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THE IMPACT OF THE POLYMER COATING NUTRISPHERE™ IN INCREASING NITROGEN USE EFFICIENCY AND CORN YIELD

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ABSTRACT

Currently, it is estimated that 50 to 60% of the N applied fertilizer is actually utilized by the crop with the remaining N lost through leaching or denitrification. A three year study was conducted at eight locations in North Carolina to examine the impact of Nutrisphere™ on corn yield, optimum N rate, maximum yield, tissue N concentration, plant biomass and N uptake. At six locations the study consisted of a split plot design where main plots were either 30% Urea Ammonium Nitrate (UAN) or 30% UAN plus Nutrisphere™ applied either at planting or layby with subplots consisting of five N rates that differed slightly across years. At two locations, two N solutions were applied at two rates to plots that received one of two starter fertilizer treatments. The overall trend indicated that Nutrisphere™ increased yield compared to the use of 30% UAN alone with a significant ($p<0.10$) yield increases of 0.74 Mg ha^{-1} from combined results at Bertie08 and Pamlico08, 0.93 Mg ha^{-1} from combined results at Guilford08 and Forsythe08 and 0.37 Mg ha^{-1} from the treatment with at planting application of N at Beaufort09 and Pamlico09. While Nutrisphere™ only reduced optimum N rate in two trials, there was a consistent increase in maximum potential yield across trials. Plant analysis found that Nutrisphere™ increased biomass at one location, although it did not affect tissue N concentration and did not result in consistent increases in plant N uptake. The significant impacts of Nutrisphere™ on plant biomass and corn yield indicate that it affects the N movement to the root surface over a short period of time after application. More research is needed to determine how Nutrisphere™ impacts N movement in the soil, N transformations and N uptake to improve recommendations regarding its use and potential for increasing yield.

Keywords: Nitrogen, Nitrogen Use Efficiency, Polymer Fertilizer Coating, Urea Ammonium Nitrate (UAN), Nutrisphere™

1. INTRODUCTION

Current trends in population growth indicate that by 2050 there will be over 8.9 billion people on this planet (FAO, 2004). To provide adequate food, fiber and renewable energy resources to meet this growth in population, we will need todramatically increase crop yields. Increasing yields, particularly in cereal crops, will require the increased use of plant nutrients such as Nitrogen (N) applied in the form of fertilizers. Unfortunately, concerns about the impact of N fertilizers on aquatic ecosystems, water quality (Hubbard and Sheridan, 1989) and climate change (Jarecki *et al*., 2008) make it imperative that the use of these fertilizers be properly managed. Currently, it is estimated that 50 to 60% of applied N fertilizer is actually used by the crop with the remaining N lost through leaching or denitrification (Blackmer and Schepers, 1996). Improving the use efficiency of N fertilizers is the key to increasing yield without increasing the amount of N

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fertilizer applied. New fertilizer additives that improve N uptake or reduce N losses offer the potential to improve N use efficiency.

While there are several fertilizer products that contain N, in the southeastern US Urea Ammonium Nitrate (UAN) containing either 30 or 32% N has become the primary N fertilizer (NASS, 2009). This is mostly due to availability, cost and ease of transportation. Half of the N in UAN is in the form of urea, which can be lost through volatilization when applied on the soil surface where the surface pH is above 6.5 (Vaio *et al.*, 2008). The remaining N in UAN is in the form of ammonium nitrate. While the ammonium in this molecule bonds readily to soil colloids, Nitrate (NO_3-N) component is highly soluble and can be lost through leaching or surface runoff (Stevenson and Baldwin, 1969).

Several practices could be used to improve the N use efficiency of fertilizer like UAN. For instance, UAN could be applied close to the root system to avoid volatilization and assure rapid uptake by the plant before heavy rainfall carries it away or moves fertilizer deeper in the soil (Stevenson and Baldwin, 1969). Unfortunately, narrow row crops and weather conditions such as wet and muddy soils can make it difficult to place fertilizer close to growing roots. Another approach would be to use controlled release fertilizers or fertilizer additives that could improve plant uptake through increasing the availability and timing of N release to match the need of the plant. For instance, by controlling the conversion of ammonium to nitrate more of N could be retained on the soil colloids. Also, more N would move through mass flow to root surfaces by increasing the solubility of urea or nitrate in water. While the potential advantages of these fertilizer additives or controlled release fertilizers include higher N concentrations in the root zone, less leaching of nutrients, longer nutrient supply, reduced volatilization of N and matched release rates with crop nutrient demand compared to conventional fertilizers, these materials currently account for a fraction of fertilizer use (Trenkel, 1997). The primary reason for this is the lack of evidence indicating the efficacy of fertilizer additives or controlled release fertilizers in achieving these advantages.

Fertilizer additive, released by Specialty Fertilizer Products, Inc. (Lenexa, KS), has the potential to overcome problems associated with weather and management by increasing yield and improving N use efficiency over a wide range of environmental conditions. Nutrisphere™ is a long chain branched polymer with a large negative charge (1800 meq 100 g^{-1}). This charge makes the molecules table at high ionic concentrations, which allows to hold other molecules in suspension. Adding it to a fertilizer like UAN, Nutrisphere™ coats the fertilizer molecule. In the soil, the Nutrisphere™ coating binds to positively charged cations such as nickel, so these cations will no longer be available in forming the urease enzyme. Without the urease enzyme the hydrolization of urea or nitrate into ammonia ceases. Since this mechanism is the primary pathway for conversion of N in the soil, efficacy of this material would be less sensitive to environmental or management conditions.

Generally, growing conditions in this study were less than ideal, which limited potential yield and influence of N. More studies are needed to determine if Nutrisphere™ is effective in increasing yield and N use efficiency either by controlling N release or by improving early uptake and crop growth. The objectives of this study were to: (1) examine the impact of the fertilizer additive Nutrisphere™ on yield in high population corn systems, (2) determine if Nutrisphere™ influences optimum N rate or maximum yield in corn and (3) determine if Nutrisphere™ affects plant tissue N concentration, biomass, or N uptake.

2. MATERIALS AND METHODS

2.1. Site Preparation and Management

Nine research trails were conducted in 2007, 2008 and 2009 at locations in Pamlico, Beaufort, Currituck, Guilford, Forsythe and Bertie Counties on wide range of soil types (**Table 1**). The key purpose of these trials was to test the impact of polymer fertilizer additive Nutrisphere™ marketed by Specialty Fertilizer Products, Inc. on N use efficiency and yield in corn. At two locations, Nutrisphere™ was tested in a combined study along with the polymer Avail™ which was added to a blended liquid fertilizer with N, Phosphorus (P) and Potassium (K) and applied as a starter. Avail™ is a high-exchange polymer similar to Nutrisphere™ and composed of long-chain molecules with highly active adsorbent sites.

2.2. 2007 Methods

At the Pamlico07 and Currituck07 locations the experimental design was a split plot with four replications. Two main plot treatments were 30% UAN and 30% UAN with Nutrisphere™ added at the recommended rate of 0.005 L 1 L^{-1}. Subplots consisted of four application rates in order to achieve 0, 56, 91, 161 and 303 kg N ha^{-1}.

Table 1. Soil and crop management information for Nutrisphere™ research trials in 2007, 2008 and 2009

Location	Soil Taxonomic Class	Planting date	Hybrid
Pamlico07	Fine-loamy, mixed, semiactive, acid, thermic Histic Humaquept	28-Mar-07	'DKC69-71'
Currituck07	Coarse-silty, mixed, semiactive, thermic Typic Endoaquult	Apr. 3, 2007	'Pioneer 31G98'
Forsythe08	Fine, kaolinitic, thermic Rhodic Kanhapludult	2-May-08	'DKC61-69'
Guilford08	Coarse-loamy, siliceous, subactive, thermic Aquic Hapludult	3-May-08	'DKC61-69'
Bertie08	Fine-loamy, siliceous, subactive, thermic Aquic Paleudult	15-Apr-08	'DKC61-69'
Pamlico08	Fine-loamy, mixed, active, thermic Typic Endoaqualf	11-Apr-08	'Pioneer 31G96'
Beaufort09	Fine, mixed, semiactive, thermic Typic Endoaquult	21-Apr-09	'Pioneer 31P42'
Pamlico09	Fine-loamy, mixed, active, thermic Typic Endoaqualf	8-Apr-09	'Pioneer 31P44'

Fertilizer was broadcast applied following corn planting. The purpose for making the application at planting was to insure that adequate N was available for early plant growth. At each location, 17-17-0 fertilizer was applied to all plots at planting in a 2×2 band at a rate of 90.4 L ha^{-1}.

2.3. 2008 Methods

At the Guilford08 and Forsythe08 sites, the Nutrisphere™ polymer test was evaluated with starter fertilizer with and without Avail™ using a randomized complete block design with four replications. Ten treatments were applied: (A) 12-12-4 applied as a starter in a 2×2 band with 30% UAN broadcast applied at 143 kg N ha^{-1}, (B) 12-12-4 in a 2×2 band with 30% UAN broadcast applied at 179 kg N ha^{-1}, (C) 12-12-4 in a 2×2 band with 30% UAN plus Nutrisphere broadcast applied at 143 kg N ha^{-1}, (D) 12-12-4 in a 2×2 band with 30% UAN plus Nutrisphere broadcast at 179 kg N ha^{-1}, (E) 12-12-4 in a 2×2 band with Avail plus 30% UAN broadcast applied at 143 kg N ha^{-1}, (F) 12-12-4 in a 2×2 band with Avail with 30% UAN broadcast applied at 179 kg N ha^{-1}, (G) 12-12-4 with Avail in a 2×2 band with 30% UAN plus Nutrisphere broadcast applied at 143 kg N ha^{-1}, (H) 12-12-4 with Avail in a 2×2 band with 30% UAN plus Nutrisphere broadcast applied at 179 kg N ha^{-1}, (I) no starter fertilizer with 30% UAN broadcast applied at 179 kg N ha^{-1} and (J) no fertilizer applied. The Avail™ polymer was added to the 12-12-4 at a rate of 0.005 L 1 L^{-1}. The starter fertilizer with or without Avail™ was applied a rate of 187 L ha^{-1}. The Nutrisphere™ polymer was added to the 30% UAN at a rate of 0.005 L 1 L^{-1}.

At Pamilco08 and Bertie08 locations, Nutrisphere™ was evaluated using a split plot design with four replications. Main plot treatments consisted of either 30% UAN or 30% UAN plus Nutrisphere™ applied at 0.005 L 1 L^{-1} as a layby application. Subplot treatments were application rates of 0, 34, 90, 202, 258 and 314 kg N ha^{-1}. At both of these locations, treatments were applied at V7. Starter fertilizer was applied in the form of 10-27-0 at a rate of 90.4 L ha^{-1} in a 2×2 band at planting. In addition to the starter, fertilizer 37 kg N ha^{-1} was broadcast applied to all of the plots at planting using 30% UAN.

2.4. 2009 Methods

The Nutrisphere™ polymer additive was tested at two sites in 2009: Pamlico09 and Beaufort09 (**Table 1**). The experimental design was a split-split plot with three replications. Main plots consisted of a broadcast treatment of either 30% UAN, or 30% UAN plus Nutrisphere™ mixed at 0.005 L 1 L^{-1}. Subplot treatments were two application dates, either at-planting (21 April) or at-layby (27 May). Sub-subplots consisted of five application rates of 0, 101, 146, 202 and 258 kg N ha^{-1}. No starter fertilizer was applied at either of these locations in 2009. Whole plant tissue samples were collected at growth stages V5 (27 May at Beaufort09 and 21 May at Pamlico09) and whole plant tissue samples, above ground biomass and N uptake were measured at R1 (27 June at Beaufort09 and 26 June at Pamlico09) from N application treatments at planting except the highest N rate. In addition, stalk samples were collected at harvest by clipping a 15 cm portion of stalk from just above the soil surface. Tissue and stalk samples consisted of five consecutive plants collected from a random sampling of the outside rows of each plot. Samples were chopped and dried and biomass was measured at R1 and sent to the North Carolina Department of Agriculture and Consumer Services (NCDA&CS) laboratory in Raleigh, NC for analyses using standard procedures for testing total % Kjehdal N (Nelson and Summers, 1973).

2.5. Common Methods

Planting dates and hybrids for each test are shown in **Table 1**. Corn was planted in 0.76 m row spacing and seeding rate of 81,510 seeds ha^{-1}. For all locations and years, plots consisted of four rows of corn that were 3.08 m wide and 12.3 m long. Bicep (*S*-metolachlor+6-chloro-*N*-ethyl-*N*'-isopropyl-1,3,5-triazine-2,4-diamine) applied at recommended rates at planting and Roundup (N-phosphonomethyl glycine) and atrazine (6-chloro-*N*-ethyl-*N*'-isopropyl-1,3,5-triazine-2,4-diamine) applied at recommended rates at layby provided excellent weed control. Insects and diseases (with the exception of the Pamlico07 location) were not a factor. The center two rows of each four row plot were harvested in September using a Gleaner K2 combine with a Harvestmaster™ system (Juniper Systems, Inc., UT) that recorded grain weight, moisture and test weight for each plot.

2.6. Data Analyses

All data were analyzed using PROC Mixed (SAS, 2005) with replicated blocks considered as random factors. Mean separations of interest were done using contrast statements. To determine economically optimum N rate grain yield response to N was modeled as a quadratic-plateau function using PROC NLIN (SAS, 2005). Economic optimum N rates were calculated using a price ratio of 7:1, where the price ratio was defined as the ratio of the price per Mg N to the price per Mg of corn. If any of the responses did not fit a quadratic-plateau function determined by the significance of the model at an alpha of 0.05, then treatment means were compared using contrast statements to determine the optimum N level. If the yield response to fertilizer N was not significant as measured by either of the above methods, the economic optimum N was set equal to zero.

3. RESULTS

3.1. Yield Comparisons

Differences in study design (N rates) from year-to-year eliminated the possibility of combining results across years. However, results were combined within years with the exception of Guilford08 and Forsythe08 locations, which were analyzed as a unit because they included starter fertilizer treatments with and without Avail™. In 2007 at the Pamlico07 and Currituck07 sites the combined analysis found a location by rate interaction ($p = 0.0022$) and a significant rate effect ($p<0.0001$). At both locations yield increased as N rate increased (**Table 2**). However, maximum corn yield was higher at Pamlico07 resulting in larger differences in yield among the N rates (**Fig. 1**). While the source by rate interaction was not significant ($p = 0.1733$) contrast statements indicated differences in corn yield between 30% UAN and 30% UAN plus Nutrisphere™ when either 90 or the highest rate of 303 kg N ha^{-1} were applied.

In 2008, at the Bertie08 and Pamlico08 sites there was a significant location by rate ($p = 0.0059$) interaction and significant rate ($p = 0.0055$), source ($p = 0.0067$) and location ($p = 0.0016$) main effects. Severe drought at the Bertie08 location resulted in no yield response to added N. This resulted in significantly different yield levels and yield responses (**Fig. 2**). Across the two locations, addition of Nutrisphere™ resulted in a significant yield increase of 0.74 Mg ha^{-1} and contrast statements indicated significant increases in yield between the two N solutions when either 202 or 258 kg N ha^{-1} were applied (**Table 2**).

At the Forsythe08 and Guilford08 locations, statistical analysis found a strong treatment effect ($p = 0.0011$). Contrast statements examined differences between 30% UAN and 30% UAN with Nutrisphere™. There was a significant yield increase ($p = 0.0152$) of 0.93 Mg ha^{-1} resulting from the use of Nutrisphere™ whenever starter fertilizer (either 12-12-4 or 12-12-4 with Avail™) was applied (**Fig. 3**). However, there was no significant difference between the two N solutions within either the 12-12-4 application or the application of 12-12-4 with Avail™.

In 2009, when the Pamlico09 and Beaufort09 locations were analyzed together, there were strong location by rate ($p < 0.0001$) and application timing by source ($p = 0.0124$) interactions. As in the earlier trials, corn yield at both locations increased as the rate of N applied increased. It was the rate at which yield increased at each location that resulted in the location by rate interaction (**Fig. 4**). Adding Nutrisphere™ to 30% UAN and applied at planting produced a significant yield increase of 0.37 Mg ha^{-1} and contrast statements found a significant yield increase when Nutrisphere™ was applied with 30% UAN at a rate of 101 kg N ha^{-1} (**Table 2**). No significant yield differences between 30% UAN and 30% UAN plus Nutrisphere™ were found with applications made at layby.

3.2. Optimum N Rate and Maximum Yield

At the Currituck07 location when 30% UAN was used alone and at the Bertie08 location when either 30% UAN or 30% UAN plus Nutrisphere™ were used, the yield responses to added N did not fit quadratic-plateau functions (**Fig. 1 and 2**). Therefore, optimum N rates and maximum yields at these locations and N sources were determined by using contrast statements to find the N rate that produced the highest yield at $p<0.05$. Both Currituck07 and Bertie08 experienced extremely dry conditions during the respective growing seasons in 2007 and 2008, which contributed to the lack of a yield response to added N.

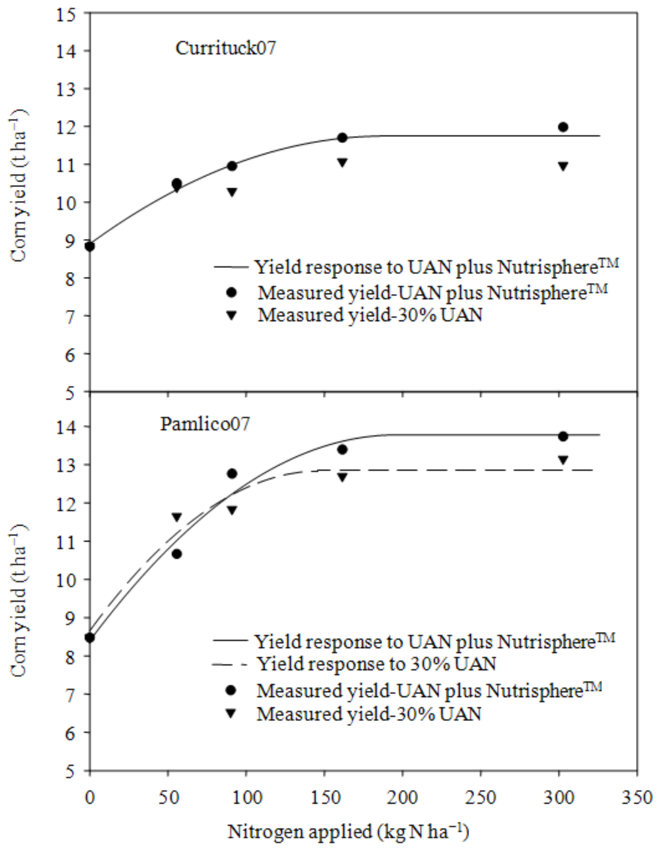

Fig. 1. Corn yield response to 30% UAN applied with or without Nutrisphere™ at planting at two locations in 2007. Lines represent a quadratic-plateau model fit to the replicated data from each N rate applied. Points represent the average grain yield at each N rate applied. If a line is not shown, a quadratic-plateau model did produce a significant ($p < 0.05$) fit at that location and N solution

Table 2. Corn yield response to 30% UAN with and without Nutrisphere™ at five nitrogen rates that differ across years

		Nitrogen rate code†					
		Mg ha^{-1}					
Timing/ Year	Nitrogen treatment	0	1	2	3	4	Average
Plant 07	30% UAN	8.65	11.02a‡	11.06a	11.88a	12.06a	10.93A§
	UAN + Nutrisphere™	8.65	10.58a	11.86b	12.55a	12.86b	11.30A
N rate averages	8.65a¶	10.80b	11.46c	12.21d	12.46d		
Layby 08	30% UAN	5.54a	6.28a	6.12a	6.89a	7.19a	6.40A
	UAN + Nutrisphere™	6.40a	6.79a	7.22b	8.08b	7.23a	7.14B
N rate averages	5.97a	6.54ab	6.67bd	7.48c	7.21cd		
Plant 09	30% UAN	7.41	11.02a	11.68a	13.24a	13.18a	11.30A
	UAN + Nutrisphere™	7.41	11.71b	12.15a	13.61a	13.50a	11.67B
N rate averages	7.41a	11.37b	11.91c	13.42d	13.34d		
Layby 09	30% UAN	7.11	11.37a	12.51a	13.39a	13.44a	11.09A
	UAN + Nutrisphere™	7.11	11.51a	12.32a	13.62a	13.87a	11.14A
N rate averages	7.11a	11.44b	12.42c	13.50d	13.65d		

†Nitrogen rates for each year were: 2007-0 = 0, 1 = 56, 2 = 91, 3 = 161 and 4 = 303 kg N ha^{-1}; 2008-0 = 34, 1 = 90, 2 = 202, 3 = 258 and 4 = 314 kg N ha^{-1}; 2009-0 = 0, 1 = 101, 2 = 146, 3 = 202 and 4 = 258 kg N ha^{-1}; ‡ Different letters within each year and rate code column indicate significant differences at $p<0.10$. § Different letters within each year under the Average column indicate significant differences between 30% UAN and 30% UAN plus Nutrisphere™ at $p<0.10$; ¶ Different letters within each row showing the N rate averages indicate significant differences at $p<0.10$

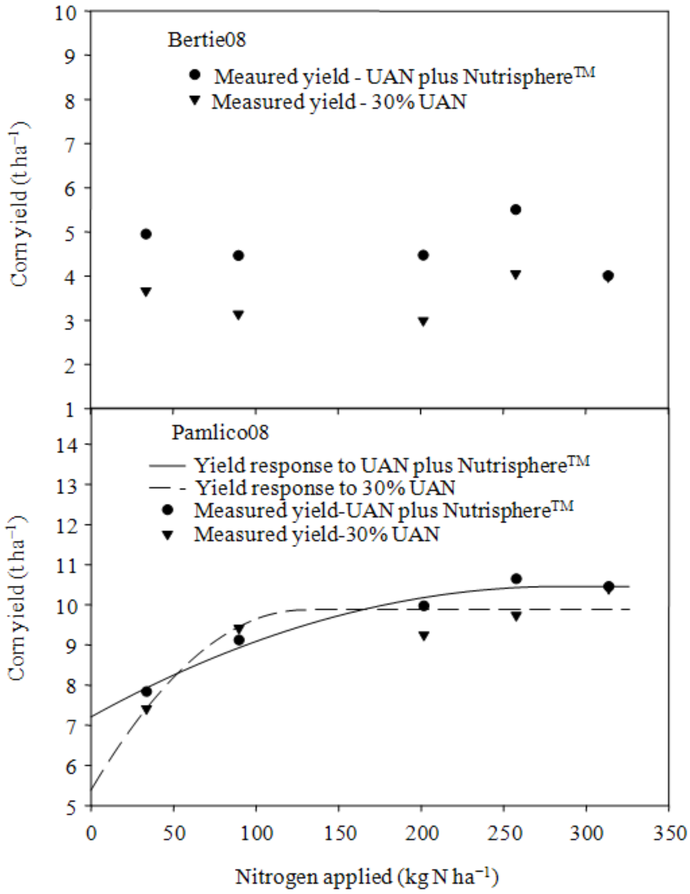

Fig. 2. Corn yield response to 30% UAN applied with or without Nutrisphere™ at layby at two locations in 2008. Lines represent a quadratic-plateau model fit to the replicated data from each N rate applied. Points represent the average grain yield at each N rate applied. If a line is not shown, quadratic-plateau model did produce a significant ($p<0.05$) fit at that location and N solution

Table 3. Optimum nitrogen rates and maximum yield predicted by a quadratic-plateau model fit to the grain yield response to five rates of 30% UAN with and without Nutrisphere™ applied at different times and locations across North Carolina

		Optimum N rate		Predicted maximum yield	
		kg N ha^{-1}		Mg ha^{-1}	
Location/Year	Application timing	Nutrisphere™†	30% UAN	Nutrisphere™	30% UAN
Currituck07	planting	145	56.0‡	11.7	10.4
Pamlico07	Planting	171.1	130	13.8	12.8
Bertie08	Layby	0‡	0‡	5.0	3.7
Pamlico08	Layby	197.5	115.9	10.5	9.9
Beaufort09	Planting	196.7	217.5	14.3	13.8
Pamlico09	Planting	212.5	253.9	12.6	13.3
Beaufort09	Layby	234.3	186.5	14.9	14.1
Pamlico09	Layby	217.3	218.5	12.8	12.8

† Nutrisphere™ was added to 30% UAN at a rate of 0.005 L 1 L^{-1}; ‡The N rate response for this N source at this location/year did not fit a quadratic-plateau model. Optimum N rate and maximum yield were determined using contrast statements to find the lowest N rate that produced the highest yield at $p<0.05$

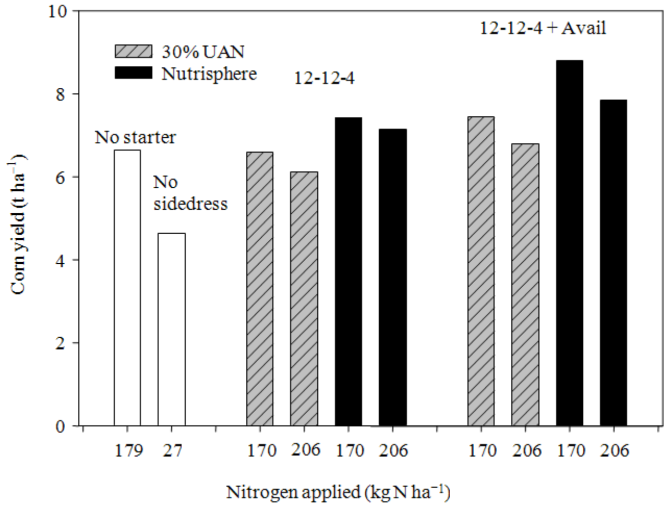

Fig. 3. Grain yield measured with various treatments including either no starter, 12-12-4, or 12-12-4 plus Avail™ applied in a 2×2 band at planting and layby application of either 30% UAN or 30% UAN with added Nutrisphere™. Contrast statements found that when either 12-12-4 or 12-12-4 with Avail™ was used, Nutrisphere™ added to 30% UAN significantly increased corn yield compared to the use of 30% UAN alone at p = 0.0152

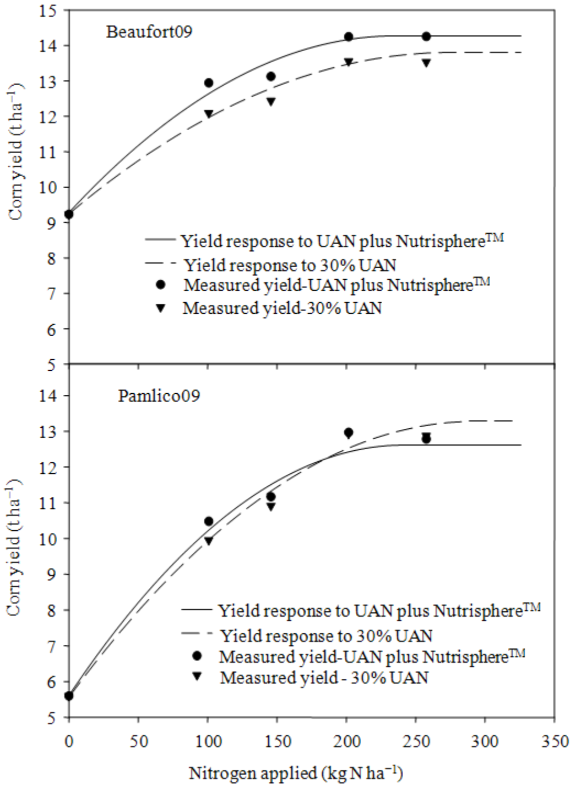

Fig. 4. Corn yield response to 30% UAN applied with or without Nutrisphere™ at planting at two locations in 2009. Lines represent a quadratic-plateau model fit to the replicated data from each N rate applied. Points represent the average grain yield at each N rate applied. If a line is not shown, quadratic-plateau model did produce a significant ($p < 0.05$) fit at that location and N solution

Across the eight trials where a range of N rates were applied, 30% UAN resulted in lower optimum N rates in four trials, while Nutrisphere™ added to 30% UAN resulted in lower optimum N rates in two trials and there was only a slight (less than 2 kg N ha^{-1}) difference between the N solutions in one trial at Pamlico09 when the materials were applied at layby (**Table 3**). In six out of eight trials, Nutrisphere™ added to 30% UAN resulted in higher maximum yield when compared to 30% UAN alone as indicated by the quadratic-plateau model or statistical comparisons of yield among applied N rates. The indicated yield advantage to the use of Nutrisphere™ ranged from 0.5 to 1.3 Mg ha^{-1}. The only trial in which the quadratic-plateau model found that 30% UAN resulted in a higher yield was in Pamlico09, when N rates were applied at planting. The trial at Beaufort09 when N was applied at planting was particularly interesting because the model indicated that the use of Nutrisphere™ resulted in more yield (0.5 Mg ha^{-1} more yield when Nutrisphere™ was used), but required 20.8 kg ha^{-1} less N to achieve that yield. This was the only trial and only N solution in which maximum yield was greater with a lower optimum N rate.

3.3. Tissue N Concentration, Biomass and N Uptake

Statistical analysis of tissue concentrations, biomass and N uptake collected from plots that received N at planting at Pamlico09 indicated that the only significant treatment factor was N rate. At both V5 and R1 tissue samples collected from plots with N rates of 101, 146 and 202 kg N ha™ had higher N concentrations than samples collected from the zero rate treatment (**Fig. 5**). The same was true for both biomass and N uptake, where measurements collected from three N rate treatments were always greater than that measured in the zero rate plot.

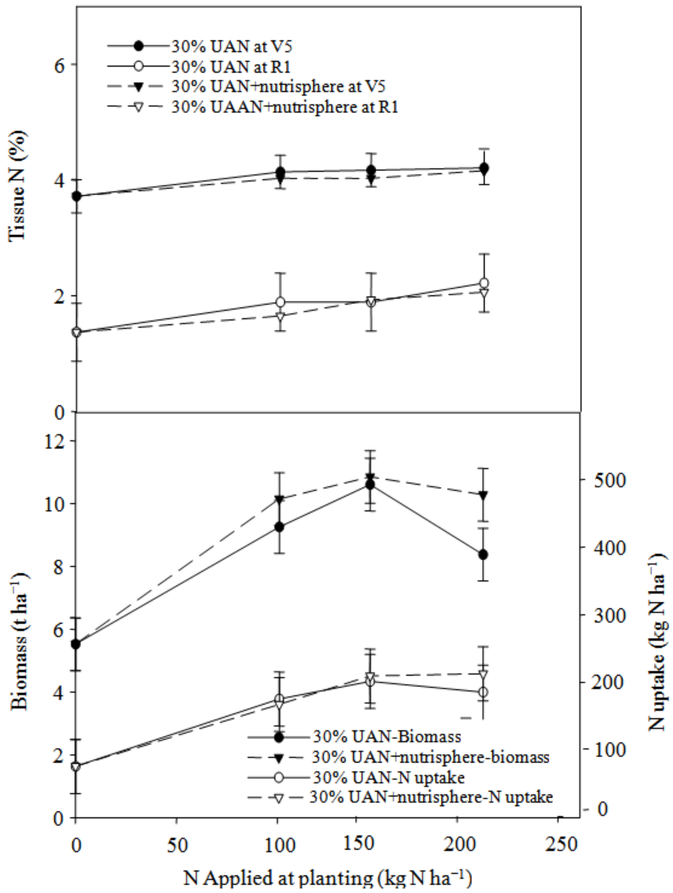

Fig. 5. Responses of tissue N concentration measured at V5 and R1, plant biomass measured at R1 and nitrogen uptake measured at R1 to 30% UAN applied with or without Nutrisphere™ at planting at Beaufort in 2009. Error bars represent significant differences at p<0.05

In the case of stalk nitrate content, no statistical differences were found among the N rate treatments. At Pamlico09, there were no significant differences between 30% UAN and 30% UAN plus Nutrisphere™ for tissue N concentration measured either at V5 or R1, N uptake, or stalk nitrate content. In general, biomass tended to be greater when Nutrisphere™ was used and contrast statements indicated a significant ($p = 0.0682$) difference between 30% UAN and 30% UAN plus Nutrisphere™ when 202 kg N ha^{-1} was applied.

At Beaufort09, N rate was the only significant factor when tissue N concentrations were measured either at V5 ($p < 0.0001$) or R1 ($p = 0.0006$). Similar to the Pamlico09 location, three higher N rates of 101, 146 and 202 kg N ha^{-1} had greater tissue N concentrations when compared to plots with no applied N (**Fig. 6**). There was a significant N solution by N rate interaction for biomass. While biomass did not differ between the two N solutions when either no N or 101 kg N ha^{-1} were applied, there were significant differences in biomass between 30% UAN and 30% UAN plus Nutrisphere™ at the two higher N rates of 146 and 202 kg N ha^{-1}. A similar observation was made by Cahill *et al*. (2010). This indicates that the use of Nutrisphere™ does affect plant growth. Despite the significant increase in biomass, statistical analysis did not find a significant N solution by N rate interaction for N uptake. Contrast statements indicated that there were differences in N uptake between the N solutions at N rates of 146 and 202 kg N ha^{-1} ($p = 0.0752$ and 0.0620, respectively). There was also a significant rate affect. The N uptake was greatest at N rates of 146 and 202 kg N ha^{-1}. There were no significant differences among N rates or between the N solutions for stalk nitrate content.

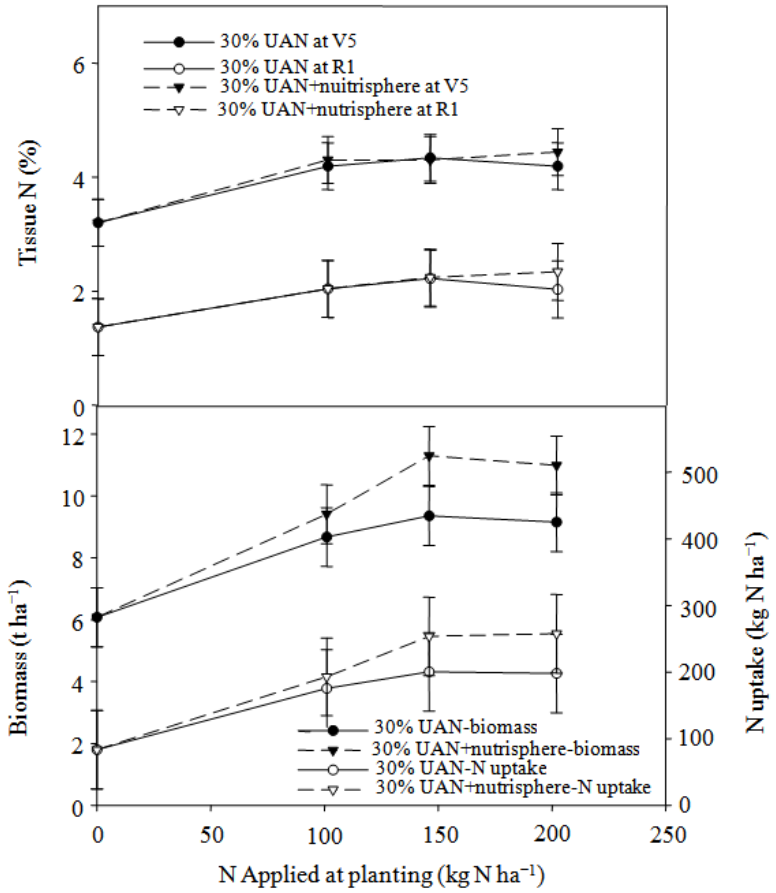

Fig. 6. Responses of tissue N concentration measured at V5 and R1, plant biomass measured at R1 and nitrogen uptake measured at R1 to 30% UAN applied with or without Nutrisphere™ at planting at Beaufort in 2009. Error bars represent significant differences at p<0.05

4. DISCUSSION

A review of synthetic slow and controlled release fertilizer literature suggests that yield increases or improvements in nutrient efficiency do occur, but only under certain weather or field conditions. On a sandy soil, Wen *et al*. (2001) found greater peanut (*Arachis hypogaea* L. cv. Hanritusei) yield and N recovery with resin-coated N fertilizer. In field and laboratory studies using conditions favorable to ammonium volatilization, Vaio *et al*. (2008) measured NH_3 losses from urea formaldehyde polymer and found that less NH_3 was lost. A two-year potato study on an irrigated loamy sand using Environmental Smart Nitrogen (ESN), polymer coated urea and a blend of urea and ammonium nitrate, found that optimum N rates were less for ESN than soluble N and potato yields under ESN were similar to those from split applied N (Wilson *et al*., 2009). In years with above average rainfall Wiedenfeld (1986) found that cabbage (*Brassica oleracea* L. Group capitata) and onion (*Allium cepa* L.) had increased yield, yield weight and leaf N content when grown with slow-release fertilizers, methylene urea and sulfur-coated urea, but there were no differences when rainfall was below average. Halvorson *et al*. (2008) studied N_2O gas flux emission from irrigated corn (*Zea mays* L.), wheat (*Triticum aestivum* L.), barley (*Hordeum vulgare*) and dry bean (*Phaseolus vulgaris*) treated with various N fertilizers on clay loam in the western great plains. Under irrigation, the polymer coated urea reduced N_2O emissions from the four irrigated crops. Kondo *et al.* (2005) compared split applications of urea with polyolefin resin-coated urea and found that apparent N recovery fraction improved with the polyolefin resin-coated urea due to less leaching under heavy rainfall or irrigation. A two-year field trial using ESN, found that on a claypan soil, ESN increased corn grain yields in a wet, low-lying field position when compared to urea (Noellsch *et al*., 2009). It is clear from this review that the benefits from the use of these controlled release fertilizers or fertilizer additives depend on the weather, soil and management conditions under which these products are applied.

While comparative research on corn done at Kansas State University (Gordon, unpublished data), University of Illinois (Ebelhar, unpublished data) and other institutions (Randall, unpublished data) indicates that Nutrisphere™ improved corn yield on a wide variety of soil types, other studies have not found improvements in yield or nutrient use efficiency on rice (Mississippi and Arkansas, unpublished data) or delays in N release (Cahill *et al*., 2010) or volatilization (Binford, unpublished data). Cahill *et al*. (2010) found that Nutrisphere™ did not improve N use efficiency in either wheat or corn, but that Nutrisphere™ did increase stover yield in corn. This was the result of earlier season vegetative growth, which did not correspond to increased yield.

5. CONCLUSION

Research studies at six locations across three years where N was applied either at planting or layby (or both) indicated that the use of Nutrisphere™ as an additive to 30% UAN did result in modest increases in corn yield ranging from 0.05 to 0.74 Mg ha^{-1}. Numerical increases in corn yield, when Nutrisphere™ was added, were noted at mostly every N rate applied at every location in each year and at both planting and layby, although there were only four instances when these differences were significant. In 2008, study combining Nutrisphere™ with a test of starter fertilizer with and without Avail™ also found significant increases in yield. As indicated by the biomass data collected at Beaufort09 and Pamlico09, differences in corn yield were the generally the result of higher growth. At Beaufort09, N uptake was also greater at higher N rates indicating that more of the fertilizer N was utilized by the plant. This resulted in greater N use efficiency at that location (less N required to achieve optimum yield). Cahill *et al.* (2010) also noted greater biomass in corn when Nutrisphere™ was applied with 30% UAN. Observations of early growth advantages in plots receiving Nutrisphere™ at planting lead to the conclusion that addition of Nutrisphere™ results in more N reaching the root surface and entering the plant.

Comparisons of optimum N rates and maximum corn yield between treatments of 30 and 30% UAN plus Nutrisphere™ also tend to support the indications that the use of Nutrisphere™ has its greatest impact on plant growth and increasing potential yield. While Nutrisphere™ did reduce optimum N rate in two trials the most consistent trend was that higher maximum corn yields were achieved when Nutrisphere™ was applied. This indicates that greater yield advantages will be found when Nutrisphere™ is used under conditions, where yield is not limited by lack of rainfall or other factors. This may be the reason for conflicting results found when testing the impact Nutrisphere™ on yield.

The rapid growth response to the addition of Nutrisphere™ resulted in the lack of differences in tissue N concentration. However, even though plant growth was affected to some extent at both Pamlico09 and Beaufort09 locations, total N uptake was only different at the two higher N rates at the Beaufort09 location. This seems to indicate that the impact of Nutrisphere™ in affecting N uptake by the plant occurs over a fairly short period. It is clear that more study is needed to determine how Nutrisphere™ is impacting N movement, transformation and uptake, so that better recommendations can be made regarding its use and potential for increasing yield.

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