POLYMER COATED UREA: MEETING PLANT NEEDS WHILE MITIGATING ENVIRONMENTAL IMPACTS — RESEARCH SUMMARY

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ABSTRACT

Fertile soil is the foundation of food production and is maintained by replacing nutrients lost in harvest or to the atmosphere and hydrosphere. Nitrogen (N) accounts for approximately half of global fertilizer inputs. However, N recovery by plants is inherently inefficient due to "leaks" in the system, causing air and water pollution. 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 PCU by 300 and 120%, respectively. Residual nitrate was 38% lower for PCU compared to uncoated urea—in cases where plants were growing in the soil. The N losses for PCU fertilized plants were at or nearly the same as background levels for the controls. In nearly all cases, PCU resulted in crop yields and/or quality which were significantly improved (average increase across our trials in potato, corn, and small grain yields is 9%) or at least equivalent to uncoated urea when managed properly. We have had instances of failures, but the reasons were typically due to improper handling or mismanagement. Some crops (e.g. sugarbeet) have not been as successful in our limited trials. However, widespread use of PCU is warranted in most crops if costs are reasonably close to uncoated urea. This will result in improved environmental quality and help meet the demands for providing food, fuel, and fiber for the seven billion people on earth.

INTRODUCTION

Fertile soil is the foundation for food production and successful civilizations and is maintained through addition of nutrients lost to 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 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, can lead 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 (http://www.nutrientstewardship.com/4rs). 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.

MATERIALS AND 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 (Table 1).

Table 1. Study ID's, location, and N rates.

Study #	Location	N Rate, lbs ac^{-1}
1	Lab	80
2	Glasshouse	134
3	Glasshouse	178
4	Lab	223
5	Lab	223
6	Field	268
7	Lab	268
8	Lab	268
9	Field	268
10	Field	268
11	Glasshouse	268
12	Glasshouse	402

Daily highs during the course of each trial ranged from 70-101°F (21-38°C). The fertilized treatments ranged from 80 to 402 lbs N ac^{-1} (90 to 450 kg N ha^{-1}). These represent low to very high rates encountered with various cropping and turfgrass systems. The N rates applied in each study were equivalent for both coated and uncoated urea. The coated urea materials were PCU, either Duration-45® (presently this product is manufactured by Koch, but the research performed was mostly accomplished when it was manufactured by Agrium) or ESN® (Environmentally Smart Nitrogen; Agrium). Fertilizer was either mixed with the soil or, in the case of turfgrass 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 each study to verify that >98% of the N was released. 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.

RESULTS AND DISCUSSION

Ammonia Volatilization

There were significant reductions in NH_3 volatilization in all 12 studies for PCU compared to uncoated urea (Fig. 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 average reduction of 300%. Total ammonia losses for the uncoated urea represented an average of 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 (Fig. 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 NH_3, but were generally highly significant (Fig. 2). 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 2.6% of the total N applied—a number much higher than is typically thought to occur, which we attribute to the fact that our methods allow capture of the gases over the entire day rather than one to three gas grabs per day typical of much of the historical research.

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 (Fig. 2).

Nitrate Accumulation

The background levels of NO_3^- accumulation in the control ranged from 3-8 ppm with fertilization resulting in ranges of 9-33 and 7-36 ppm for urea and PCU, respectively; with averages of 4, 18, and 17 for control, urea, and PCU, respectively. Ammonium differences were generally not significant between the fertilized and control treatments with ranges of 2.4-4.9 ppm (data not shown).

Five of the studies (those conducted under "Lab" conditions as found in Table 1) did not include growing plants. Three of these studies showed significant increases in NO_3^- accumulation but, curiously, two did not. There is no significant difference in NO_3^- accumulation between urea and PCU in these studies (Fig. 3). As significantly more N was lost to the atmosphere (Figs. 1-2) from the soils for the urea treatments compared to PCU, it would be possible that more nitrate would accumulate in the absence of plant growth for PCU. However, microbial populations were active and likely buffered the residual NO_3^- accumulated via temporary immobilization. We would expect that this NO_3^- would be released later in the season and not "lost".

With regard to the studies in which plants were growing (those grown under "Glasshouse" and "Field" conditions as found in Table 1), the coated and uncoated urea resulted in significant increases in NO_3^- accumulation over the control in all studies (Fig. 3). However, urea had significantly greater NO_3^- accumulation over PCU in two of the seven studies—with PCU never being significantly greater than urea. Again, this could be considered somewhat surprising, as less N was lost to the atmosphere for the PCU treatments and, therefore, could result in more NO_3^- accumulation as more total N remained in the soil system. However, this did not appear to occur and is attributed to increased plant/microbial N uptake and/or growth for the PCU treatments in these studies. This is especially true for some of the turfgrass studies—as the urea treated plants had an initial flush of N release with dramatic impacts on growth but then declined towards the end of the study (with associated N release back into the soil via mineralization) at the time when the NO_3^- was measured.

It is noteworthy that there were no significant leaching events in any of these studies—including the field studies. It would be expected that a leaching event could dramatically alter these results, especially for urea at a time close to application after hydrolysis occurred but before plant uptake. Rather, these results examine NO_3^- accumulation under non-leaching conditions.

Impacts on Plants

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

Studies with potato (*Solanum tuberosum* L.), corn (*Zea mays* L.), wheat (*Triticum* spp.), barley (*Hordeum vulgare* L.), and Kentucky bluegrass (*Poa pratensis* L.) sod showed no negative impacts for these species. [Note: the 12 studies we report here (Table 1) either did not include growing plants (all of the “lab” studies) or had turfgrass (all of the “field” studies and studies 11 and 12 for the “glasshouse” studies) or corn (studies 2 and 3 for the “glasshouse” studies).] In other studies (where we did not measure gas losses), we have generally found positive results with PCU.

Potato yields were equal or greater in 33 studies, with significant increases for the coated over uncoated urea at the same rate in 25 of those studies. 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.

Four corn studies were conducted in Idaho with similar yields in two trials and significant increases in the other studies with an average of 12 bu/ac increase. Three wheat and two barley studies were also conducted in Idaho with three of these showing significant yield increases for PCU over urea at the same N rate with an average increase of 5 bu/ac. The average yield increase for our crop studies in Idaho and Utah was 9% increase for PCU compared to urea at the same N rate.

We also completed three sugarbeet studies. This was our only crop that did not show a yield increase due to PCU in any instance. Although yields were not different for PCU vs. urea, sugar concentration in the beets actually declined for PCU—presumably due to excess N resulting in prolonged vegetative growth late in the season. If using PCU on sugarbeet, we recommend applying ahead of planting and avoiding extremely long release PCU products.

Although rare, we have also observed some problems in grower fields with PCU use. Excessive handling of the PCU in fertilizer handling and spreading equipment can result in the coatings cracking and prematurely releasing the N. Care in handling is essential.

Also, in the case of potato, we consistently observe that petiole tissue nitrate concentrations average about 2,000 ppm less for PCU than urea. Weekly petiole sampling is commonly used in potato production to guide in-season “spoon-feeding” fertilization needs. Research based calibration curves are used to determine if and how much N fertilizer needs to be applied. Our data shows that the PCU calibration curves need to be adjusted downward by 2,000 ppm compared to the ones for uncoated urea in order to avoid applying excessive in-season N.

In addition to row crop evaluations, we have also conducted several Kentucky bluegrass field studies. The results show that two applications of PCU (spring and fall) was statistically equivalent to “spoon fed” urea applied every 30 d, but gave more even growth than uncoated urea applied all at once (height at 14 d after fertilization was 1.1 in. (2.8 cm) lower for PCU than urea applied all at once). Verdure, as measured by visual ratings, and normalized difference vegetative index (NDVI) show that PCU performed as well as urea applied monthly and was significantly greater than urea applied all at once 90 d after fertilization. However, a single application of PCU in either spring or fall did not perform as well as split applied urea.

SUMMARY

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 while NO_3^- accumulation was 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 could greatly mitigate environmental risks related to air and water quality while meeting the demands of providing food, fuel, and fiber for more than seven billion people.

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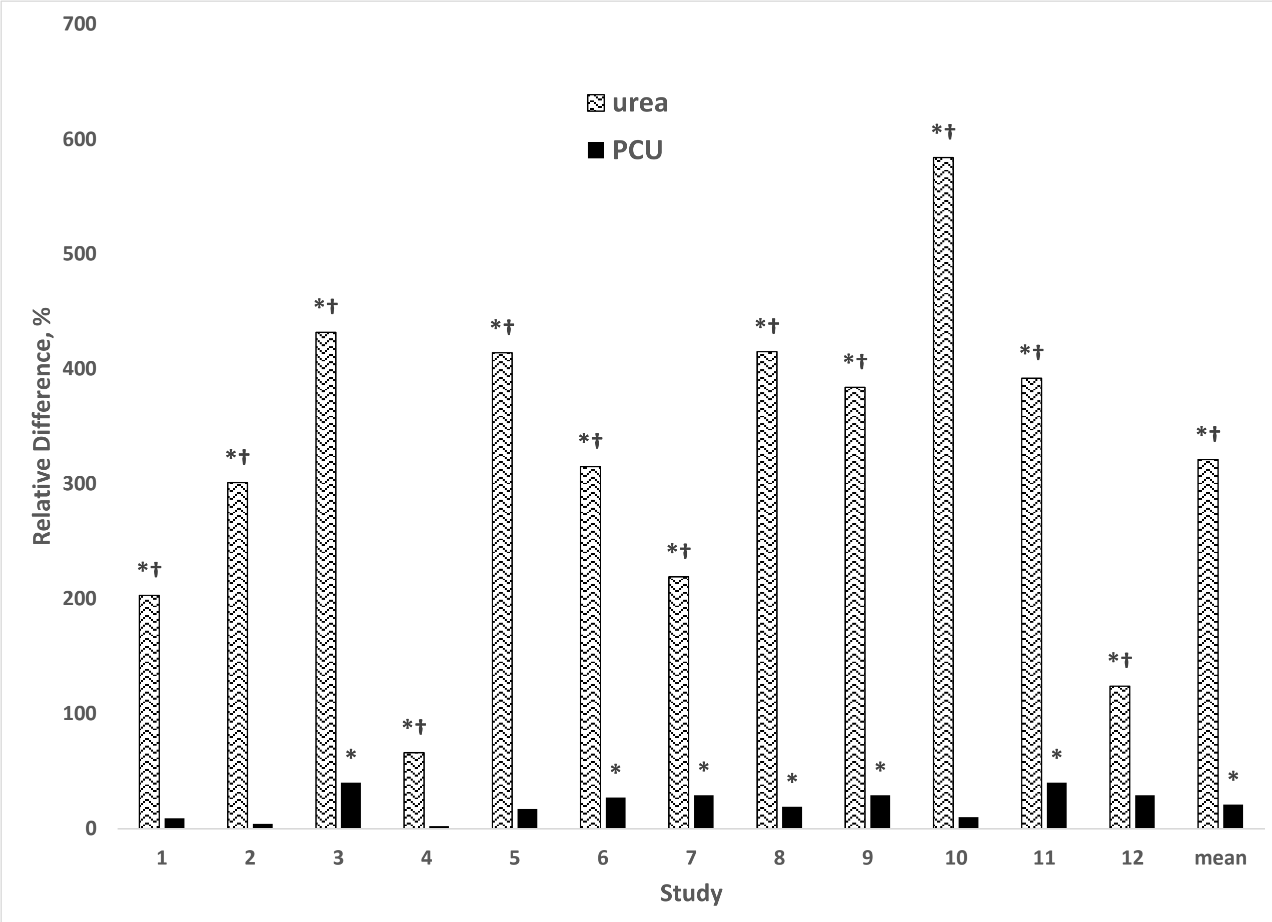

Fig. 1. Relative differences in cumulative N loss as ammonia gas (NH_3) compared to an untreated control for coated (PCU) and uncoated fertilizers for 12 lab, glasshouse, and field trials (as measured every hour during each study). Statistical significance compared to the control is indicated by a "*" at the end of each data bar. Difference between fertilized treatments is indicated by a "†" at the end of the urea data bar. If there is not a symbol present, the difference is not significant. $P<0.05$

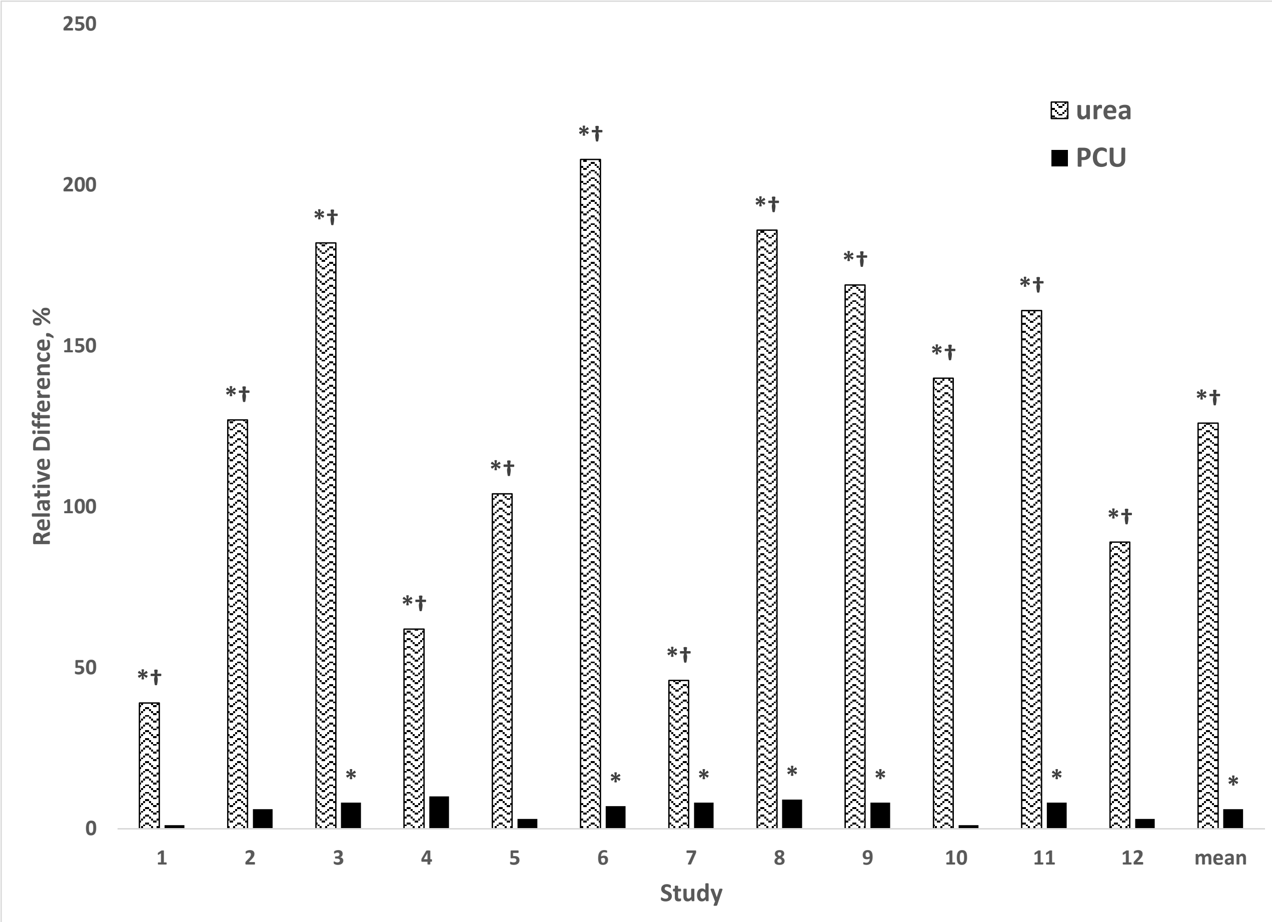

Fig. 2. Relative differences in cumulative N loss as nitrous oxide gas (N_sO) compared to an untreated control for coated (PCU) and uncoated fertilizers for 12 lab, glasshouse, and field trials (as measured every hour during each study). Statistical significance compared to the control is indicated by a "*" at the end of each data bar. Difference between fertilized treatments is indicated by a "†" at the end of the urea data bar. If there is not a symbol present, the difference is not significant. P<0.05

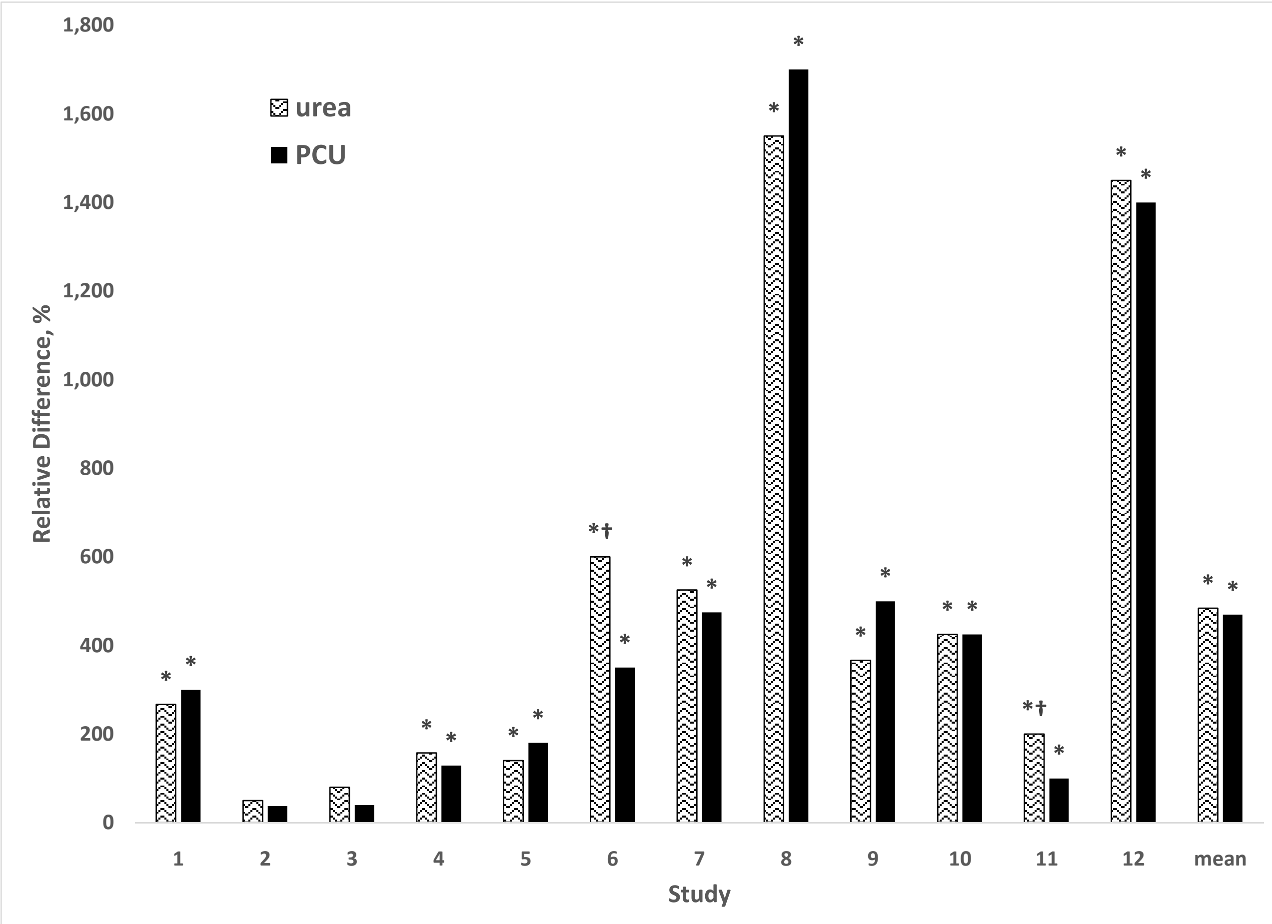

Fig. 3. Relative differences in N loss as soil solution nitrate (NO_3^-) accumulation compared to an untreated control for coated (PCU) and uncoated fertilizers for 12 lab, glasshouse, and field trials. (as measured at the end of each study). Statistical significance compared to the control is indicated by a "*" at the end of each data bar. Difference between fertilized treatments is indicated by a "†" at the end of the urea data bar. If there is not a symbol present, the difference is not significant. P<0.05