

# Evaluation of Polyolefin-coated Urea for Potato Production on a Sandy Soil

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*Additional index words.* *Solanum tuberosum*, polyolefin-coated urea, controlled-release fertilizer, economic analysis

**Abstract.** Field studies were conducted on a Hubbard loamy sand (sandy, mixed, frigid Entic Hapludoll) during 1996 and 1997 at Becker, Minn., to evaluate the effect of a polyolefin-coated urea (POCU) fertilizer (Meister, Chisso Co., Japan) on yield and quality of irrigated ‘Russet Burbank’ potatoes (*Solanum tuberosum* L.). The POCU was a 3:1 mixture of 70-day and 50-day release formulations, respectively, based on historical soil temperatures at the site. The study compared five banded nitrogen (N) rates (110, 155, 200, 245, and 290 kg·ha<sup>-1</sup> N) as a split application of urea applied at emergence and hilling, vs. POCU applied at planting. All plants received an additional 30 kg·ha<sup>-1</sup> N as monoammonium phosphate band-applied at planting. Yields were higher in 1996 because of cooler temperatures and poor tuber set in 1997. Total and marketable yields averaged, respectively, 3.9 and 3.3 Mg·ha<sup>-1</sup> higher with POCU than with urea. Total yield was not affected by rate of N application regardless of source, but marketable yield increased linearly with N rate. The yield of marketable tubers larger than 170 g increased linearly with N rate in both years. Gross return was 10% higher with POCU than with urea, but estimated net return showed a significant source × N rate interaction. The net return increased by \$3.13 per kg of urea-N applied, but there was no significant change across POCU application rates.

In the upper midwestern United States, the potato is often grown on glacial outwash soils that are generally infertile, with low water-holding capacity and rapid drainage. Nitrogen and water requirements of the crop are met through high rates of N fertilizer application and sprinkler irrigation. These factors, together with the shallow root system of potato plants and unpredictable rainfall, can lead to significant leaching of nitrate (NO<sub>3</sub><sup>-</sup>) to shallow groundwater.

Current practices to minimize NO<sub>3</sub><sup>-</sup> leaching in potato production involve split-application of soluble N fertilizers, with a small fraction of the total N requirement applied at or before planting. Subsequent applications are usually split at emergence and hilling, with later applications based on petiole analysis (Errebhi et al., 1998a, 1998b). However, because of the high N and water requirements of the potato and the use of highly soluble N fertilizers, controlling NO<sub>3</sub><sup>-</sup> leaching is difficult.

Another approach that merits further investigation is use of controlled release fertilizers (CRF). Previous studies with potatoes,

however, have generally resulted in lower yields with CRF than with soluble N sources (Maynard and Lorenz, 1979; Waddell et al., 1999). Lorenz et al. (1972, 1974) reported lower yields of ‘White Rose’ potatoes with sulfur-coated urea (SCU) and ureaform than with ammonium sulfate. Cox and Addiscot (1976) reported similar results for ‘Pentland Crown’ potatoes; yields with SCU were lower than those obtained with calcium nitrate. For ‘Russet Burbank’ potatoes, Liegel and Walsh (1976) found that SCU was a better N source than urea only in cases where severe leaching occurred. In general, however, yields with urea were higher than with SCU under normal soil moisture conditions. Based on these studies, Maynard and Lorenz (1979) concluded that N release rates from conventional CRFs such as SCU or ureaform are too slow to meet the N demand of the potato plant early in the growing season. In addition, late season release of N from CRFs cannot substitute for retranslocation of high internal N concentrations from early season uptake. Under Minnesota conditions, Rosen et al. (1992, 1993) found that ≈70% to 80% of the N uptake by ‘Russet Burbank’ potatoes occurs between 20 and 60 d after emergence. Having N available for uptake during this period is therefore critical. If N is available too early in the season, it may be lost by leaching before uptake by the crop; if N is available too late it may not be used efficiently for tuber production. These studies suggest that some soluble N fertilizer may be needed along with a CRF at planting to meet early potato N needs.

Recently, several new controlled-release N fertilizer products have been developed (Trenkel, 1997). The new products are coated

with polymers that allow N release to be synchronized better with crop N demands than when conventional CRFs are used. Release of N from polyolefin-coated urea (POCU) is primarily influenced by soil temperature (Gandeza et al., 1991). Since plant growth is also temperature-dependent, a more synchronous relationship between N demand and availability may be attained during the season. Use of such fertilizers may be an efficient means to maximize N use efficiency and minimize NO<sub>3</sub><sup>-</sup> losses. Results from recent studies demonstrated that polyolefin-coated (POC) CRF not only improved N use efficiency of corn (Shoji et al., 1991), but also decreased NO<sub>3</sub><sup>-</sup> leaching (Alva, 1992; Wang and Alva, 1996). The influence of these newer CRFs on irrigated potato yield has not been documented. The objectives of this research were to: 1) determine the effects of POCU fertilizer on potato yield and quality; and 2) evaluate the economics of using POCU vs. soluble urea as the N source.

## Materials and Methods

Field studies were conducted during 1996 and 1997 at the Univ. of Minnesota Sand Plain Research Farm in Becker, Minn., on a Hubbard loamy sand (sandy, mixed, frigid Entic Hapludoll). During each year prior to establishment of the experiment, rye (*Secale cereale* L.) was grown without fertilizer N in the experimental field to minimize the potential effects of residual profile NO<sub>3</sub><sup>-</sup>-N on crop response to N treatments. The experiment each year was conducted in a different field, but on soils with similar properties. Soil samples were collected from the surface 15 cm each spring for initial soil test analyses before treatment. Residual soil NO<sub>3</sub><sup>-</sup>-N was determined in composite samples taken to a depth of 60 cm. After drying at 35 °C and grinding to pass a 2-mm sieve, the soil samples were analyzed for pH (Thomas, 1996), organic matter content (Nelson and Sommers, 1996), extractable phosphorus (Bray P1) (Kuo, 1996), and exchangeable potassium (Knudsen et al., 1982). Nitrate-N in the samples was measured conductimetrically after extraction with 2 M KCl (Carlson et al., 1990). Selected soil chemical properties in the 0–15-cm depth prior to planting averaged: pH, 6.7; organic matter, 2.1%; Bray P1, 36 mg·kg<sup>-1</sup>; and exchangeable K, 137 mg·kg<sup>-1</sup>. Nitrate-N in the top 60 cm was 12 kg·ha<sup>-1</sup> in 1996 and 20 kg·ha<sup>-1</sup> in 1997.

The test cultivar was ‘Russet Burbank’, an indeterminate cultivar maturing in ≈120–130 d, and the one most widely grown for potato processing in the upper Midwest. Cut “A” size seed potatoes were planted by hand the third week in April each year. Each plot received standard basic fertilization recommended for ‘Russet Burbank’ potatoes in the area (Rosen and Eliason, 1996). One week prior to planting each year, 225 kg·ha<sup>-1</sup> potassium-magnesium sulfate and 225 kg·ha<sup>-1</sup> potassium chloride were broadcast and incorporated. At planting, monoammonium phosphate and additional potassium fertilizer were banded 7.5 cm to the side and 5 cm below each seed

Received for publication 25 Apr. 2000. Accepted for publication 10 Aug. 2000. We thank Michael P. Russelle and Satish C. Gupta for their helpful comments on an earlier draft of the manuscript. This study was supported by Helena Chemical Co. (USA) and Chisso Co. (Japan). The cost of publishing this paper was defrayed in part by the payment of page charges. Under postal regulations, this paper therefore must be hereby marked *advertisement* solely to indicate this fact.

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piece to supply 30, 55, 166, 20, and 40 kg-ha<sup>-1</sup> of N, P, K, Mg, and S, respectively. The preweighed fertilizers were carefully applied at row opening using a precalibrated, tractor-drawn applicator.

Two sources of N were evaluated at five rates of application. The sources were urea (46-0-0) and POCU (40-0-0), which is a CRF. The CRF was a 3:1 mixture, based on historical soil temperatures at the site, of 70-d (75%) and 50-d- (25%) release POCU formulations. The formulations are so-named because, when immersed in water at 25 °C according to the standard test procedure, they release 80% of their N in 70 and 50 d, respectively (Shoji and Gandeza, 1992). Since the polyolefin coating material is thermoplastic, release rate and duration vary with soil temperature. The N rates were 110, 155, 200, 245, and 290 kg-ha<sup>-1</sup>, in addition to the 30 kg-ha<sup>-1</sup> N applied at planting to all plots. All urea at each rate was added in two equal split applications at emergence (last week in May) and hilling (second week in June), according to conventional practice in the region. All POCU N was applied at planting along with the starter fertilizer. Both fertilizers at all rates were applied in a double band, as described above for the basic fertilization (Rosen and Eliason, 1996). Weeds, pests, and diseases were controlled using standard practice (Hutchison, 1996). Irrigation water requirements to supplement rainfall were scheduled according to the checkbook method (Wright and Bergsrud, 1991) to maintain a soil moisture deficit of 25 mm or less during the vegetative growth stage and 14 mm or less during tuber bulking. Rainfall and air temperature data were collected from a weather station located near the experimental plots.

Treatments were laid out in a 2 × 5 factorial consisting of two sources of N and five rates of application in a randomized complete-block design with four replications. Each plot was 6 m in length and 4 rows wide, the middle two rows of which were harvest rows. Spacing was 25 cm in the row and 90 cm between rows.

Vines in the harvest rows were chopped 2 weeks before final tuber harvest to allow for sufficient time for tubers to set skin. Potato tubers were harvested the third week in September, using a one-row, tractor-drawn mechanical digger from the full length of the two harvest rows (minus the two border plants in each row). The tubers were size-graded and weighed for total and graded yield. Marketable yield was calculated by subtracting misshapen (cull) and undersized (<85 g) tuber yields from the total yield. A 25-tuber sample was taken from each plot to determine hollow heart incidence and specific gravity. Hollow heart was assessed after cutting the sample tubers in half. Tubers with incipient (brown center) or fully developed hollow heart at least 1.25 cm in diameter were counted and the data were expressed as a percentage of all tubers assessed per plot. Specific gravity was measured using the hydrometer method (Snack Food Association, Alexandria, Va.).

Data were compared using analysis of variance (ANOVA) procedures, and N rate main effects and interactions were partitioned into

linear and quadratic components. Statistical analyses were performed using SAS version 6.12 (SAS Institute, 1990). Combined analysis was performed across years for all parameters. Replicates and years were treated as random effects in the analysis. Main effects and interactions were considered significant if  $P \leq 0.10$ .

## Results and Discussion

**Weather.** The 1996 season was slightly cooler in April than the long-term average, but the remainder of the growing season was close to the average for the region (Table 1). Rainfall was above average in May, with over one-half occurring during the third week in May, but slightly below the long-term average for the region for the remainder of the season. The 1997 season was characterized by cool and dry conditions until mid-June followed by a wet and warm July and a dry and warm August and September. Irrigation water totaling 320 mm in 1996 and 269 mm in 1997 was applied to supplement the rainfall. Based on water balance calculations, there were two major leaching events (>5 cm water within a 48-h period) in 1996 occurring at about 20 and 50 d after emergence, and three major leaching events in 1997 occurring at ≈40, 50, and 75 d after emergence.

**Tuber yield.** Total tuber yield, averaged across N sources and rates, was significantly higher in 1996, probably because of cooler growing conditions and poor tuber set in 1997 (Table 2). Total yield was 3.9 Mg-ha<sup>-1</sup> greater with POCU than with urea. Similar effects of cropping year and N source were observed for marketable yield (i.e., yield of tubers >85 g minus culls) and yield of tubers in the 170–340-g and >340-g size grades. The percentage of marketable yield that graded into the >170-g category was similar for both N sources in 1996 (mean = 62.6%) but significantly higher with POCU (73.4%) than with urea (68.3%) in 1997. This yield category is important because premiums are awarded or penalties imposed depending on the percentage of the marketable yield that falls in the >170-g category, as discussed in the economic analysis below.

Yield results obtained in this study suggest better N use efficiency with POCU than with urea. This, in turn, could reduce loss of N through leaching.

Trend analysis of the data revealed significant linear relationships between rate of N

application and all yield parameters except total and cull tuber yields (Table 2). Yield of undersized (≤85 g) and medium-sized (85–170 g) tubers decreased 8.47 ( $r^2 = 0.95$ ,  $P \leq 0.01$ ) and 2.07 kg-ha<sup>-1</sup> N ( $r^2 = 0.99$ ,  $P \leq 0.01$ ), respectively, whereas yield of large (170–340 g) and jumbo (>340 g) tubers increased 1.02 ( $r^2 = 0.68$ ,  $P \leq 0.1$ ) and 2.27 kg-ha<sup>-1</sup> N ( $r^2 = 0.85$ ,  $P \leq 0.05$ ), respectively, as additional N rate increased from 110 to 290 kg-ha<sup>-1</sup> (Table 3). However, the linear trend differed between years ( $P \leq 0.01$ ) for marketable tubers larger than 170 g (Table 3). In 1996, yield in this category increased 0.076%/kg N, whereas the increase was 0.029%/kg N in 1997. In both years, these yield increases were significant at  $P = 0.01$ .

These results corroborate earlier reports that positive N responses usually involve higher rates of N application increasing the proportion of total yield in the large size categories while reducing that in the small size grades (Moorby, 1967; Waterer, 1997). The quadratic component of response to rate of N as either urea or POCU was not significant for any of the yield parameters.

Note that although the total yield was lower in 1997, the percentage of the yield in the >170-g size grade was higher than that obtained in 1996, suggesting that tuber set, which was not measured in this study, may have been poor in 1997. This is consistent with reports cited by Vos (1999), which indicate that mean tuber set is inversely related to the number of tubers set per plant.

Our yield results differ from the negative responses reported with SCU, nitroform, and IBDU in previous studies (Elkashif et al., 1983; Lorenz et al., 1972, 1974). Several reasons may be offered for this difference. First, POCU used in the current study was designed to release N at a faster rate than SCU, nitroform, and IBDU. Second, a small amount of soluble N (30 kg-ha<sup>-1</sup>) was used in all treatments in this study to ensure adequate early growth. Third, Lorenz et al. (1972, 1974) used a 100-d cultivar, compared with the 120–130-d cultivar used in the current study, which allowed a longer period for N release and subsequent uptake by the crop. Finally, the soil in this study had a coarser texture and was therefore more susceptible to leaching losses, giving the CRF an advantage over the more leachable soluble form. In another study, Liegel and Walsh (1976) reported better yields with SCU than with urea only when leaching prevailed during part of the growing season.

Table 1. Mean monthly rainfall and air temperature data for the 1996 and 1997 growing seasons and the 30-year mean at Becker, Minn.

Month	Rainfall			Temp		
	1996	1997	30-year mean <sup>2</sup>	1996	1997	30-year mean <sup>2</sup>
	mm			°C		
April	32	13	61	4.2	5.6	6.4
May	106	43	87	13.4	11.0	13.3
June	82	62	115	20.8	21.3	18.2
July	101	245	98	20.5	22.2	21.2
August	62	113	102	21.6	20.1	19.5
September	40	38	86	16.3	17.4	14.1

<sup>2</sup>Average for the 30-year period 1961–90.

Table 2. Effect of source and rate of N application on 'Russet Burbank' potato tuber grade, yield, and quality.

Variable	Tuber grade (g)					Total yield	Marketable yield	Specific gravity	Hollow heart	
	Culls	<85	85–1700	170–340	>340					
Year	Mg·ha <sup>-1</sup>					%				
1996	2.2	7.8	19.4	24.3	8.7	62.4	52.4	62.6	1.0911	22.9
1997	2.9	5.1	11.8	18.6	10.3	48.8	40.7	70.8	1.0877	15.8
N source										
Urea <sup>a</sup>	2.2	6.5	15.7	20.9	8.3	53.6	44.9	65.3	1.0893	20.2
POCU <sup>a</sup>	2.9	6.4	15.6	22.0	10.6	57.5	48.2	68.1	1.0895	18.5
N rate (kg·ha <sup>-1</sup> )										
110	2.3	7.2	17.6	20.6	7.2	55.0	45.4	61.8	1.0900	16.0
155	2.7	6.9	16.5	20.6	8.2	54.9	45.2	63.8	1.0888	20.0
200	2.3	6.2	15.4	22.2	10.7	56.7	48.2	68.2	1.0899	20.3
245	2.6	6.1	14.8	21.4	10.0	54.9	46.2	68.5	1.0889	19.2
290	2.9	5.8	13.8	22.5	11.4	56.4	47.8	71.4	1.0891	21.1
ANOVA	<i>P</i> > <i>F</i>									
Year (Yr)	0.28	<0.01	<0.01	<0.01	0.09	<0.01	<0.01	0.01	0.04	0.08
Source (So)	<0.01	0.85	0.90	0.05	<0.01	<0.01	<0.01	<0.01	0.65	0.42
Rate	0.48	<0.01	<0.01	0.07	<0.01	0.61	0.15	<0.01	0.38	0.59
Linear	0.23	<0.01	<0.01	0.02	<0.01	0.40	0.09	<0.01	0.32	0.22
Quadratic	0.73	0.62	0.65	0.95	0.33	0.90	0.73	0.55	0.70	0.53
So × Rate	0.24	0.22	0.47	0.44	0.77	0.61	0.37	0.58	0.45	0.52
Yr × So	0.78	0.24	0.06	0.62	0.34	0.56	0.82	0.04	0.88	<0.01
Yr × Rate	0.42	0.18	0.11	0.17	0.10	0.69	0.50	0.03	0.89	0.66
Yr × So × Rate	0.23	0.13	0.19	0.48	0.24	0.62	0.73	0.10	0.73	0.39

<sup>a</sup>Expressed as percentage of marketable yield (i.e., yield of tubers >85 g minus culls).

<sup>b</sup>Split equally between emergence and hilling.

<sup>c</sup>Applied in a single application at planting.

**Tuber quality.** Both specific gravity and internal tuber disorder, averaged across N sources and rates, were higher in 1996 than in 1997 (Table 2). However, year × source interaction was significant for hollow heart, with incidence of the disorder remaining the same in both years when POCU was applied, while it decreased from 28% in 1996 to 13% in 1997 with urea application. This interaction is not easily explained. Hollow heart and specific gravity were not affected by N rate (Table 2).

Since 'Russet Burbank' potatoes in the upper Midwest are grown primarily for processing, high specific gravity is desirable. In the present study, specific gravity averaged 1.0911 in 1996 and 1.0877 in 1997, and was within the range (1.071 to 1.090) considered normal for most types of potatoes (Curwen et al., 1982; Martin et al., 1993).

**Economic considerations.** For economic analysis, the price of marketable potato tubers was assumed to be \$0.10/kg. The price of urea was set at \$0.55/kg N and that of POCU at \$3.75/kg N (Trenkel, 1997). The application cost was assumed to be \$22.00/ha per application. In accordance with current standard market practice, a premium of \$0.10 per 100 kg was awarded for each percentage point above 60% with respect to yield of tubers larger than 200 g (percentage of marketable yield). Conversely, a penalty of \$0.11 per 100 kg was imposed for each percentage point below 55%. Net return was calculated based on the cost of the N fertilizer plus its application and the gross value of the potato crop.

At equivalent N rate, estimated returns were higher in 1996 than in 1997 (Table 4). Gross return, averaged across years and rates, was 10% higher with POCU than with urea ( $P \leq 0.01$ ). This is consistent with marketable yield and the yield of tubers larger than 170 g, which showed similar responses to POCU.

Gross and net return increased \$5.48 and \$3.33/kg N, respectively, in 1996 but showed no significant response to N application in 1997 (Table 5). Responses (slope coefficients) of both returns to N rate differed for 1996 and 1997 ( $P = 0.04$  for both gross and net return), and for urea and POCU (Table 5). With urea, net return increased linearly with N rate (\$3.13/kg N), but there was no significant change across POCU application rates.

In the absence of regulatory limits for N application, soluble urea would be the source of choice because of higher net return at the higher N rates. However, this analysis does not take into account the environmental costs due to potentially higher NO<sub>3</sub><sup>-</sup> leaching associated with urea than with POCU. With better economic conditions, such as higher prices for potatoes or lower costs for POC fertilizers, and if government regulation sets N application at lower rates to reduce NO<sub>3</sub><sup>-</sup> loss, the situation might shift in favor of POC fertilizer use.

Table 3. Effect of cropping year on the linear response of 'Russet Burbank' tubers >170 g to N application.

N rate (kg·ha <sup>-1</sup> )	Marketable tubers >170 g <sup>a</sup>	
	1996	1997
	%	
110	55.1	68.6
155	58.6	69.0
200	65.4	71.5
245	64.7	71.6
290	69.1	73.6
Regression		
Intercept	47.5	65.2
Slope	0.0756	0.0289
r <sup>2</sup>	0.92**	0.94**

<sup>a</sup>Expressed as percentage of marketable yield (i.e., yield of tubers >85 g minus culls).

\*\*Significant at  $P \leq 0.01$ .

Results obtained in this study corroborate recent findings on the economics of using multinutrient CRFs, including POC fertilizers, in citrus production (Obreza et al., 1999). Obreza et al. (1999) concluded that the use of CRFs alone is not economical unless it is combined with conventional fertilizer application, or the cost of coating CRFs decreases.

Table 4. Economic analysis of POCU and urea N applications for irrigated Russet Burbank potatoes.

Variable	Gross return	Net return <sup>a</sup>
Year	\$/ha	
1996	4980	4500
1997	4080	3610
N Source		
Urea <sup>b</sup>	4320	4150
POCU <sup>c</sup>	4740	3970
N Rate (kg·ha <sup>-1</sup> )		
110	4230	3950
155	4290	3910
200	4840	4380
245	4520	3920
290	4810	4140
ANOVA	<i>P</i> > <i>F</i>	
Year	0.01	0.01
Source	<0.01	0.05
Rate	<0.01	0.11
Source × rate	0.34	0.04
Year × source	0.75	0.75
Year × rate	0.09	0.09
Year × source × rate	0.65	0.65
Contrasts		
N rate linear	<0.01	0.21
N rate quadratic	0.43	0.43
Source × linear N	0.55	0.01
Source × quadratic N	0.97	0.97
Year × linear N	0.01	0.01
Year × quadratic N	0.77	0.77

<sup>a</sup>Net return = gross return minus fertilizer N cost minus cost of N application.

<sup>b</sup>Split equally between emergence and hilling.

<sup>c</sup>Applied in a single application at planting.

Table 5. Linear response of gross and net returns from irrigated 'Russet Burbank' potatoes as affected by year and N source.

N rate (kg-ha <sup>-1</sup> )	Gross return		Net return <sup>z</sup>			
	1996	1997	1996	1997	Urea <sup>y</sup>	POCU <sup>x</sup>
110	4490	3971	4209	3690	3948	3951
155	4576	3994	4199	3617	3729	4087
200	5289	4321	4815	3889	4533	4099
245	5156	3958	4532	3387	4234	3745
290	5430	4187	4762	3520	4400	3882
Regression						
Intercept	3893	3904	3849	3860	3543	4166
Slope	5.48	0.88	3.33	-1.27	3.13	-1.07
r <sup>2</sup>	0.83*	0.17 <sup>ns</sup>	0.64 <sup>++</sup>	0.30 <sup>ns</sup>	0.46 <sup>++</sup>	0.26 <sup>ns</sup>

<sup>z</sup>Net return = gross return minus fertilizer N cost minus cost of N application.

<sup>y</sup>Split equally between emergence and hilling.

<sup>x</sup>Applied in a single application at planting.

<sup>ns</sup>, <sup>++</sup>, <sup>ns</sup> Nonsignificant or significant at  $P \leq 0.1$  or  $0.05$ , respectively.

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