Polymer Coated Urea: Mitigating Nitrogen Loss to the Environment

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Abstract
Fertile soil is the foundation for food production and successful civilizations and is developed and maintained through the addition of nutrients lost through harvest. Nitrogen (N) accounts for approximately half of global fertilizer inputs. However, N recovery by plants is inherently inefficient with uptake of applied fertilizer N less than most other nutrients. Losses from the soil system can cause negative air and water resource impacts. Additionally, poor fertilizer efficiency is a waste of natural resources and potentially reduces yields, crop quality, and grower profits. Nitrogen-use efficiency (NUE) is increased through using optimal source, rate, timing, and placement. Polymer coated urea (PCU) is a source of N fertilizer that, when correctly managed, can result in virtually no N loss beyond background levels. A summary of our laboratory, glasshouse, and field research trials shows significantly less N loss from soil to the air and water due to dramatic increases in NUE from PCU compared to uncoated urea. Average ammonia volatilization and nitrous oxide emissions were lower for PUC by 300 and 120%, respectively. Residual nitrate was 38% lower for PCU compared to uncoated urea. The N losses for PCU fertilized plants were at or nearly the same as background levels for the controls. In all cases, PCU resulted in crop yields and/or quality which were significantly improved or at least equivalent to uncoated urea when managed properly. The global use of PCU is warranted to greatly improve environmental quality and to meet the demands for providing food, fuel, and fiber for the seven billion plus people on earth.

Key Words
polymer coated urea (PCU), nitrogen fertilizer yield response, nitrous oxide emissions, ammonia volatilization, nitrate leaching, environment

Introduction
Fertile soil is the foundation for food production and successful civilizations and is developed and maintained through the addition of nutrients lost through harvest (Hopkins et al 2008). Nitrogen accounts for approximately half of global fertilizer inputs (FAO 2011). Unfertilized soil systems receive N from atmospheric deposition and microbial conversion of the inert atmospheric N gas, but these mechanisms generally supply less N than is needed for sustainable crop production. Although efforts are being made to enhance this avenue of nitrogen supply, the present situation is that fertilization is vital for providing the food, fuel, and fiber for the seven billion and rapidly growing number of people on this earth (Hopkins et al 2008). Indeed, the advent of modern fertilization is one of the primary components of the green revolution. Without it, massive starvation would be the result (Hopkins et al 2008).

However, N recovery by plants is inherently inefficient and losses from the soil system can cause negative air and water resource impacts (Blaylock et al 2005, Cameron et al 2013, Easton and Petrovic 2004, Guillard and Kopp 2004, LeMonte et al 2016, Snyder et al 2007). Nitrous oxide (N_2O) is a greenhouse gas approximately 300 times more potent than carbon dioxide (Burton et al 2003, Cameron et al 2013; Hirsch et al 2006, LeMonte et al 2016, Snyder et al 2007, Sutton et al 2008). Ammonia (NH_3) is another N gas that can be lost to the atmosphere at elevated rates following N fertilization and can be an air quality hazard, as well as having negative impacts when it is deposited in sensitive environments (Cameron et al 2013; LeMonte et al 2016, Sutton et al 2008). Nitrogen deposited from air or transported through or over soil to surface water may lead to problematic algal blooms which, among other problems, leads to the deaths of organisms through eutrophication or direct toxicity (Cameron et al 2013; LeMonte et al 2016). Furthermore, high levels of nitrate (NO_3^-) in drinking water can be toxic to organisms—most notably methemoglobinemia purported in mammalian infants (Cameron et al 2013; LeMonte et al 2016). Additionally, poor fertilizer efficiency is a waste of natural resources (Hopkins et al 2008; LeMonte et al 2016). Although N comes from a ubiquitous atmospheric supply, non-renewable natural gas is used in the process of converting N_2 gas to ammonium (NH_4^+) and NO_3^- for use in fertilizer materials.

For these reasons, the fertilizer industry has made significant efforts to improve fertilizer efficiency through their 4R program of using the right source, right rate, right timing, and right placement (Hopkins et al 2008).

Polymer coated urea (PCU) is a source of N fertilizer that has been used successfully for several decades (Adams et al 2013, Blaylock et al 2005, Hopkins et al 2008). These materials have become increasingly sophisticated and at costs more closely matched to uncoated urea (Adams et al 2013, Blaylock et al 2005, Buss 2016, Hopkins et al 2008, LeMonte 2011, LeMonte et al 2016, Ransom 2014, Taysom 2015). A significant body of research has been conducted showing that, with correct management, these materials can be highly effective for use in agricultural and urban systems (Buss 2016, Hopkins et al 2008, Hyatt et al 2010, LeMonte 2011, LeMonte et al 2016, Ransom 2014, Taysom 2015).

The purpose of this paper will be to review several studies conducted to document the mitigation of N loss from NH_3 and N_2O gas losses, as well as measuring NO_3^- accumulation in soils when using PCU compared to uncoated urea.

Methods

An untreated control was compared to two fertilizer sources in five laboratory, four glasshouse, and three field studies, each replicated 5-6 times in a randomized complete block design, with a variety of calcareous soils. Daily highs during the course of each trial ranged from 21.2 -38.1°C. The fertilized treatments ranged from 90 to 450 kg N ha^{-1} (low to very high rates encountered with various cropping and turfgrass systems) additionally, one laboratory study was done at a very high N rate of 450 kg N ha^{-1}) in these studies, although the N rates applied in each study were equivalent for both coated and uncoated urea. The coated urea materials were PCU either Duration-45® or ESN® (Environmentally Smart Nitrogen; Agrium). Fertilizer was either mixed with the soil or, in the case of sod, applied to the surface. Soil moisture was maintained at approximately field capacity.

The headspace air above the soil was collected every 20 minutes for 45 d in each study using Innova 1309 multiplexer and analyzed for N_2O and NH_3 using an Innova 1412 Photoacoustic Field Gas analyzer (Lumasense Technologies). Fertilizer prills were evaluated at the end of the study to verify that >98% of the N was evacuated from them. Soils were analyzed for residual soil NO_3-N and NH_4-N concentrations at the end of each study through extraction with 1 M KCl and determination by Flow Injection Analysis (Lachat).

The significance between treatment means was analyzed using ANOVA ($P<0.05$), with significant means separated using a Tukey-Kramer test. Additional analysis averaging across all trials was also performed. The N source by study interaction was generally not significant and, as a result, the mean across studies was calculated and reported.

Results

Ammonia Volatilization

There were significant reductions in both NH_3 volatilization and N_2O gas emission in all 12 studies for PCU compared to uncoated urea (Table 1). Ammonia loss was always significantly lower for PCU than uncoated urea with a range of 64 to 574% less volatilization and a highly significant 300% average. Total ammonia losses for the uncoated urea represented about 13% of the total N applied.

Although much less than uncoated urea, N fertilization with PCU did result in a significant increase in NH_3 volatilization over the control in half of the studies (Table 1) with a range of 2 to 40% and a significant mean increase of 21%.

Nitrous Oxide Emission

The magnitude of the N_2O reductions were less than for NH_3, but were generally highly significant (Table 1). PCU resulted in significantly less N_2O gas emission in 11 of 12 studies with a range of 38 to 201% reduction and a highly significant average difference of 120%. Total N_2O gas losses from the uncoated urea were 2% of the total N applied.

The N_2O emissions were virtually no different than background levels with just four of the studies showing a significant increase for PCU over the control with a range of 1 to 10% and the mean of 6% being not significantly different for PCU and the control (Table 1).

Nitrate Accumulation

There was significantly less NO_3^- accumulated in the soils in eight of the studies for PCU use compared to uncoated urea, with a range of 1 to 98% and a significant average mean reduction of 38% (Table 1). The level of NO_3^- accumulation for PCU compared to the control was only significantly increased in two studies, with a range of -8 to 16% and a mean of 3% being not significant.

Impacts of Plants

Although not reported fully here, it is of interest to note that PCU never resulted in negative impacts to plant growth in these or any of the other studies we have performed. In many cases, yields have increased and, more often, crop quality has improved as a function of a steady, controlled release of N to the plants.

Studies with potato (*Solanum tuberosum* L.), maize (*Zea mays* L.), and Kentucky bluegrass (*Poa pratensis* L.) sod showed no negative impacts for these species. Potato yields were equal or greater. Potato is very sensitive to a lack of a consistent supply of available N with negative impacts on tuber quality. An average increase of 4.1 Mg ha^{-1} of US No. 1 tubers was measured. In the glasshouse study in the trial reported herein, the early season maize biomass yields were found to be statistically equivalent. The Kentucky bluegrass field studies showed that PCU application was statistically equivalent to urea applied every 30 d, but gave more even growth than uncoated urea applied all at once (height at 14 d after fertilization was 2.8 cm lower for PCU than urea applied all at once). Verdure, as measured by visual ratings and normalized difference vegetative index (NDVI) showed that PCU performed as well as urea applied monthly and was significantly (0.712) greater than urea applied all at once (0.645) 90 d after fertilization.

Table 1. Summary of percent N loss via NH_3 and N_2O gases and NO_3^- subject to leaching for 12 lab, glasshouse (GH), and field studies comparing polymer coated urea (PCU) to uncoated urea and an unfertilized control (* = significant at the P < 0.05 level; NS = not significant)

	Location	N Rate, kg ha^{-1}	Reduction of N loss for PCU compared to uncoated urea, %						Increase of N loss for PCU compared to an untreated control, %					
			NH_3		N_2O		NO_3^-		NH_3		N_2O		NO_3^-	
1	Lab	90	194	*	38	NS	10	NS	9	NS	1	NS	5	NS
2	GH	150	297	*	121	*	1	NS	4	NS	6	NS	2	NS
3	GH	200	392	*	174	*	40	*	40	*	8	*	-8	NS
4	Lab	250	64	*	52	*	43	*	2	NS	10	*	7	NS
5	Lab	250	397	*	101	*	5	NS	17	NS	3	NS	-5	NS
6	Field	300	288	*	201	*	18	*	27	*	7	NS	16	*
7	Lab	300	190	*	38	*	39	NS	29	*	8	NS	4	NS
8	Lab	300	396	*	177	*	31	*	19	*	9	*	11	NS
9	Field	300	355	*	161	*	44	*	29	*	8	NS	-4	NS
10	Field	300	574	*	139	*	44	*	10	NS	1	NS	6	NS
11	GH	300	352	*	153	*	98	*	40	*	8	*	-4	NS
12	GH	450	95	*	86	*	77	*	29	NS	3	NS	8	*
	Mean		*300*	*	*120*	*	*38*	*	*21*	*	*6*	*NS*	*3*	*NS*

Conclusion

Polymer coated urea is a source of N fertilizer that, when correctly managed, can result in significantly less N loss compared to background levels.

A summary of our laboratory, glasshouse, and field research trials shows significantly less N loss from soil to the air and, potentially, to the water as well for PCU compared to uncoated urea. Average ammonia volatilization and nitrous oxide emissions were lower for PCU by 300 and 120%, respectively. Residual nitrate was 38% lower for PCU compared to uncoated urea. This residual nitrate would be subject to leaching or lateral movement losses with any soil water flow. The N losses for PCU fertilized plants were at or nearly the same as background levels for the controls with a significant increase of just 21% for PCU over the control for NH_3 volatilization and N_2O gas loss and NO_3^- accumulation being statistically indistinguishable for PCU compared to the control.

PCU resulted in crop yields and/or quality which were significantly improved or at least equivalent to uncoated urea when managed properly in these studies (only the field and glasshouse studies included live plants). Other studies have shown similar effects.

These data, along with the findings of many other researchers, suggest that the global use of PCU is could greatly mitigate environmental risks related to air and water quality while meeting the demands for providing food, fuel, and fiber for the seven billion plus people on earth.

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