EXPLORING CONTROLLED RELEASE NITROGEN FERTILIZERS FOR VEGETABLE AND MELON CROP PRODUCTION IN CALIFORNIA AND ARIZONA

***Eric Ellison, *Alan Blaylock, [†]Charles Sanchez, and [‡]Richard Smith**
*Agrium Advanced Technologies, [†]University of Arizona, [‡]University of California Cooperative Extension

ABSTRACT

Various forms of polymer coated urea (PCU) were examined as sources of controlled release nitrogen for production of cauliflower, watermelon, carrot, and spinach in Arizona or California. Studies were designed to demonstrate the effectiveness of PCU for supplying 100 percent of the fertilizer nitrogen needed for an entire growing season in a single pre-plant application. In each study, two or more N rates were tested. PCU having an appropriate release time for a given set of growing conditions consistently increased yield over split application of standard nitrogen fertilizer (SNF). Average yield increases of 9, 27, 64, and 13 percent were observed for the aforementioned crops, respectively. At low N rates, where yield is more sensitive to N loss, PCU was superior to SNF. Soil testing showed that, compared to SNF, PCU consistently maintained higher levels of soil nitrate in the root zone. While there may be skepticism of PCU based on the extra cost of the polymer coating, the simplicity and lowered cost of making only one fertilizer application is attractive. The single application approach also provides an intangible benefit considering uncertainties associated with labor, logistics, and proper timing of split application programs including fertigation. The body of work summarized herein demonstrates that PCU should be explored in more detail as an N source for specialty row crops.

INTRODUCTION

Controlled release fertilizers (CRFs) are produced by an industrial process in which a continuous polymer film or coating is placed on the surface of a standard granular fertilizer such as urea (Trenkel 2010). The resulting polymer coating is only a few micrometers thick and contains molecular-sized pore openings that, upon exposure of the fertilizer to a moist soil environment, allow for release of plant nutrients to the soil by diffusion. The polymer coating maintains integrity through the growing season and does not “break down” or “crack open” to release nutrients. For a given coating chemistry, the time scale over which fertilizer nutrients are released to the soil depends mainly on temperature and coating thickness both of which affect the rate of solute diffusion through the coating. The right controlled release product or coating thickness can be chosen to best match nutrient release to a given set of growing conditions and the demands of a given crop for nutrients.

For agricultural applications, CRFs can be used to protect fertilizer nitrogen from soil biological processes that transform urea, ammonium ion, or nitrate ion into forms more prone to loss. As long as the nitrogen is held inside the polymer coating, it remains protected. In contrast, SNFs such as anhydrous ammonia, urea, or ammonium nitrate are unprotected and leave the nitrogen completely exposed to soil processes once applied. Approaches to increasing the efficiency of SNFs include split application that involves side-dressing or fertigation, and the use of chemical additives such as urease or nitrification inhibitors.

When used properly, CRFs can be an effective tool for managing N loss and increasing N use efficiency (Trenkel 2010, Shaviv and Mikkelsen 1993). CRFs can also be used to apply all of the fertilizer N needed for an entire growing season in a single application, usually before planting, thereby eliminating the need for split application programs commonly associated with using SNFs. The single application approach is appealing to growers because it removes uncertainty about when side-dress or water-run applications of standard fertilizer can or should be made and reduces costs associated with applying fertilizers. CRFs can also be used to essentially spoon-feed nitrogen to crops to avoid salt burn, unwanted luxury consumption, and excessive vegetative growth all of which are sometimes associated with applying large doses of SNFs.

The most widely available form of controlled released nitrogen for agriculture is ESN® (Environmentally Smart Nitrogen), a form of PCU manufactured by Agrium Advanced Technologies (AAT). As an enhanced efficiency nitrogen fertilizer, ESN has gained widespread adoption in broad-acre agriculture with applications supported by 800-plus site years of data. Annual ESN production has increased from 325,000 tons in 2012 to a projected 500,000 tons in 2013. Production in 2012 represents 1.2 percent of the total annual nitrogen consumed as fertilizer in the United States, which is on average about 12 million short tons. Despite the extra cost of the polymer coating over urea, growers are using ESN to increase profitability. With corn and wheat markets at all-time highs, growers are motivated to avoid N loss and maximize productivity.

For specialty agriculture, the use of controlled release fertilizers has been limited for lack of available information about their effectiveness. In recent years, AAT has funded several research studies exploring applications of PCU, including ESN and Duration Ag®, for vegetable, lettuce, and melon crop production. Replicated studies on cauliflower, watermelon, carrot, and spinach are summarized herein. The results show that PCU applied prior to planting, in which only one application of nitrogen fertilizer is made for the entire growing season, consistently performs as well as or better than split application of SNFs. They also show that, as a nitrogen source, PCU becomes more effective than SNF as N rate decreases. The latter result is important for crop production in environmentally sensitive areas where growers must comply with regulatory demands for nitrogen budgeting and reduced N rates.

METHODS

PCU sources tested. Three sources of PCU were tested including ESN (44-0-0), Duration Ag 45-Day 44-0-0 (D45) and Duration Ag 120-Day 43-0-0 (D120) manufactured by Agrium. At 20°C (68°F), the release times in water of as-manufactured D45, ESN, and D120 are 45, 90, and 120 days, respectively. These values refer to the time at which 80 percent of the urea will be released upon exposure to sufficient moisture. The release times change approximately by a factor of two for each 10°C (18°F) change in temperature. For example, the 80-percent release time of D120 is approximately 60 days at 30°C (86°F) and 240 days at 10°C (50°F).

Cauliflower, watermelon, and carrot. Studies were conducted at either the Yuma or Maricopa Agricultural Centers in Arizona under the direction of Dr. Charles Sanchez (U. Arizona). All studies had the following in common: 1) pre-plant fertilizers were applied to the bed tops and incorporated by roto-mulching; 2) all plots including the check received 30-40 lb N/ac as pre-plant MAP (11-52-0); 3) sprinkler irrigation was used for establishment followed by level (no slope) furrow irrigation; 4) four to five plot replications were used per fertilizer treatment; 5) the plot size was 700 ft^2 or 200 row-feet; 6) marketable yield was determined by harvesting from an area of 20 row-feet within each plot.

Cauliflower was seeded into 42-inch beds on Oct 14 in Yuma and thinned at the 4-leaf stage. Marketable yield was evaluated on Jan 28. The soil texture was a silty clay loam.

Seedless watermelon transplants (cv. Summer Sweet) were mechanically set into 84-inch beds on Feb 25 in Yuma. The pollinator (cv. Summer Flavor) was planted in adjacent beds. Marketable yield was evaluated on five separate pickings from May 25 through Jun 13. The soil texture was a loamy sand.

Carrot (cv. Samantha) was seeded in four lines on elevated 40-inch beds on Jan 6 in Maricopa and thinned to approximately 210,000 plants per acre. Harvest was conducted at maturity on May 15 and yields of grades US#1 and US#2 carrot were determined. The soil texture was a loam.

Spinach. Studies were conducted in Salinas, CA under the direction of Richard Smith (U. California Cooperative Extension). Spinach (Missouri) was planted into 80-inch beds on May 1 in a commercial production field under sprinkler irrigation. Harvest was conducted on Jun 4. The soil texture was a sandy loam. Pre-plant fertilizers were applied to bed tops on Apr 27 followed by roto-mulching. Top-dress fertilizers were applied to bed tops either immediately after planting or on May 21 followed by irrigation. Plot sizes of 15 row-feet were replicated 4 times per treatment in a RCBD. An area of 5.4 ft^2 per plot was harvested for yield analysis.

RESULTS AND DISCUSSION

Cauliflower. ESN and D120 were chosen for testing on cauliflower based on an average soil temperature of 60°F over a 110-day growing season starting Oct 14 (warm → cool). D120 was blended with ESN in various proportions to determine whether a longer release time would improve crop performance. A simulated grower practice involving two side dressings of UAN32 applied mechanically on Nov 13 and Dec 2 (one-half each) was used for comparison against pre-plant PCU applied on Oct 11.

Table 1. Cauliflower yield and soil nitrate-N at harvest (in parentheses) as affected by N rate and N source (Yuma, AZ).

Total N applied (lb/A)	Marketable Yield (ton/A); Check = 3.7 ton/A Soil nitrate-N at harvest (ppm); Check = 11.5 ppm			
	sd-UAN32	pp-ESN	pp-3/1 ESN/D120	pp-1/1 ESN/D120
107	4.9 (15.4)	5.5 (26.9)	5.7 (40.4)	5.2 (17.3)
174	6.0 (13.5)	6.4 (26.9)	6.1 (30.8)	5.5 (11.5)
Yield: N rate (Q**); N source ($LSD_{0.05}$ = x ton/A) Soil nitrate-N: N rate (ns); N source ($LSD_{0.05}$ = 23.3 ppm)				

Table 1 lists marketable cauliflower yields according to N rate and N source. Applied N caused a significant increase in yield over the check which utilized 40 lb N/A from MAP. Yield followed a quadratic response to N rate ($P < 0.01$), but was not significant with N source at the 0.05 level. However, at both N rates, pp-ESN and pp-3/1 ESN/D120 gave higher yields than sd-UAN32. ESN produced, on average, a 9% increase in yield over that of sd-UAN32. Among the PCU sources tested, a trend towards increasing yield with increasing fraction of ESN was observed. With cool soil temperatures late in the growing season, N release from D120 extends well beyond 120 days and the 110-day growing season. Thus D120 may not be suitable due to slow release. ESN is preferred over D120 for fall-planted cauliflower in Yuma.

Table 1 also lists the level of residual soil nitrate in the upper foot of plots at harvest (values given in parentheses). A trend showing increased residual soil nitrate with increasing ESN usage can be seen in the data. Such a result implies that the pp-ESN program is more effective than the sd-UAN32 program for maintaining available nitrogen in the upper soil profile or root zone.

Watermelon. ESN and D120 were chosen for testing on watermelon based on an average soil temperature of 73°F over a 105-day growing season beginning Feb 25 (cool → warm). Given the warm temperatures, D120 and a 3/1 D120/ESN blend were tested. ESN was included as a means of providing more early season N than D120 alone. A simulated grower practice involving three applications of urea in which the urea was applied pre-plant and in two side dressings on Apr 13 and May 2 (one-third each by hand shortly before irrigation) was compared against pre-plant PCU applied Feb 21.

Table 2. Seedless watermelon yield and soil nitrate-N at harvest (in parentheses) as affected by N rate and N source (Yuma, AZ).

Total N applied (lb/A)	Marketable Yield (ton/A); Check = 11.1 ton/A Soil nitrate-N at harvest (ppm); Check = 21.3 ppm		
	sd-Urea	pp-D120	pp-3/1 D120/ESN
174	20.0 (13.8)	27.3 (169)	23.5 (34)
307	25.3 (17.5)	30.3 (100)	28.3 (31)
Yield: N rate (L**Q**); N source ($LSD_{0.05}$ = 7.4 ton/A) Soil nitrate-N: N rate (ns); N source ($LSD_{0.05}$ = 123 ppm)			

Table 2 lists marketable watermelon yields according to N rate and N source. A significant response to applied N was observed as revealed by low yields in the check plot which included 40 lb N/A from MAP. Yield followed both a linear and quadratic response to N rate. For a given N rate, there were no significant differences in yield due to N source at the 0.05 level. However, yields for the PCU treatments were consistently higher than for sd-urea at both N rates. A trend can also be seen towards improved performance from D120 at lower N rates where yield is more sensitive to N loss. Based on the results, pp-D120 is the preferred fertilizer source for spring-harvested watermelon producing, on average, a 27% increase in yield over sd-urea.

Soil nitrate-N at harvest was higher for D120 compared to all other sources tested (see Table 2). D120 provided the nitrate-N needed to maintain yields over multiple harvests and gave the highest yields in initial pickings.

Carrot. ESN and D120 were chosen for testing on carrot based on an average soil temperature of 62°F over a 130-day growing season beginning Jan 6 (cool → warm). D120 was blended with ESN in various proportions to determine whether a longer release time would improve crop performance. A simulated grower practice involving three applications of urea in which the urea was applied pre-plant and in two side dressings on Mar 25 and Apr 26 (one-third each by hand shortly before irrigation) was compared against pre-plant PCU applied Jan 4.

Table 3 lists fresh market carrot yields according to N rate and N source. A significant response to supplemental N was observed as shown by lower yields in the check which included 31 lb N/A from MAP. US#1 grade carrot yields were significantly higher using any of the three PCU treatments compared to split application of urea. On average, US#1 yields increased by 64% when using PCU over sd-urea. The trends for US#2 carrot yields were generally reversed indicating that PCU increased the proportion of US#1 grade carrots. US#2 grade carrots have a much lower market value. All PCU treatments performed similarly, although at the low N rate (120 lb N/A) the 1/1 ESN/D120 treatment was superior to the other PCU treatments.

Table 3. Carrot yields and levels of soil nitrogen at harvest as affected by N source and total N rate (Maricopa, AZ).

N rate (lb/A)	N Source	Yield US#1 (ton/A)	Yield US#2 (ton/A)	NH_4^+-N (ppm)	NO_3^--N (ppm)
31 (MAP)	Check	5.9	5.2	3.6	4.5
120	Urea	9.3	5.1	13.5	11.7
210	Urea	10.7	4.9	10.9	8.9
120	ESN	13.8	4.1	3.4	5.2
210	ESN	17.4	3.3	3.2	5.4
120	3/1 ESN/D120	13.9	4.0	3.2	4.3
210	3/1 ESN/D120	17.8	2.4	3.2	6.2
120	1/1 ESN/D120	17.2	3.5	3.2	4.1
210	1/1 ESN/D120	18.2	3.2	3.9	9.0
N Rate		L**Q*	L*	ns	ns
N Source LSD$_{0.05}$		2.0	1.1	1.8	2.7

Interestingly, residual exchangeable ammonium and soluble nitrate after harvest were higher for the urea treatments compared to the PCU treatments (Table 3). At 210 lb N/A, a trend towards increasing nitrate levels with increasing proportion of D120 in the PCU treatments reflects extended N release from D120. For the PCU treatments at 120 lb N/A, the increase in US#1 yield for 1/1 ESN/D120 reflects that extended release from D120 may provide a benefit over ESN and may be more important at lower N rates.

Spinach. Due to cool soil temperatures and the short cropping season (35 days), only D45 was evaluated as a PCU source for spinach. D45 has a slightly lower coating weight than ESN. All PCU treatments were compared against the grower practice which included a pre-plant application of a urea-ammonium sulfate blend followed by a top-dress application of ammonium sulfate two weeks prior to harvest.

Table 4. Spinach data. Yield and tissue N were evaluated on Jun 4, 33 days after germ water was applied (May 2).

Total N Rate (lb/A)	Fertilizer Treatment†	Yield (fresh tons/A) LSD$_{0.05}$ = 2.2 P < 0.0001	Tissue N (lb/A) LSD$_{0.05}$ = 13.4 P < 0.0001	Soil N (ppm) NO_3^- (NH_4^+)		
				May 16	May 23	Jun 6
Check	None	6.8 d	43.1c	11.9 (3.0)	8.2 (9.2)	2.6 (2.3)
120	1. 120 pp-D45	14.3 ab	136.5a	28.6 (5.6)	29.6 (9.2)	5.3 (4.7)
120	2. 80 pp-D45 40 ap-AMS	13.1 bc	117.8b	27.4 (11.6)	32.4 (11.6)	5.8 (2.8)
160	3. 80 pp-D45 80 ms-AMS	15.9 a	136.7a	21.0 (7.3)	23.9 (36.5)	6.1 (9.2)
160	4. 80 ap-D45 80 ms-AMS	12.3 bc	102.0b	18.2 (15.2)	16.7 (52.7)	5.5 (12.4)
160	5. 80 ap-AMS 80 ms-AMS	13.1 b	108.9b	26.5 (22.0)	19.0 (86.8)	3.1 (23.2)
182 Grower	6. 87 pp-AMS/U 95 ms-AMS	12.7 bc	106.3b	22.9 (7.4)	18.8 (24.5)	4.6 (8.6)

†Values represent N rates in lb/A. Abbreviations: pp = pre-plant incorporated (Apr 27); ap = at-planting top-dress (May 1); ms = mid-season top dress (May 21); D45 = Duration Ag 45-day 44-0-0; AMS = ammonium sulfate (21-0-0); U = urea (46-0-0)

Table 4 shows the effects of various fertilizer treatments on yield, tissue N, and soil N. Yield, tissue N, and soil nitrate-N were highest for treatments in which D45 was incorporated into the soil prior to planting (pp-D45). When applied at 120 lb N/A, pp-D45 (trt#1) gave a 13 percent yield increase over the grower program which used 182 lb N/A (trt#6) or 62 lb/A additional N. When applied in combination AMS top-dressed two weeks before harvest, ppD45 gave a 25 percent increase in yield over the grower program (trt#3). A top-dress application of D45 made at planting was significantly less effective than pp-D45 (compare trt#3 and trt#4). An additional treatment that utilized ammonium sulfate only (trt#5) gave similar yields to the grower practice. The results imply that spinach growers can maintain productivity at reduced N rates by utilizing pp-D45. Further studies are needed to optimize N rates.

Levels of root zone soil nitrate-N at critical stages of crop development were maintained above 20 ppm through the growing season by using ppD45 (Table 4). Soil ammonium levels on May 23 were elevated due to ammonium sulfate applications on May 21. The results show that pp-D45 is more effective than standard N sources for maintaining available nitrogen in the root zone of shallow-rooted crops such as spinach.

SUMMARY

A large portion of the cool season leafy greens and vegetable crops produced in the United States during the fall-winter-spring months are grown in the low desert region of southern Arizona and southern California. Relatively large areas are also under production in the adjacent states of Sonora and Baja, Mexico. In summer months, production shifts to the central coast region of California. Nitrogen is the nutrient most limiting to crop production in these areas. Due to rigid produce quality standards enforced by the market, vegetable crops receive appreciable amounts of N fertilizer for optimal yield and quality. Excess N is often used as insurance against N loss. There is concern that over-fertilization of crops in Arizona and California may be contributing excess amounts of nitrate to ground water. As a result, regulations aimed at controlling or reducing N inputs have become a reality in some areas. In order to comply with regulations, growers will need to use less N and, at the same time, maintain productivity to remain competitive. As part of the approach to managing N loss, controlled release nitrogen should not be overlooked as an option. The studies summarized here indicate that PCU becomes more effective than SNF as N rate decreases or where yield is more sensitive to N loss. PCU should be further explored as a means of managing N loss at reduced N rates where the economics for PCU usage are more favorable.

In addition to the benefits of PCU as an enhanced efficiency fertilizer, PCU can also be used to simplify fertilizer applications and spoon-feed nitrogen to crops. The studies summarized here consistently demonstrate that PCU can be used to apply all of the nitrogen needed for an entire growing season in a single, pre-plant application without any tradeoff in yield or quality compared to simulated grower practices employing split application of SNF.

REFERENCES

Shaviv, A. and R.L. Mikkelsen. 1993. Controlled-release fertilizers to increase efficiency of nutrient use and minimize environmental degradation- A review. *Fertilizer Research* **35**: 1-12.

Trenkel, M.E. 2010. Slow- and Controlled-Release and Stabilized Fertilizers: An Option for Enhancing Nutrient Use Efficiency in Agriculture. *International Fertilizer Industry Association*, Paris, France.