasons (May to September), respectively.

Table 1. Soil NO3-N levels in three depth increments from May 20 to July 29, 2010 from the N source treatments (significant N treatment x sampling day interaction teraction).

N treatment*	20-May	3-Jun	16-Jun	30-Jun	15-Jul	29-Jul
	DOY140**	DOY 154	DOY 167	DOY 181	DOY 196	DOY 210
0-15.2 cm soil depth, kg NO3-N ha-1						
Urea	9.6a***	31.2a	24.2abcd	25.1bc	7.1a	4.8bc
ESNssb	11.7a	13.3bc	11.6 cd	14.2cd	9.5a	26.7a
ESN	6.3a	11.4c	8.6d	11.9cd	6.1a	8.2b
SuperU	8.8a	17.5bc	18.2bcd	17.9bcd	15.0a	4.9bc
UAN	8.3a	33,5a	33.9ab	28.9ab	21.0a	8,8b
UAN+Nf	7.8a	37.2a	41.1a	30.7ab	16.4a	6.1bc
UAN+AP	9.2a	24.6ab	30.0abc	40.7a	16.7a	6.3bc
Blank	8.8a	11.4c	7.1d	6.2d	3.7a	4.3bc
Check	7.2a	9.9c	8.0d	5.6d	3.3a	3.5c
0-30.5 cm soil depth, kg NO3-N ha-1						
Urea	20.5a	40.9ab	44.3ab	42.5ab	12.0a	10.3b
ESNssb	22.2a	21.0cd	22.1bcd	21.3cd	13.9a	31.7a
ESN	13.9a	19.1d	17.9cd	18.3d	9.2a	11.8b
SuperU	18.8a	27.1cd	31.4ab	29.1bcd	20.6a	8.8b
UAN	19.8a	43.3ab	52.1a	38.5abc	28.5a	15.2ab
UAN+Nf	17.8a	47.4a	52.7a	44.3ab	22.2a	10.3b
UAN+AP	20.8a	33.7bc	42.5ab	50.2a	20.4a	9.7b
Blank	20.4a	18.8d	16.1d	12.0d	6.6a	7.5b
Check	15.2a	18.3d	16.7cd	11.5d	6.7a	7.6b
0-61.0 cm soil depth, kgNO kg NO3-N ha-1						
Urea	39.8a	57.3ab	65.6ab	70.6a	25.3bcd	25.0a
ESNssb	44.7a	36.6de	38.2bcd	39.1bcd	26.1bcd	37.5a
ESN	27.6a	34.4cde	33.3cd	35.4cd	18.6bcd	16.0a
SuperU	32.9a	43.6bcd	49.7abc	52.8abc	35.0ab	14.3a
UAN	37.9a	60.3a	72.5a	58.6ab	45.4a	24.2a
UAN+Nf	40.4a	66.6a	69.9a	70.1a	36.3ab	16.0a
UAN+AP	44.4a	51.7abc	59.6ab	69.3a	31.6abc	14.0a
Blank	44.1a	34.0de	31.3cd	27.7d	14.7cd	11.2a
Check	26.2a	28.1e	26.6d	21.3d	12.3d	12.4a

** ESNssb = ESN subsurface band; ESN = polymer-coated urea; SuperU = stabilized granular urea; UAN = urea-ammonium nitrate; UAN+Nf = UAN with Nfusion; UAN+AP = UAN with AgrotainPlus.*

*** DOY, day of year.*

**** Values within a column followed by the same lower-case letter are not significantly different at the probability level = 0.05.*

“Corn grain yields were not different among N sources but greater than treatments with no N applied”

N_2O Fluxes increased within days following the application of all N sources, except for ESN, which had a delayed release of N_2O in 2009 (Figure 4) and 2010 (Figure 5). N_2O fluxes were highest the first 30 days following N fertilization with urea and UAN when WFPS was highest and then declined to near background levels in ~45 days. Similarly, N_2O-N fluxes from Super U increased within days following application but were of a smaller magnitude than for urea and UAN, then decreasing to background levels in ~45 days both years. This trend corresponds to the trend of soil NO_3N levels being lower for Super U in 2010 in the 0- to 15.2- and 0- to 30.5-cm soil depths during June than urea and all UAN treatments (Table 1). Also, N_2O-N flux peaks resulting from UAN +Nfusion and UAN +AgrotainPlus application occurred within days of application but were of a much smaller magnitude than those observed for UAN alone, even though the measured soil NO_3-N levels were similar to UAN (Table 1). Nitrous oxide fluxes from surface banded ESN and ESN subsurface banded (ESNssb) followed a different pattern, remaining low until mid-June when N_2O-N fluxes started to increase both years (Figures 4 and 5). In 2010, the soil NO_3 levels for the ESN treatments were generally less than for the other N sources during the early part of the growing season following N application. On 29 July, the ESNssb treatment had higher soil NO_3-N levels than the other treatments (Table 1). The N_2O flux peaks from the ESN treatments during the growing season were greater in 2010 (Figure 5) than in 2009 (Figure 4), possibly due to a faster release of the urea N from the polymer-coated granule because of higher soil temperatures in 2010 than in 2009 (Figure 1). The N_2O peaks from ESN application tended to be higher than those from the other N sources during mid-June through August but tended to be smaller and of shorter duration than the peaks observed just after urea or UAN application. The late-season N_2O-N fluxes from the ESN are consistent with earlier results. The rapid increase in N_2O emissions following N application is consistent with earlier work by others where it was reported that 50% of the N_2O emissions occurred shortly after N application, regardless of tillage or crop rotation practices.

In 2009, we were able to collect N_2O flux measurements during the non-crop period (1 Oct. 2009 to 22 Mar. 2010). Nitrous oxide fluxes remained near background levels for the entire period for all N treatments, with a slight rise in N_2O emissions on 4 Mar. 2010, as the frozen soil had thawed and soil temperatures increased, with a decline to background levels at the 12 Mar. sampling date. The slight increase in N_2O emissions as the soil thawed out is consistent with the observations of others who have reported increased N_2O fluxes at spring thaw. Average N_2O-N emissions (174 d) for the non-crop period were: 1.44a, 1.23ab, 1.18ab, 1.13bc, 0.99bed, 0.88cd, 0.87cd, 0.80d, and 0.79d g N ha^{-1}d^{-1} for ESNssb, ESN, SuperU, urea, UAN+AgrotainPlus, UAN+Nfusion, check, UAN, and blank, respectively, with significant differences indicated by lowercase letters following the daily emission value. The ESNssb treatment had the highest daily non-crop period emissions and the blank (no N applied) had the lowest emissions. The ESNssb

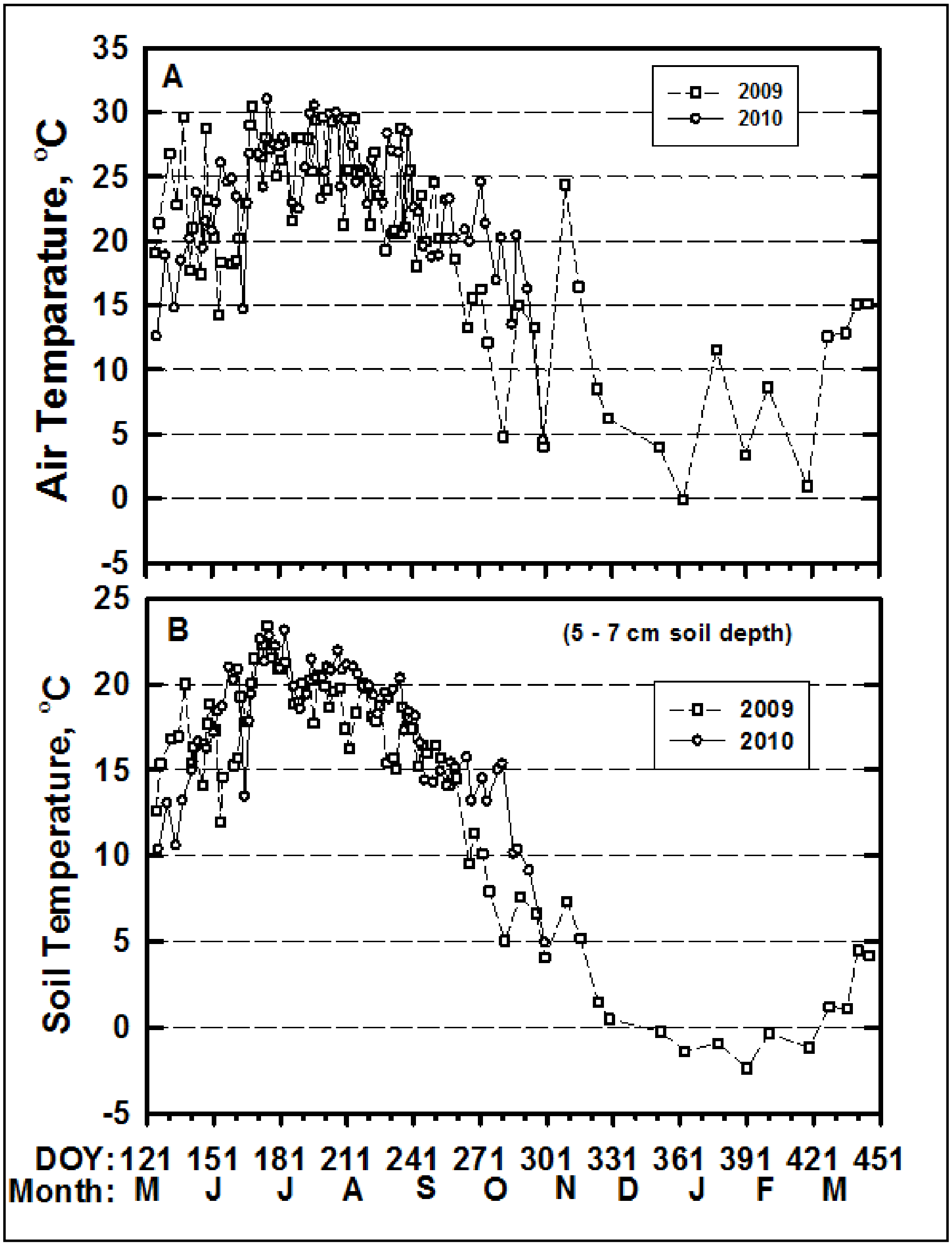

Figure 1. Air (A) and soil temperature (B) at about the 5-7 cm depth measured at the time of gas flux measurement in 2009 and 2010.

treatment also had the highest level of residual soil NO_3-N in late November 2009 (Table 2), which probably accounts for the slightly higher N_2O emissions during the non-crop period. Nitrification was probably the dominant pathway of soil N_2O loss from applied N fertilizer from this ST, irrigated system based on WFPS being generally <70% both years, except for a short period in early 2010 when WFPS was 80% before N fertilization. The slightly elevated level of residual soil NO_3-N at the end of the growing season with the ESNssb treatment is consistent with observations by others who have reported slightly elevated residual soil N with polymer-coated urea than with conventional urea.

Cumulative daily N_2O-N fluxes during the corn growing season are shown in Figure 6 for 2009 and Figure 7 for 2010. A rapid rise in cumulative daily flux levels for urea and UAN was very apparent both years following N application, with SuperU, UAN+Nfusion, and UAN+AgrotainPlus also showing rapid rises in cumulative N_2O emissions immediately following N application in 2010. Cumulative growing season emissions were greater in 2010 than 2009 for all N treatments, except for urea, which was similar both years but followed similar relative emission patterns both years. The rise in cumulative daily N_2O-N flux was slower for all enhanced efficiency N sources than for urea and UAN both years. The delayed release of N_2O-N from ESN until about mid-June was very prominent in 2010. The N_2O emissions from the blank (no N applied) treatments that had received 202 kg N ha-1 in previous years was very similar to that from the check treatment that had not had any N applied since 1999. The residual soil NO_3-N (Table 3) in the 0- to 15.2-, 0- to 30.5-, and 0- to 61- cm depths was significantly greater in the N source plot area where the blank treatment resided than in the check treatment located in an adjacent plot. Although the residual soil NO_3-N was greater in the blank plot area than in the check plot area before corn planting, we did not observe a significant difference (Table 4) in the growing season N_2O emissions between the blank and check treatments. A critical soil NO_3-N concentration of 5 mg NO_3-N kg^{-1} has been reported in the literature below which N_2O emissions may be much reduced, even at high levels of WFPS. In this study, the difference in NO_3-N levels between the check and blank treatments in the 0- to 15.2-cm soil depth had disappeared by 20 May 2010 (DOY 140). A soil NO_3-N concentration of 5 mg NO_3-N kg^{-1} would equate to 11 kg NO_3-N ha^{-1} in this study, with the blank and check treatments generally having lower NO_3-N levels than 11 kg NO_3-N ha^{-1} during the growing season. This may help explain why there was little difference in N_2O emissions between the blank and check during the growing season. This observation between the blank and check treatments was observed both years. This would tend to indicate in our system that the fresh application of N fertilizer was stimulating microbial activity and the nitrification process resulting in N_2O loss from the N fertilizer applied. The fact that WFPS (Figure 3) was generally <70% most of the growing season would support the theory that nitrification is the main pathway of N_2O loss at this location.

Table 2. Residual soil NO3-N in four soil depth increments after corn harvest in 2009 and 2010 and averages over years (no significant interaction between N treatment and years)

Sampling Date	**N treatment***				
		Soil depth			
		0-15.2 cm	0-30.5 cm	0-61.0 cm	0-91.5 cm
		kg NO3-N ha^{-1}			
25 Nov. 2009 (DOY 329)**	Urea	9.1a***	29.3bc	53.1bc	88.3ab
	ESNssb	10.6a	62.9a	121.7a	152.0a
	ESN	11.1a	37.3ab	66.5b	83.9b
	SuperU	5.1a	15.0bc	34.3bc	52.6bc
	UAN	6.2a	19.4bc	40.6bc	83.0b
	UAN+Nf	5.2a	15.0bc	27.3bc	39.8bc
	UAN+AP	4.6a	13.4bc	27.7bc	57.8bc
	Blank	2.8a	8.4bc	13.9c	16.3c
	Check	2.0a	6.2c	11.7c	14.6c
2 Nov. 2010 (DOY 306)	Urea	10.2a	19.4a	28.9a	39.1a
	ESNssb	36.0a	53.4a	64.4a	73.6a
	ESN	14.6a	24.6a	34.5a	39.8a
	SuperU	14.1a	32.8a	53.1a	66.1a
	UAN	14.7a	26.02a	35.7a	44.2a
	UAN+Nf	18.1a	30.2a	42.2a	50.2a
	UAN+AP	17.3a	28.1a	40.9a	55.5a
	Blank	5.4a	9.2a	12.7a	15.9a
	Check	6.1a	9.6a	14.0a	16.2a
Avg. 2009 and 2010	Urea	9.7b	24.3b	41.0b	63.7ab
	ESNssb	22,6a	63.4a	101.6a	118.7a
	ESN	13.7ab	29.5ab	49.0ab	63.4ab
	SuperU	9.6b	23.9b	43.7b	59.4b
	UAN	10.4ab	22.7b	38.2b	63.6ab
	UAN+Nf	11.6ab	22.6b	34.7b	45.0b
	UAN+AP	10.9ab	20.7b	34.3b	56.5b
	Blank	4,1c	8.8c	13.3c	16.1c
	Check	4.1c	7.9c	12.9c	15.4c

**ESNssb = ESN subsurface band; ESN = polymer-coated urea; SuperU = stabilized granular urea; UAN = urea ammonium nitrate; UAN+Nf= UAN with Nfusion+AP = UAN with AgrotainPlus.*

***DOY = day of year*

**** Values within columns followed by the same lower case letter are not significantly different at probability level = 0.05*

Nitrous oxide emissions for the two growing seasons (5 May to 29 September 2009 and 6 May to 29 September 2010) are reported in Table 4, with a significant N source x year interaction. This interaction probably resulted from ESNssb, SuperU, UAN, UAN+Nfusion, and UAN+AgrotainPlus having significantly greater N_2O emissions in 2010 than in 2009 but no difference between years for urea, ESN, blank, and the check treatments. Averaged over both years, growing season N_2O-N emissions from all enhanced-efficiency N fertilizers were significantly lower than granular urea, including UAN. The ESNssb treatment had significantly higher N_2O emissions than the UAN+Nfusion, UAN+AgrotainPLus, blank, and check treatments. The UAN+Nfusion and UAN+AgrotainPlus treatments had lower N_2O emissions than UAN. The blank and check treatments had the lowest level of growing season N_2O-N emissions and were not significantly different.

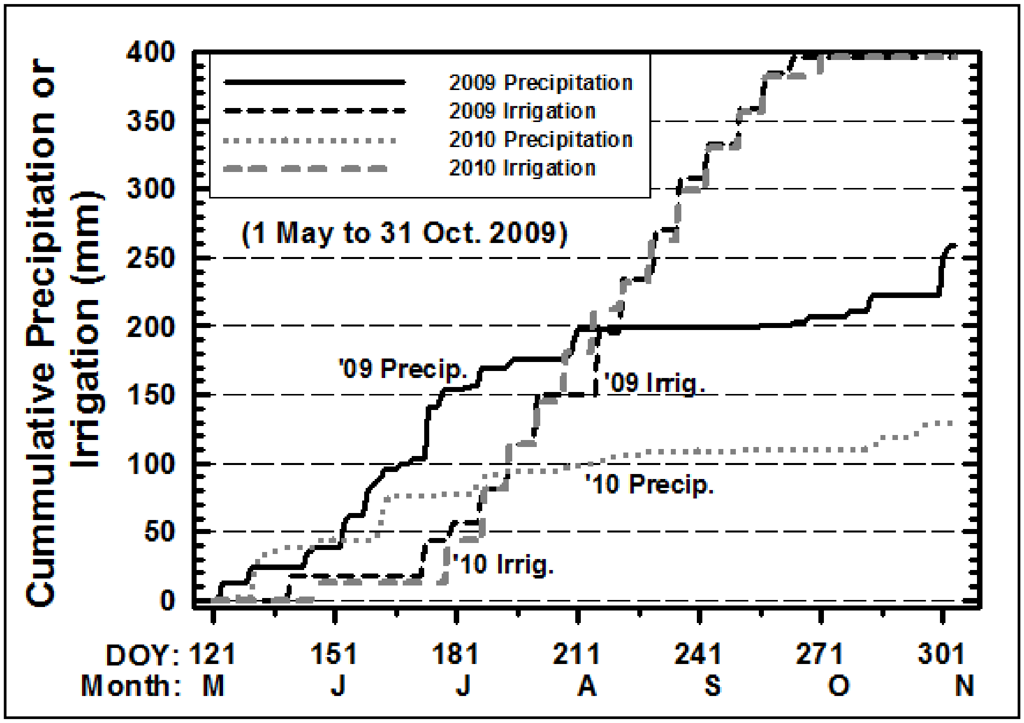

Figure 2. Cumulative growing season precipitation and irrigation amounts applied in 2009 and 2010.

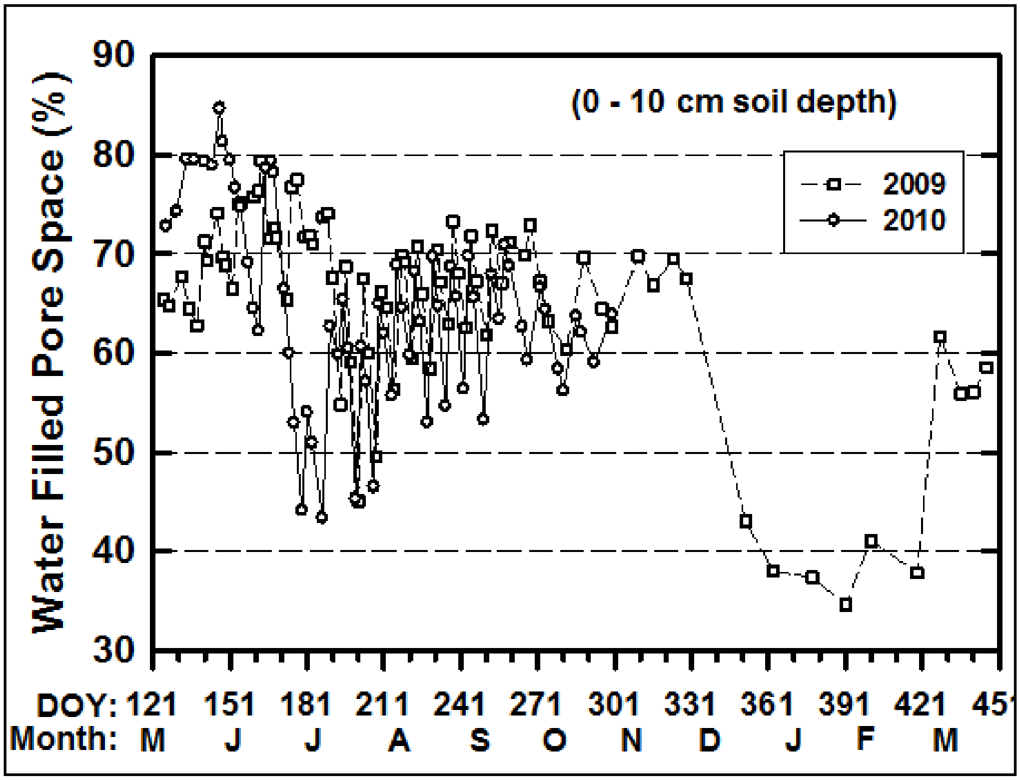

Figure 3. Water filled pore space in the 0 to 10-cm soil depth from 5 May 2009 through 22 March 2010 and 6 May 2010 through 31 October 2010.

Table 3. Spring soil NO_3-N and NH_4-N content prior to planting the corn crop and N fertilization in 2009 and 2010, with no significant N treatment by year interactions.

		Soil depth					
		0-15.2 cm		0-30.5 cm		0-61.0 cm	
		NO_3-N	NH_4-N	NO_3-N	NH_4-N	NO_3-N	NH_4-N
Year	N Treatment			---------kg N ha^{-1}----------			
2009	Check	12.0b*	12.9a	17.4b	28.6a	19.7b	46.9a
2009	N source	40.6a	11.2a	60.5a	20.5b	90.5a	34.2b
2010	Check	6.3b	6.6a	13.2b	18.0a	17.7b	28.2a
2010	N source	10.6a	6.6a	26.1a	12.9b	48.9a	21.8b
2-yr avg.	Check	9.1a	9.8a	15.3b	23.3a	18.7b	37.5a
2-yr avg.	N source	25.6a	8.9a	43.3a	16.7a	69.7a	28.0a
2009	Avg.	26.3a	12.0a	39.0a	24.5 a	55.1a	40.5a
2010	Avg.	8.5b	6.6b	19.6b	15.4b	33.3a	25.0b

*Values within a column data group followed by the same letter are not significantly different at the probability level = 0.05.

Table 4. Cumulative growing season N_2O-N flux (5 or 6 May - 29 Sept.) and fertilizer-induced N_2O-N emissions as a percentage of N applied (significant N treatment x year interaction for growing season N_2O emission only).

	Cumulative growing season N_2O-N emissions			**N_2O-N emissions as % of fertilizer N applied**		
N Treatment*	2009	2010	Avg.	2009	2010	Avg.
	N_2O-N, g N ha^{-1}			%		
Urea	1698a**	1726a	1712a	0.77a	0.77a	0.77a
ESNssb	856cde	1439ab	1147b	0.36b	0.63b	0.49b
ESN	716def	1028bcde	872bc	0.29c	0.42bc	0.36cd
SuperU	631ef	972bcd	801bc	0.25cd	0.40bc	0.32cd
UAN	765de	1214abc	989b	0.31bc	0.52b	0.41bc
UAN+Nfusion	468fg	1001bcd	734c	0.16de	0.41bc	0.29de
UAN+AgrotainPlus	352g	665ef	509d	0.11e	0.24c	0.18e
Blank (no N added	136hi	172h	154e	-	-	-
Check (no N added)	99i	123hi	111e	-	-	-
Avg.	636B***	927A		0.34B	0.51A	

** ESNssb = subsurface band; ESN = polymer-coated urea; SuperU = stabilized granular urea; UAN = urea-ammonium-nitrate; UAN+Nf =UAN with Nfusion; UAN+AP = UAN with AgrotainPlus.*

***Values within a column followed by the same lowercase letter are not significantly different at the probability level = 0.05 or across 2009 and 2010 columns for N2O growing season emissions.*

****Values within a row followed by the same uppercase letter are not significantly different at the probability level = 0.05.*

Averaged over N sources, growing season N_2O emissions were lower in 2009 than in 2010. The higher WFPS in 2010 during May through mid-June than in 2009 (Figure 3) may have contributed to the yearly difference, with some denitrification possibly contributing to the increased N_2O loss.

Compared with granular urea (averaged over years), UAN+AgrotainPlus reduced N_2O-N emissions 70%, UAN+Nfusion 57%, SuperU 53%, ESN 49%, UAN 42%, and ESNssb 33% in this ST production system. Compared with liquid UAN, UAN+AgrotainPlus reduced N_2O-N emissions 49%, UAN+Nfusion 26%, SuperU 19%, and ESN 12%, results that are in agreement with our previous studies.

The N_2O-N emission losses as a percentage of fertilizer N applied are reported in Table 4, with no significant interaction between N source and year. The N_2O-N loss was significantly higher in 2010 than in 2009, with N sources having significant differences in N_2O-N loss. All other N sources had significantly lower N_2O-N emission losses than granular urea. This result indicates that the potential for reduction of N_2O-N emissions with the use of controlled-release, slow-release, and stabilized N fertilizer sources in ST systems is substantial. The calculations above show that the fertilizer-induced component of N_2O-N emissions could be reduced up to 70% by using enhanced-efficiency N sources in semiarid, irrigated cropping systems. The degree of reduction may vary strongly, depending on cropping

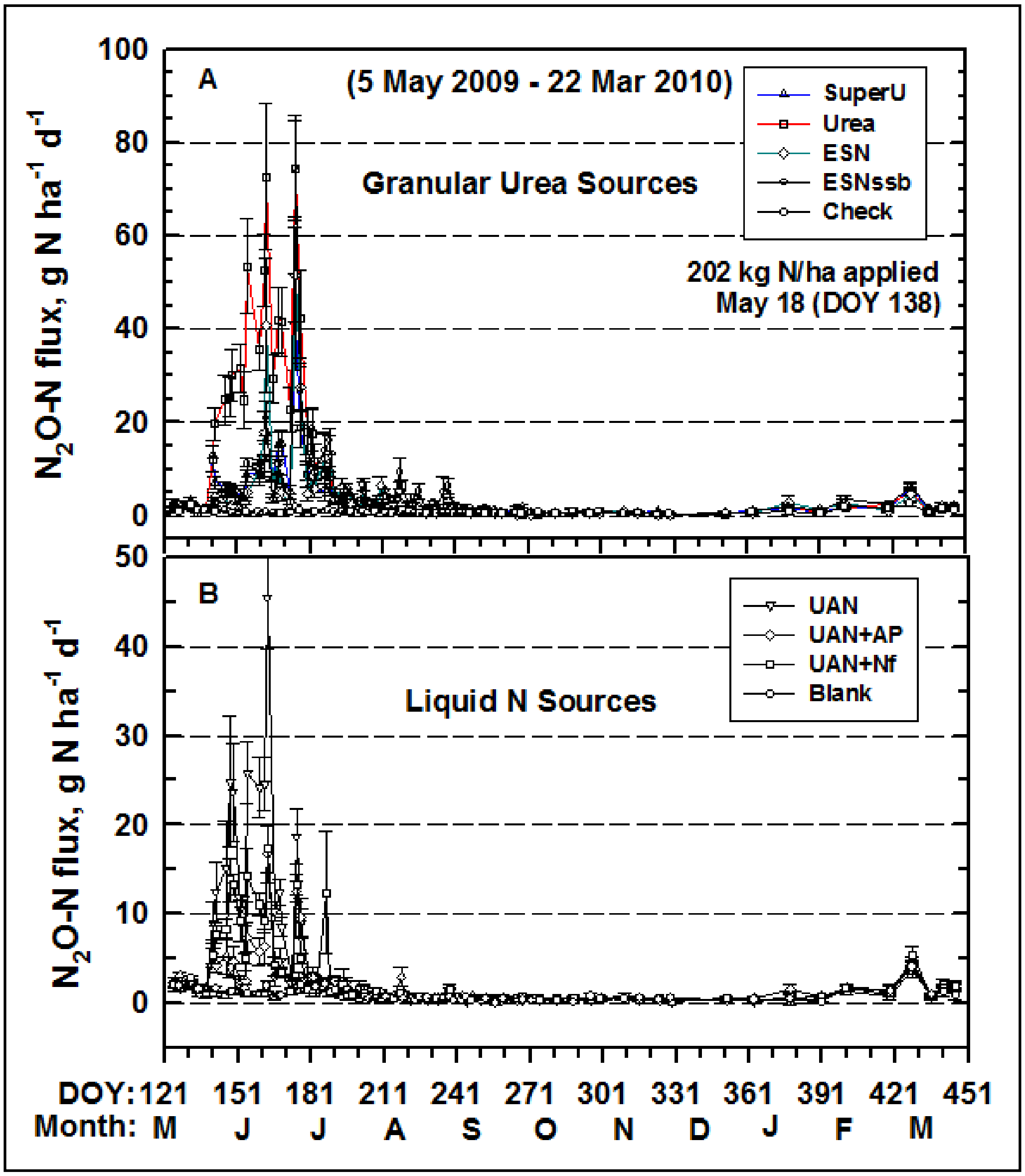

Figure 4. Daily N_2O-N fluxes with standard error bars at each sampling date in 2009 with for (A) SuperU, urea, ESN, ESN subsurface band (ESNssb), and check; and (B) urea-ammonium nitrate (UAN), UAN+AgrotainPlus (AP), UAN+Nfusion (Nf) and blank. Note the different scales on Y axis.

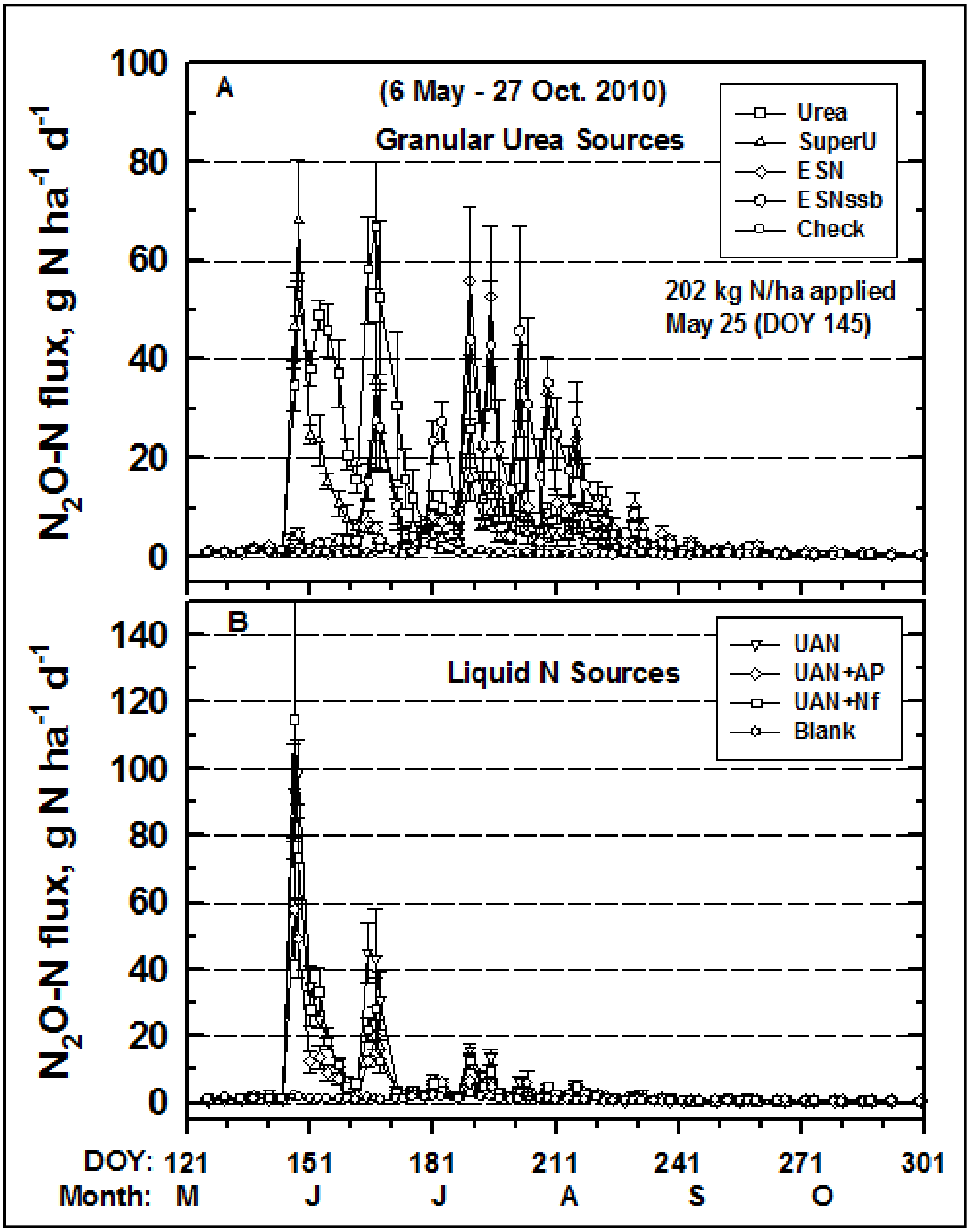

Figure 5. Daily N_2O-N fluxes with standard error bars at each sampling date in 2010 with for (A) SuperU, urea, ESN, ESN subsurface band (ESNssb), and check; and (B) urea-ammonium nitrate (UAN), UAN+AgrotainPlus (AP), UAN+Nfusion (Nf) and blank. Note the different scales on Y axis.

system, tillage management, and site-specific conditions. The growing season N_2O-N emissions from the application of a unit of the enhanced-efficiency N fertilizers used in this study were considerably lower (<0.5%) than the default 1% from Tier 1 methodology used by the IPCC to estimate yearly N_2O-N emissions resulting from N fertilizer application. This indicates the need for source and sight-specific N_2O emission data. The results presented here may indicate that irrigated soils under semiarid conditions have relatively low N_2O-N losses, provided irrigation is well managed to avoid water-logged conditions and potential for denitrification. In only one out of nine years have N_2O-N emissions exceeded 1% of N applied at this site with the one year (2003) having very wet soil conditions at fertilization, planting, and during the early growing season.

Summing up

Controlled-release, slow-release, and stabilized N sources reduced N_2O-N emissions from an irrigated ST continuous corn cropping system when compared with granular urea. Nitrous oxide fluxes resulting from urea, UAN, SuperU, UAN+Nfusion, and UAN+AgrotainPlus applications peaked within days after application, whereas N_2O flux peaks from ESN and ESNssb occurred 4 to 6 weeks after application but with flux peaks generally of lower magnitude than with conventional urea. All enhanced-efficiency N fertilizers and UAN reduced growing season N_2O emissions, when compared with urea and UAN+Nfusion and UAN+AgrotainPlus, did so in comparison to UAN. Nitrification was probably the main pathway of soil N_2O loss from applied N fertilizer from this ST, irrigated system throughout most of the growing season, except for possibly some loss due to denitrification in early May 2010 when WFPS reached 80% for a short period. Growing season N losses as N_2O-N were consistently <0.5% of N applied for all enhanced-efficiency N sources, including UAN, with urea having a loss of <0.8%. Expressing N_2O emissions as a function of grain yield and N uptake showed greater agronomic N use efficiency for the enhanced-efficiency N fertilizers than for urea.

This study shows that N source can affect N_2O-N emissions following N fertilizer application. Choice of N source can be a valid management alterative for reducing N_2O emissions to the environment in the semiarid western United States. Additional work is needed to verify the effectiveness of these fertilizer sources in reducing N_2O emissions in other rain-fed and irrigated cropping systems, especially in humid areas with large amounts of untimely spring rainfall, which can contribute to N_2O losses through denitrification.

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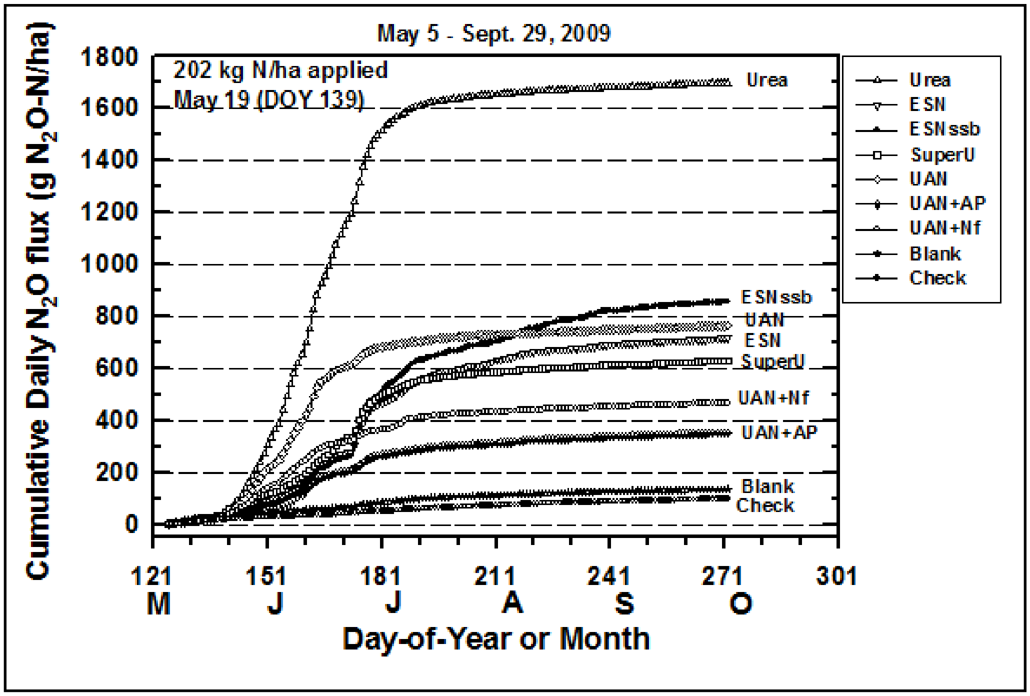

Figure 6. Cumulative daily N2O-N emissions during the 2009 growing seasons for each N treatment: urea, urea-ammonium nitrate (UAN), ESN, ESN subsurface band (ESNssb), SuperU, UAN+Nfusion (Nf), UAN+AgrotainPlus (AP), blank, and check.

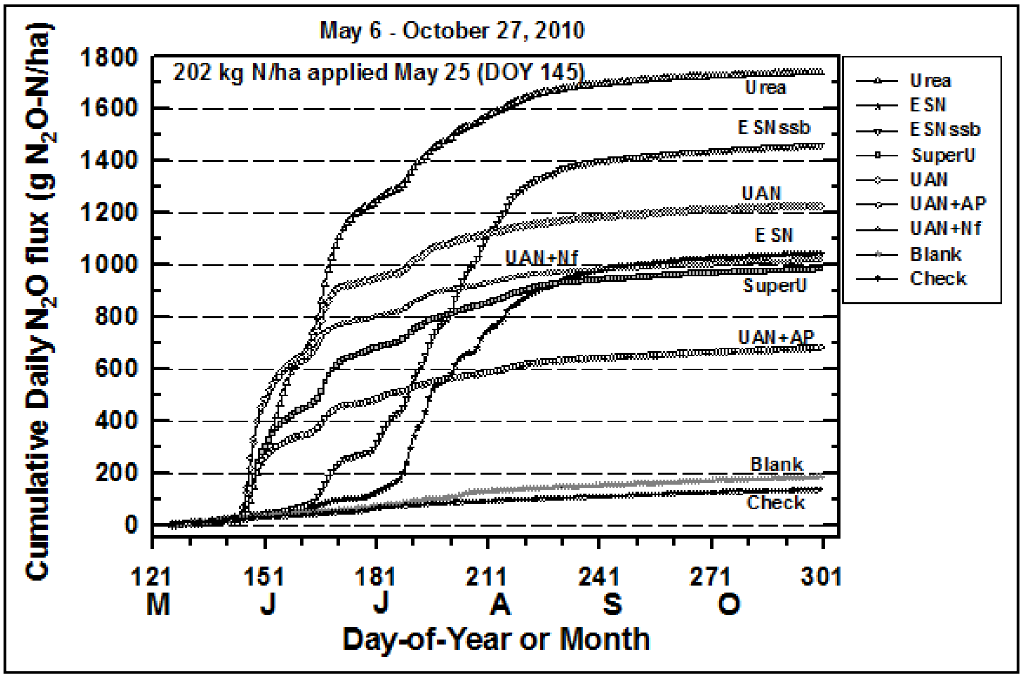

Figure 7. Cumulative daily N_2O-N emissions during the 2010 growing seasons for each N treatment: urea, urea-ammonium nitrate (UAN), ESN, ESN subsurface band (ESNssb), SuperU, UAN+Nfusion (Nf), UAN+AgrotainPlus (AP), blank, and check.