NITROUS OXIDE EMISSIONS: ASSESSMENT AND MITIGATION IN IRRIGATED COTTON IN THE WESTERN USA

Kevin Bronson, Doug Hunsaker, Kelly Thorp, and Clinton Williams
USDA-ARS, US Arid Land Agricultural Research Center, Maricopa, AZ
Kevin.Bronson@ars.usda.gov

ABSTRACT

Nitrogen from fertilizers is a major source of the potent greenhouse gas nitrous oxide (N_2O) in irrigated cropping systems. To date, N_2O emission data is scarce for row crops in the Western USA, especially, the desert southwest, where seasonal irrigation quantities can exceed 40 inches. The objective of these studies was to assess the effect of N fertilizer management on N_2O emissions from furrow-, overhead sprinkler-, and subsurface drip-irrigated (SDI) cotton (*Gossypium hirsutum* L.) in Central Arizona. We also tested the enhanced efficiency N fertilizer, Agrotain Plus for the surface and sprinkler irrigated fields as an N_2O mitigation management option. Cotton was planted from mid-April to May 1 from 2012 to 2016 on 40-inch-wide beds. Nitrogen fertilizer rates as liquid urea ammonium nitrate (UAN) (32-0-0) varied from 0 to 208 lb N ac^{-1} per season. We applied two split applications of N fertilizer in surface irrigation study, three splits under the sprinkler, and 24 fertigation events in the buried drip field. Emissions were measured weekly with 4-qt vented chambers placed for 24-minute periods in the bottom of furrows. Fifty-ml samples were taken at 0, 12, and 24 minutes and analyzed for N_2O with an ECD-GC. During the cotton growing season N_2O emissions were measured from May to August. Nitrous oxide emissions were not agronomically significant, but increased as many as 16-fold, compared to zero-N, with the addition of N fertilizer. Emission factors, defined as percent of added N fertilizer emitted as N_2O-N, ranged from 0.10 to 0.54 % in the surface irrigation and from 0.15 to 1.1% in the overhead sprinkler fields. In 2012 and 2013 with furrow irrigation, knifing-in of N fertilizer resulted in lower N_2O emissions than fertigating into the header irrigation line. The addition of Agrotain Plus to UAN had inconsistent mitigation effects on N_2O emissions. Agrotain Plus probably breaks down quickly in the desert environment, making its use an N_2O emission inhibitor not consistent. Nitrous oxide fluxes ended 2-3 d after irrigation events that were as high as 5 inches in furrow irrigation, and declined during the season, as plant N uptake progressed for the surface and overhead sprinkler fields. On the other hand N_2O emissions in buried drip were low throughout the season, similar to fluxes from zero-N plots in the surface and sprinkler plots. Notably, there was no effect of N fertilizer in the buried drip field, meaning the emission factor was zero.

INTRODUCTION

Water and N fertilizer are the first and second constraints to cotton production in the western USA (Morrow and Krieg, 1990). Canal infrastructure for irrigation water in Arizona means that surface basin and furrow irrigation are still the most common irrigation methods. Nitrogen fertilizer recovery, however, is usually less than 50 % in surface-irrigated Western cotton (Navarro et al. 1997; Booker et al., 2007, and Bronson et al. 2007 and Bronson, 2008). Long-term drought in the Western US and competition from growing urban areas has led to renewed interested in overhead sprinkler and subsurface drip irrigation (SDI) systems. However, recent N management research and recommendations in the western US are lacking for surface, overhead sprinkler, and for SDI for cotton. Recovery efficiency of N for irrigated cotton ranges from 12 % for surface irrigation to 75 % in SDI (Bronson et al., 2008).

Nitrous oxide is a potent greenhouse gas with a heat-trapping potential 300 X that of CO_2 (USEPA, 2015). Agricultural, particularly N fertilizers make up 74 % of the N_2O emissions in the USA (USEPA, 2015). Nitrous oxide is produced in cropped soils primarily during the anaerobic reduction of NO_3 to N_2. A secondary pathway of N_2O production is during the oxidation of NH_4 to NO_3. In the last 20 years there has been hundreds of field studies measuring N_2O emission from N-fertilized cropped fields, mostly on corn (Halvorson et al., 2014; Hatfield and Venterea, 2014; Thapa et al., 2016). Many of those studies test enhanced efficiency N fertilizers such as Agrotain Plus. Far fewer such studies have been conducted on cotton (Scheer et al., 2008; Liu et al., 2010, Wang et al., 2013).

METHODS

Nitrogen fertilizer management studies were conducted at Maricopa, AZ from 2012-2016. Surface irrigation, overhead sprinkler, and SDI was employed for 2012-2013, 2014-2015, and for 2016, respectively. In March, of each year, pre-plant soil sampling to 7 feet. for NO_3 was done on four samples (two per plot in 2014 and 2015) per plot. Cotton ‘DP1044B2RF’ was planted in late April to May 1 of each year, except for 2016 when ‘DP1549B2XF’ was planted on 12 April. In 2012 and 2013 plots were 8, 40-inch rows wide by 550 feet. In 2014 and 2015 plots were 6, 40-inch rows wide by 120 feet. In 2016, plots were 8, 40-inch rows wide by 330 feet.

Nitrogen fertilizer (32-0-0) treatments for surface irrigation in 2012 and 2013 (applied either by fertigating in the water run or knifing in the day before irrigation) are listed in Table 1. Nitrogen fertilizer (32-0-0) was applied in 2014 and 2015 (treatments listed in Table 2) with a high clearance tractor by spraying into the furrow with fertilizer nozzles just prior to overhead sprinkler irrigations. In 2016, 32-0-0 (treatments listed in Table 3) was fertigated in 24 events in a six week period from first square to mid bloom. Fertigations were done for each N-fertilized, 8 row x 330-foot plot with an 8 gallon per day diaphragm pump.

Irrigation was applied in 5-inch amounts every 10 days in the surface-irrigated field. With the overhead sprinkler, irrigation was 2-4 times a week in 0.6-inch amounts. In the SDI system, irrigations at first square were initially twice a week. Starting at early bloom in SDI, 0.4- inch irrigations were applied daily. In all cases irrigations were managed with FAO crop coefficient ET procedures at 100 % ET replacement (Allen et al., 1998) (with an additional irrigation treatment added of 75% ET in 2016.

Surface flux of N_2O was measured weekly for 10 weeks during the seasons using 4-qt vented and insulated chambers (Yabaji et al., 2009). One chamber per plot were placed in traffic and non-traffic furrows, respectively for 24-minute periods. In the buried drip system in 2016, chambers were inserted in the side of the bed. Fifty-mL samples were taken at 0, 12, and 24 minutes. Nitrous oxide analysis was performed on a Shimadzu 2014 gas chromatograph fitted with a ^{63}Ni electron capture detector (Mosier and Mack, 1980). Nitrous oxide fluxes were calculated according to the logarithmic equation of Hutchinson and Mosier (1981). If the increase in N_2O concentration in the chamber headspace in the 12-24 minute period was not equal to the 0-12 minute increase in concentration, then a linear increase in N_2O was estimated as suggested by Venterea and Baker (2008).

Soil moisture to 72 inches was determined every week with a neutron probe and the water balance was calculated with irrigation amounts, rain and estimated ET (Maharjan et al., 2014). Nitrous oxide emissions data was analyzed by date, and with date as an effect, with a mixed model using SAS (SAS, 2013). Replicate was considered random, and N treatment, date, and date by N treatment were considered fixed. Since N_2O data often has a log-normal distribution, the statistical analysis was also conducted using PROC GLIMMIX with a log distribution.

RESULTS AND DISCUSSION

Nitrous oxide emissions increased in some of the N fertilizer treatment plots relative to zero-N in from 2021-2014 (Tables 1-2). At comparable N rates of 106 to 156 lb N/ac, the largest season N_2O fluxes were in the overhead sprinkler studies of 2015 with a maximum emission of 648 g N_2O-N with an 117 lb fertilizer-N/ac rate in 2015 (Table 2). The surface irrigated studies generally had lower N_2O emission than the sprinker with a maximum emission of 400 g N_2O-N/ac with 106 lb 32-0-0-N with Agrotain Plus (Table 1). Apparently the two-four times a week irrigation frequncy of the overhead sprinkler created optimal moisture conditions for N_2O emission via nitrifcation and or denitrification. It is also important to note that the N fertilizer was split two and three times in the 2012-2015 studies. Substantial soil drying occurred in the surface layer of the surface irrigation fields a the end of the 10-day irrigation cycles. Most N_2O production in soil occurs in the surface soil layers, with very little in the subsoil, since soluble C is limited. The buried drip study in 2016 had seasonal N_2O emission that did not exceed 90 g N_2O-N/ac (Table 3). In additon to low N_2O emissions in the drip irrigated study, there was no statistical increase with N fertilizer relative to zero-N.

There is a great deal of interest in calculating “emission factors” with N_2O flux field data from N fertilizer treatments. This is simply the percentage of applied N fertilizer emitted as N_2O, with the fluxes from zero-N plots subtracted out. The IPCC makes the assumption that an average, single emission factor of 1.0 % can be used for N-fertilized field crops (IPCC, 2006), but emission factors are often lower or higher than 1.0 % (Lesschen et al., 2011). Nitrous oxide emissions, rarely reach economically significant levels. In the 2012-2015 data, the N_2O emission factors were measured were ocassionaly in line with the IPCC factor, but were more often much less than 1.0 %. Two recent studies on N_2O emissions with irrigated cotton in China reporte emission factors of 1.0 % (Liu et al., 2010; Wang et al., 2013), and a study in Uzbekistan measured an emission factor 1.5 % (Scheer et al., 2008). Published studies with Agrotain Plus in corn, often show strong mitigation of N_2O emissions (Halvorson et al, 2014; Thapa et al., 2016). It is notable that in our study and in a similar study with SDI in Texas (Yabaji et al., 2009), there is a zero emission factor. This is likely due to the fact that drip irrigation is a highly efficient irrigation system with little leaching or evaporative losses of irrigation water. Additionally, fertigating in 24 doses in SDI amounts to “spoon feeding” N to the crop.

Nitrogen management treatment differences in N_2O emissons were rare and inconsistent in the studies. Knifing-in of 32-0-0 resulted in lower N_2O emission in 2012, but not in 2013. Agrotain Plus addition to 32-0-0 reduced N_2O emissions in 2014 under the sprinkler at the 160 lb N/ac rate only. There was no affect of Agrotain Plus at low N rates in 2014, in 2015 under the sprinkler, or in 2013 with surface irrigation.

Water balances for the five site-years are presented in Tables 4-5. Deep percolation losses were high in the surface irrigation studies at 18-27 % of irriation and rain. No deep leaching was calculated in the overhead sprinkler studies of 2014-2015 (Table 4). Surprisingly, deep percolation losses of 6 % were calculated in the SDI study of 2016.

SUMMARY

Nitrous oxide emissions were greater in the overhaead sprinkler studies than in the surface irrigated fields, with emission factors generally less than 1.0 %. Emissions of N_2O were very low in the SDI study, with an emission factor of zero. The very high number (24) of small fertigations in the SDI study probably contributed to the low emissions. Other N management options such as N placement or the use of Agrotain Plus had inconsistent effects on N_2O emissions.

REFERENCES

Allen, R.G., L.S Pereira, D. Raes, D. and M. Smith. 1998. Crop evapotranspiration –Guidelines for computing crop water requirements – FAO Irrigation and Drainage paper no. 56. Food and Agriculture Organization of the United Nations, Rome.

Booker, J.D., K.F. Bronson, C.L. Trostle, J.W. Keeling, and A. Malapati. 2007. Nitrogen and phosphorus fertilizer and residual response in cotton-sorghum and cotton-cotton sequences. Agron. J. 99:607-613.

Bronson, K.F. 2008. Nitrogen Use Efficiency Varies with Irrigation System. Better Crops with Plant Food. 92 (4): 20-22.

Bronson, K.F., J.C. Silvertooth, and A. Malapati. 2007. Nitrogen fertilizer recovery efficiency of cotton for different irrigation systems. 2007 Proceedings Beltwide Cotton Conferences. [CD-ROM computer file]. National Cotton Council of America, Memphis, TN.

Halvorson, A.D., C.S. Synder, A.D. Blaylock, and S. J. Del Grosso. 2014. Enhanced-efficiency nitrogen fertilizers: Potential role in nitrous oxide emission mitigation. Agron. J. 106: 715-722.

Hatfield, J.L. and R.T. Venterea. 2014. Enhanced efficiency fertilizers: A multi-site comparison of the effects on nitrous oxide emissions and agronomic performance. Agron J. 106:679-680.

Hutchinson, G.L., and A.R. Mosier. 1981. Improved soil cover method for field measurement of nitrous oxide fluxes. Soil Sci. Soc. Am. J. 45:311–316.

IPCC, 2006. In: Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T., Tanabe, K. (Eds.), 2006 IPCC Guidelines for National Greenhouse Gas Inventories. IGES, Hayama, Japan Prepared by the National Greenhouse Gas Inventories Programme.

Lesschen, J.P., G.L. Velthof, W. de Vries, and J. Kros. 2011. Differentiation of nitrous oxide emission factors for agricultural soils. Environ. Pollut. 159:3215–3222.

Liu., C., X. Zheng, Z. Zhou, S. Han, Y. Wang, K. Wang, W. Liang, M. Li, D. Chen, and Z. Yang. 2010. Nitrous oxide and nitric oxide emissions from an irrigated cotton field in Northern China. Plant Soil. 332:123-134.

Maharjan, B., R.T. Venterea, and C. Rosen. 2014. Fertilizer and irrigation management effects on nitrous oxide emissions and nitrate leaching. Agron. J. 106:703-714.

Morrow, M.R. and D.R. Krieg. 1990. Cotton management strategies for a short growing season environment: water-nitrogen considerations. Agron. J. 82:52-56.

Mosier, A.R. and L. Mack. 1980. Gas chromatographic method for precise, rapid analysis of nitrous oxide. Soil Sci. Soc. Am. J. 44:1121-1123.

Navarro, J.C., J.C. Silvertooth, and A. Galadima. 1997. Fertilizer nitrogen recovery in irrigated Upland cotton. A College of Agriculture Report. Series P-108, University of Arizona, Tucson, AZ. p. 402-407.

SAS Institute Inc. 2013. The SAS system for Windows version 9.3. SAS Inst., Cary, NC.

Scheer, C., R. Wassman, K. Kienzler, N. Ibragimov, and R. Eschanov. 2008. Nitrous oxide emissions from fertilized irrigated cotton (*Gossypium hirsutum* L.) in the Aral Sea Basin, Uzbekistan: Influence of nitrogen applications and irrigation practices. Soil Biol. Biochem. 40:290-301.

Thapa, R., A. Chatterjee, R. Awale, D.A., McGranahan, and A. Daigh. 2016. Effect of enhanced efficiency nitrogen fertilizers on nitrous oxide emissions and crop yields: A meta-analysis. Soil Sci. Soc. Am. J. 80:1121-1134.

Wang, K., X. Zheng, M. Pihlatie, T. Vesala, C. Liu, S. Happanala, I. Mammarella, U. Rannik, and H. Lie. 2013. Comparison between static chamber and tunable diode laser-based eddy covariance techniques for measuring nitrous oxide fluxes from a cotton field. Agric. Forest Meteorolology. 171-172:9-19.

USEPA. 2015. Inventory of US Greenhouse Gases and Sinks: 1990–2013. EPA 430-R-15-004. Washington, DC. 564 pp. www.epa.gov/climatechange/ghgemissions/usinventoryreport (accessed 14 Jan. 2017).

Venterea, R.T., and J.M. Baker. 2008. Effects of soil physical nonuniformity on chamber-based gas flux estimates. Soil Sci. Soc. Am. J. 72:1410–1417.

Yabaji, Rajkumari, J.W. Nusz, K. F. Bronson, A. Malapati, J. D. Booker, R.L. Nichols, and T. L. Thompson. 2009. Nitrogen management for subsurface drip irrigated cotton: Ammonium thiosulfate, timing, and canopy reflectance. Soil Sci. Soc. Am. J. 73:589-597.

Table 1. Nitrous oxide emissions as affected by N management in surface-irrigated ‘DP 1044 RR F’ cotton, Maricopa, AZ 2012 and 2013.

Nitrogen treatment	Fertilization mode	Fertilizer source	Fertilizer rate		Seasonal N_2O flux		N_2O Emission factor	
			2012	2013	2012	2013	2012	2013
			lb N/ac		g N_2O-N/ac/96 d	g N_2O-N/ac/83 d	%	
Zero-N			0	0	51 b#	148 b	-	-
Soil test-based N†	Knife	Urea amm. Nitrate	132	106	114 b	208 ab	0.10	0.10
Soil test-based N†	Fertigate	Urea amm. Nitrate	132	106	375 a	337 ab	0.54	0.32
Soil test-based N†	Fertigate	Urea amm. nitrate + Agrotain Plus	132	106	215 ab	398 a	0.18	0.42

† Based on lint yield goal of 3.5 bale/ac, and a 175 lb N/ac N requirement, minus 0 - 36 in. soil NO_3-N and estimated irrigation input of 20 lb N/ac (estimated 40 inch irrigation of 2 ppm NO_3-N water).

Means followed by a similar letter are not statistically different at $P = 0.05$.

Table 2. Nitrous oxide emissions as affected by N management in overhead sprinkler--irrigated ‘DP 1044 RR F’ cotton, Maricopa, AZ, 2014 and 2015.

Nitrogen treatment	Fertilizer source	Fertilizer rate		Seasonal N_2O flux		N_2O Emission factor	
		2014	2015	2014	2015	2014	2015
		lb N/ac		g N_2O-N/ac/91 d	g N_2O-N/ac/113 d	%	
Zero-N		0	0	30 b#	111 b	-	-
Soil test-based N†	UAN	160	117	449 a	648 a	0.58	1.01
1.3*Soil test-based N†	UAN	208	152	496 a	1104 a	0.53	1.05
Soil test-based N†	UAN + Agrotain	160	117	107 b	346 ab	0.15	0.44
Reflectance-based N-1‡	UAN	80	59	405 ab	316 b	1.11	0.77
Reflectance-based N-2§	UAN	104	76	282 ab	437 ab	0.60	0.95
Reflectance-based N-1‡	UAN + Agrotain	80	59	258 ab	305 b	0.71	0.72
Reflectance-based N-2§	UAN + Agrotain	104	76	213 b	359 b	0.45	0.72

† Based on lint yield goal of 4.0 bale/ac, and a 200 lb N/ac N requirement, minus 0 - 36 in. soil NO_3-N and estimated irrigation input of 20 lb N/ac (estimated 40 inch irrigation of 2 ppm NO_3-N water).

‡ First split equals 50 % treatment no. 2, second and third splits based on NDVI relative to treatment no. 2.

§ First split equals 50 % treatment no. 2, second and third splits based on NDVI relative to treatment no. 3.

Means followed by a similar letter are not statistically different at $P = 0.05$.

Table 3. Nitrous oxide emissions as affected by N management and irrigation level in subsurface drip-irrigated ‘DP 1549 B2XF’ cotton, Maricopa, AZ 2016.

Nitrogen treatment	Irrigation level	Fertilizer rate	N_2O Emissions	N_2O Emission factor
	inches	lb N/ac	g N/ac/117 d	%
Zero-N	26.5	0	45 a#	-
Soil test-based N	35.3	156	89 a	0
Reflectance-based N	35.3	141	39 a	0
Zero-N	35.3	0	90 a	0
Soil test-based N	26.5	156	62 a	0

Means followed by a similar letter are not statistically different at *P* = 0.05.

Table 4. Water balances† for N management studies in surface and in sprinkler-irrigated "DP 1044 B2RF" cotton, Maricopa, AZ 2012-2015.

Irrigation	Year	ET	Rain	Irrigation	Change soil storage (7 ft)	Deep perc	Deep perc (% of irrig and rain)
		------------------------ inches				-----------------------	
Surface	2012	-32.6	3.8	33.4	-2.0	6.6	17.8
Surface	2013	-25.8	0.4	32.8	-1.4	9.0	27.1
Sprinkler	2014	-34.7	3.4	28.8	-2.9	0	0
Sprinkler	2015	-38.8	1.5	31.4	-3.1	0	0

†Days covered were 112, 87, 91, and 118, for 2012, 2013, 2014, and 2015, respectively.

Table 5. Water balances† as affected by N management and irrigation level in subsurface drip-irrigated 'DP 1549 B2XF' cotton, Maricopa, AZ 2016.

N treat.	Irrigation level‡	ET	Rain	Irrigation	Change soil storage (0-7 ft)	Deep perc	Deep perc (% of irrigation and rain)
	-------------------------------- inches	---------------------------------					
Soil test-based N	35.3	-34.0	1.2	32.0	-3.9	2.1	6.4
Reflectance-based N	35.3	-34.0	1.2	32.0	-3.3	1.5	4.6
Zero-N	35.3	-34.0	1.2	32.0	-0.3	-1.5	0
Soil test-based N	26.5	-27.6	1.2	23.2	-4.3	1.1	4.6
Zero-N	26.5	-27.6	1.2	23.2	-2.1	-1.1	0

†Covers 120 days.

‡ Includes irrigation for germination before neutron probe tube installation.