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Kidney bean (*Phaseolus vulgaris* L.) production on an irrigated, coarse-textured soil in response to polymer coated urea and tillage: I. Grain yields, disease severity, and a simple economic analysis

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ABSTRACT

Kidney beans (*Phaseolus vulgaris* L.) in Minnesota are commonly grown on irrigated, coarse-textured soils that are susceptible to nitrate leaching. A dense Bt layer that is present in these soils restricts root growth and may increase severity of *Fusarium* root rot. Anecdotal evidence from local growers suggests that breaking up the Bt layer reduces the impact of root rot. This study was conducted to assess different tillage depths and the use of polymer coated urea (PCU, Agrium U.S. Inc. and WSPCU, Specialty Fertilizer Products) on grain yields, net monetary returns and disease severity. The study was conducted over three years as a split plot design. Whole plots were deep and shallow tillage (chisel plowed to an average of 47 and 29 cm, respectively) while N treatments were subplots. Three rates of PCU applied at emergence were compared with equivalent rates of urea split applied at emergence and prebloom. Also, one rate of each source, including WSPCU, was applied at planting and a 0 N control was included. Differences between tillage depths were not found. Disease severity was not significantly affected by tillage depths or N treatment. Emergence applied PCU resulted in lower grain yields and monetary returns than split urea applications. PCU applied at planting, however, resulted in similar yields and monetary returns compared with split and planting urea, which suggests a more optimal N regime for kidney bean production. Planting applied WSPCU also resulted in similar yields and net returns as planting applied urea.

Keywords: kidney bean, polymer coated urea, nitrogen rate, tillage, disease severity, yield and economic analysis.

INTRODUCTION

Dry edible beans are an important agronomic crop in the United States. Minnesota, one of the top five bean producing states in the country, is currently the leading producer of dark red kidney beans (*Phaseolus vulgaris* L.) (NASS, 2004). In 2007, approximately 59 thousand hectares of beans were harvested in the state (NASS, 2007). Dry bean production is comparatively new to Minnesota, relative to other bean producing areas, with large scale production beginning in the 1970s (McMartin et al., 1982). Dry beans are typically grown in areas with well drained soils, although irrigation is often needed to ensure that 2.5-3.8 cm of water every 4-5 days are provided (Egel et al., 2008). Dry beans are a short season crop, with plants typically reaching maturity in 90 - 100 days, depending on the variety. In Minnesota, the crop is sown in late May and harvested in early September.

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Dry beans have special management needs due to their limited ability to fix nitrogen and high susceptibility to disease. A symbiotic relationship with *Rhizobium phaseoli* allow dry beans to fix nitrogen, although as a species they are poor at it compared with other legumes (Piha and Munns, 1987). For instance, on average dry beans fix a total of 85 kg N_2 ha^{-1} while soybeans fix 248 kg N_2 ha^{-1} (Unkovich and Pate, 2000). Nitrogen fixation may be limited by several factors alone or more often in combination: low levels of micronutrients, competition with native (but usually ineffective) soil rhizobia, and high inputs of N which tend to inhibit fixation (Graham and Ranalli, 1997). Studies have shown that inoculation of dry beans with effective rhizobia helps with nitrogen fixation and increases yields (Duque et al., 1985; Da Silva et al., 1993; Camacho et al., 2001), but yields were not affected in the Upper Midwest (Weiser et al., 1985). Even when inoculated, some studies have found higher yields with the addition of N fertilizers (Edje et al., 1975; Henson and Bliss, 1991). Current N fertilizer recommendations for coarse textured soils in Minnesota are to apply a total of 45-68 kg N ha^{-1} (depending on yield goal) at emergence and prebloom (Rehm et al., 1995).

Fusarium root rot of dry beans is a widespread disease that has had a significant impact on production (Hall, 1996). In Minnesota, root rot is often caused by *F. solani* f. sp. *phaseoli* in complex with *R. solani* and *F. oxysporum* and yield losses due to this disease can be up to 50% (Estevez de Jensen, 2000; Estevez de Jensen et al., 2002). The increasing incidence and severity in this area has been attributed to shortening of rotation intervals, increased acreage, heavy N fertilization and the use of highly susceptible cultivars (Estevez de Jensen et al., 2004). In Central Minnesota, dry beans are typically produced on irrigated coarse textured soils that have a well defined Bt layer with increased bulk density and reduced hydraulic conductivity (Sexton et al., 1996). A Bt horizon can be restrictive to root growth and often aggravates root rot by confining the pathogen to the plow layer (where roots are also concentrated) and by allowing for the buildup of soil moisture in the root zone (Burke et al., 1972; Allmaras et al., 1988). While several studies have shown that breaking up a restrictive layer through tillage can increase yields and reduce disease severity (Burke et al., 1972; Harveson et al., 2005), there is only anecdotal evidence in Minnesota.

Current recommendations for coarse textured soils in Minnesota include N fertilizer applications, even though fertilizer N recovery is often low (<50%) (Rennie and Kemp, 1983; Tsai et al., 1993; Kipe-Nolt and Giller, 1993). This in combination with additional N supplied by biological N fixation and unpredictable rain increases the potential of nitrate (NO_3) leaching to groundwater. Breaking up of the Bt layer may further exacerbate the NO_3 leaching problem by increasing water percolation beyond the root zone.

Controlled release fertilizers are one option to reduce NO_3 leaching while maintaining yields by matching the release of N to plant uptake. Sulfur coated ureas (SCU) have shown mixed results on potatoes and corn. In a severe leaching year, corn yields were similar and potato yields were higher when fertilized with SCU compared with urea, but yields and N recovery for both corn and potato were significantly reduced when fertilized with SCU under normal weather conditions (Leigel and Walsh, 1976). Polymer coated ureas (PCU), however, have more predictable release patterns than SCU (Trenkel, 1997) and have resulted in similar or higher yields in potato and rice compared with soluble N sources (Shoji et al., 2001; Hutchinson et al., 2003; Carreres et al., 2003).

While studies have shown promising results with PCU, producers have been hesitant to adopt the fertilizer due to high prices (Trenkel, 1997; Zvomuya and Rosen, 2001). Recent advances have significantly lowered production costs and a new brand of PCU, called Environmentally Smart Nitrogen (ESN; Agrium U.S. Inc), is competitively priced with other N fertilizers. With potato, this PCU resulted in similar yields compared with untreated N sources (Hopkins et al., 2008; Wilson, 2008). The effect of any PCU on dry bean production has not been previously reported.

The overall objectives of this study were to compare several variables on dry bean yields, disease severity and net monetary returns, including: 1) deep tillage versus shallow tillage (breaking up the Bt horizon versus not), 2) PCU versus untreated urea at varying N rates and timing of application, and 3) interactions between tillage depth and N treatments.

METHODS AND MATERIALS

A preliminary field experiment conducted in 2005 and a two-year field study from 2006 – 2007 were conducted at the Central Lakes College Agricultural Irrigation Experiment Station near Staples, MN. This site had a past history of severe root rot and soil was naturally infested with *Fusarium oxysporum*, *F. solani* f. sp. *phaseoli*, and *Rhizoctonia solani* AG-4 (Estevez de Jensen et al., 2004). The soil at the site is a somewhat excessively drained Verndale sandy loam (frigid Typic Argiudoll), with a 17 cm thick Bt layer beginning at approximately 25 cm below the top of the soil. Sexton et al. (1996) reported that bulk density of the Ap, Bt and C horizons ranged from 1.5-1.7 Mg m^{-3}, 1.6-1.9 Mg m^{-3}, and 1.5-1.6 Mg m^{-3}, respectively. The authors also reported that saturated hydraulic conductivity measurements indicated that the Bt horizon limited water movement.

The previous crop in all three years was non-fertilized, irrigated corn (*Zea mays* L.). Representative soil samples from 0-15 cm were collected in the spring before planting for routine soil tests (Brown, 1998) (Table 1) and from 0-60 cm soil depth to determine KCl extractable nitrate-N (NO_3-N) and ammonium-N (NH_4-N). Extractable soil NH_4-N in the top 60 cm was 61.4, 28.7, and 73.5 kg ha^{-1} in 2005, 2006, and 2007, respectively. Extractable soil NO_3-N was 25.1, 25.1, and 6.3 kg ha^{-1} in consecutive years. Weather data were collected on station, and thirty year precipitation and temperature normals for Staples, MN were obtained from the National Weather Service for comparison (MCWG, 2007).

Table 1. Soil properties before spring planting at Staples, MN.

	0-15 cm			
	pH	Bray-P (mg kg-1)	Organic Matter (%)	K[1] (mg kg-1)
Average	6.5	32.2	2.2	111.0

[1]Extractable

The experimental design for all three years was six replicates of randomized complete blocks with a split plot restriction on randomization. Two tillage treatments were replicated as whole plots: deep tillage was intended to break up the Bt horizon, while conventional shallow tillage was not. Subplots consisted of eight nitrogen (N) treatments in 2005 and ten N treatments in 2006/2007 (Table 2). Subplots were four rows wide and 6 m in length with row spacing of 76 cm.

Table 2. Nitrogen treatments for kidney beans (*Phaseolus vulgaris* L.).

Treatment[1]	N Source	Planting	Emergence	Prebloom Sidedress	Total N Rate
		kg N ha^{-1}			
1	None	0	0	0	0
2	WSPCU	67	0	0	67
3	Urea	67	0	0	67
4	PCU	67	0	0	67
5	Urea	0	34	0	34
6	PCU	0	34	0	34
7	Urea	0	34	35	67
8	PCU	0	67	0	67
9	Urea	0	34	67	101
10	PCU	0	101	0	101

[1]Treatments 2 and 3 were not included in the 2005 study

In the spring before planting, plots were disked, tilled with a chisel plow and then disked again to level the area for sowing. Tillage plots were plowed to approximately 47 cm for deep and 29 cm for shallow tillage, respectively, under each chisel shank. The plow layer in between chisel shanks ranged from 23 – 39 cm for deep and 17 - 29 cm for shallow tillage. Shallow tillage did plow through the top 4 cm of the Bt horizon on average, but only deep tillage broke though the bottom of the dense layer which ended at an approximate depth of 42 cm. The non-inoculated red kidney bean cultivar "Montcalm" was sown on 31 May 2005, 24 May 2006 and 1 June 2007 to achieve an approximate density of 192 x 10^3 plants ha^{-1}. Planter applied starter fertilizer consisted of 37 kg K ha^{-1} and 17 kg S ha^{-1} as 0-0-40-15. Weeds were controlled by hand and with a pre-emergence application of dimethenamid-p and split applications of bentazon post-emergence.

Two sources of N, uncoated urea and a 90-day release polymer coated urea (PCU), were compared across several rates and timing schemes in all three years. In 2006/2007 two additional treatments compared an additional N source, Nutrisphere Nitrogen (NSN; Specialty Fertilizer Products, Belton, MO) and urea to PCU at the same rate at planting. NSN is reported to delay conversion of urea to ammonium and ammonium to nitrate (Balderson et al., 2007) and is coated with a water soluble polymer. It will be referred to as a water-soluble PCU (WSPCU) from this point on. Urea, PCU and WSPCU applied at planting were banded 5 cm to the side and 5 cm below the seed. PCU and urea applied at emergence were broadcast by hand on 16 June 2005, 8 June 2006 and 21 June 2007. Urea applied at prebloom was sidedressed by hand on 29 June 2005, 28 June 2006, and 5 July 2007. Emergence and sidedress N applications were cultivated or irrigated into the soil within one day of application.

Release rate of N from PCU was determined by burying 3 grams of the fertilizer in sealed plastic mesh containers for two different application timings. Two to three replications of 10 bags were buried at planting and emergence to the depth of the fertilizer band. The mesh bags were retrieved periodically throughout the season, placed in a paper bag and air dried. This method was also used to determine N release from WSPCU, but on the first and subsequent sampling dates no fertilizer remained in the mesh bags. For PCU, the fertilizer prills were removed from the mesh containers by hand, separated from the soil and weighed on a scale. The amount of weight loss was assumed to be equivalent to the amount of N released (Wilson, 2008). Percent of N release (%NR) as a function of cumulative soil growing degree days (GDD) and time (days after planting) was determined by regression. GDD was calculated with soil temperatures based on techniques in Zvomuya et al. (2003), with a base value of 5°C, the temperature below which release of N from the PCU is thought to be limited.

Disease severity (DS) and adventitious roots were evaluated to determine the extent of root rot in each study. Adventitious roots often occur in infected plants (Estevez de Jensen et al., 2002). Nodules were also rated to determine the effect of N treatments on nodulation. In 2005, all ratings were determined during pod-fill in mid-August, while in 2006 and 2007 ratings were estimated when approximately 50% of plants had flowered in mid-July. Five plants from one of the center 2 rows outside of the harvest area were pulled by hand and evaluated. Rating methods are described in Table 3. DS ratings were based on a 1-9 scale in all three years (Estevez de Jensen, 2000), but ratings in 2006 and 2007 had more resolution compared with 2005. Adventitious roots and nodule ratings were based on ranges found in the field for each particular study.

Beans were harvested on 16 September 2005, 29 August 2006 and 7 September 2007. Plants were pulled by hand from the center 3 m of the center two rows in each plot and threshed in a combine to separate beans from plant material. Harvested dry beans were dried to 0% moisture and then weighed for final yield.

A simple economic analysis was conducted to compare net monetary returns of each N and tillage treatment. Dry bean prices were set at \$1.24 kg^{-1}. The cost for deep tillage was \$69 ha^{-1} while shallow tillage was approximately \$40 ha^{-1} (Dale

Schock, personal communication, 2008). Soluble urea was priced at \$1.34 per kg N, PCU at \$1.54 kg^{-1} N, and WSPCU at \$1.52 kg^{-1} N. Application costs were considered \$0 ha^{-1} when fertilizer was applied at planting, since it is applied simultaneously with starter fertilizer. Fertilizer application at sidedress was estimated to be \$17 ha^{-1} per application (Edwards and Smith, 2008). Split sidedressed applications cost double this amount. Net monetary return was calculated based on gross value of the bean crop minus the cost of fertilizer, application and tillage.

Table 3. Methods for rating disease severity, nodules and adventitious roots by year.

2005 Methods	
Disease Ratings	
1	Little to no root rot
3	Visible infection
5	Moving into vascular system
7	Vascular system affected, taproot in tact
9	Complete death of taproot.
Nodule Ratings	
0	No nodules
1	Presence of very few (0-5) small nodules
2	Small number (5-15) of nodules
3	Greater number (15-25) of nodules
4	Highest amount of nodules on plants observed in field (30-40). Also reflected viable live nodulation.
Adventitious roots	
0	No adventitious roots
1	Indicates adventitious (hydroponic) roots.
2006/2007 Methods	
Disease Ratings	
0	No root rot
1	No root rot to Little To Visible
2	Little To Visible infection
3	Visible infection
4	Visible infection to Moving into vascular system
5	Moving into vascular system
6	Moving into vascular system to Vascular system affected, taproot in tact
7	Vascular system affected, taproot in tact
8	Vascular system affected, taproot in tact to Complete death of taproot.
9	Complete death of taproot.
Nodule Ratings	
0	No nodules
1	Presence of very few (0-15) small nodules
2	Small number (15-30) of nodules
3	Greater number (30-45) of nodules
4	Highest amount of nodules on plants observed in field (>45). Also reflected viable live nodulation.
Adventitious roots	
1	0-5 adventitious roots
2	5-15 adventitious roots
3	>15 adventitious roots.

Data from the study were analyzed using PROC MIXED (SAS Institute Inc., 2004) with replications as random variables. Values less than a p-value of 0.10 were considered significant. The 2005 data were analyzed separately, due to the difference in N treatments from the other years. The 2006 and 2007 data were combined and years were also considered random effects. Treatment means were compared using least-square means and contrast statements (SAS Institute Inc., 2004). As described by Littell et al. (2006), differences among treatments within years (the year by treatment interaction), were assessed by year-specific inference using best linear unbiased predictors (BLUPs). For the PCU release rate study and yield data, regression models were fit for each N timing treatment or N source treatment, respectively, and analyzed using PROC MIXED, while final regression equations were estimated with PROC REG (SAS Institute Inc., 2004). Correlations between variables were measured using PROC CORR (SAS Institute Inc., 2004). Spearman correlation coefficients were used if one or more variables were rank data, otherwise Pearson correlation coefficients were used.

RESULTS AND DISCUSSION

Weather

Mean temperature and rainfall for the 2005 through 2007 growing seasons (June through August) and following fall months are compared with 30 year averages for Staples, MN in Table 4. While all three years were warmer than average, 2005 was wetter and 2006 and 2007 were drier than normal. Precipitation totals for the main growing season (June - August) were 29.7, 18.2, and 9.6 cm for consecutive years. The surplus of 1.8 cm of rain in 2006 was increased by rainfall in September and October to a surplus of 4.6 cm. Above average precipitation in September and October of 2006 and 2007 decreased rain deficits of 9.7 and 18.3 cm, respectively, to 8.9 and 7.2 cm, respectively. Supplementary irrigation varied over years (Table 4), but in addition to precipitation, dry beans in 2005 received more water than in 2006 while the crop in 2007 received the lowest amount of water due to a severe drought that limited water supply.

Table 4. Average monthly rainfall and precipitation compared to 30-year averages for Staples, MN.

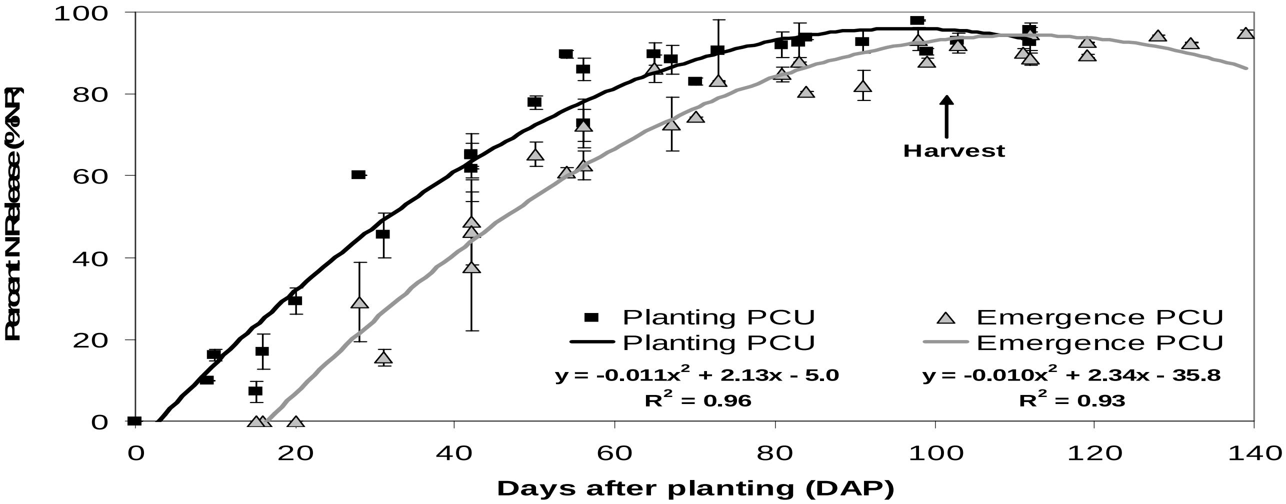
	Rainfall				Temperature			
Month	2005	2006	2007	30-Year Mean[1]	2005	2006	2007	30-Year Mean[1]
	cm				°C			
June	14.2	6.4	4.7	10.8	19.4	18.4	19.4	17.4
July	3.6	4.6	2.9	9.0	21.3	22.6	21.3	19.8
August	11.9	7.2	2.0	8.0	18.5	19.5	18.4	18.8
September	9.1	9.5	14.0	6.6	15.6	12.8	14.4	13.2
October	6.8	4.5	10.2	6.6	7.9	5.1	8.6	6.5
Irrigation	11.7	21.4	27.5					

[1] Average for the 30 year period from 1971-2000.

Nitrogen Release Rate from PCU

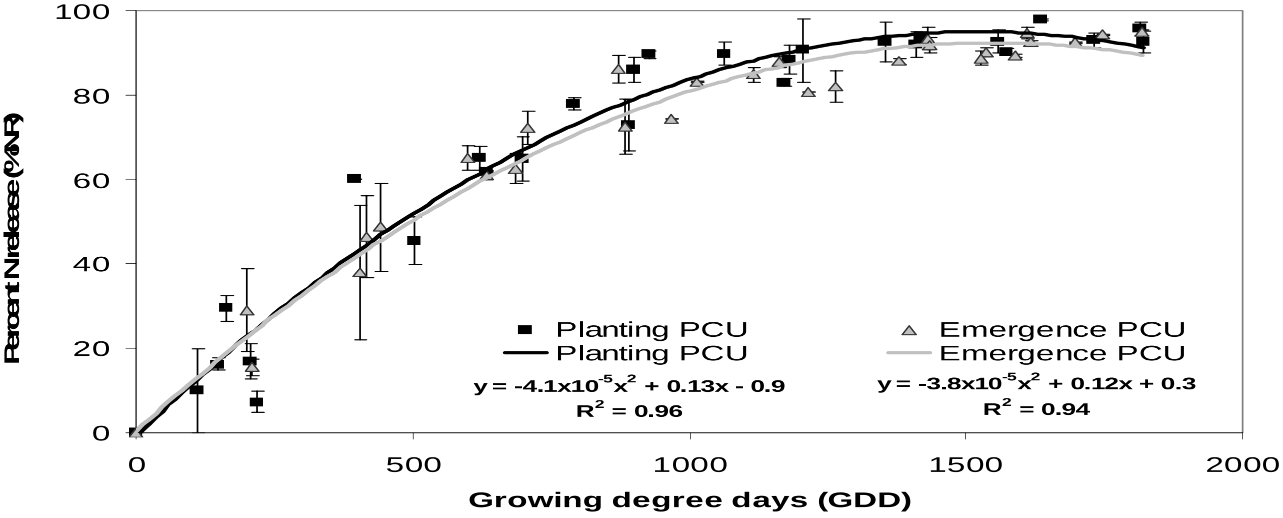
In order to compare N release of PCU at different application times (planting and emergence), equations were used to model release rate. Percent of N release (%NR) was a quadratic function of days after planting (DAP). No differences in regression slopes were found between years for each treatment ($p>0.10$) so one quadratic line is used to describe each timing of application treatment (Figure 1). The intercepts were significantly different between the two treatments due to the difference in application timing. Emergence PCU was typically applied between 15 and 20 DAP during this study. Slopes were not significantly different, indicating that PCU had the same release pattern regardless of application timing. According to the equations, planting and emergence PCU had released approximately 95% and 93% by the average harvesting date (101 DAP), respectively. Total N accumulation for unfertilized dry bean was reported to increase at the highest rate between approximately 45 and 60 DAP (Kimura et al., 2004). Planting PCU had released approximately 60% of the total N supply by 45 DAP, while emergence PCU had only released about 45%. This suggests that emergence application of PCU may be delayed too long for maximum uptake by dry bean, assuming that dry beans accumulate N similarly with or without N fertilizer applications.

Figure 1. Percent of N release (%NR) from a polymer coated urea (PCU) placed at the fertilizer band depth as a function of the number of days of planting (DAP) averaged over three growing seasons.



The release rate of N from PCU is mainly determined by soil temperature when soil moisture is not limiting (Salman et al., 1989; Gandeza and Shoji, 1991). To further explore the relationship between soil temperature and N release, PCU release was expressed as a function of cumulative soil growing degree days (GDD) at the fertilizer band depth. The %NR was determined to be a quadratic function of GDD, agreeing with the model chosen in Zvomuya et al. (2003). One equation was used to describe each treatment when no differences in regression slopes were found between years ($p>0.10$) (Figure 2). The intercepts and slopes for each N timing treatment were not significantly different, suggesting that PCU requires a specific number of GDD to release N, regardless of the number of days needed to accumulate them. This also indicates that the amount of N released from PCU can be predicted if GDD is known. Under the conditions of this study, over 90% of N had been released by 1300 GDD. In each year, beans were harvested at approximately 1650 GDD.

Figure 2. Percent of N release (%NR) from two different application timings of polymer coated urea (PCU) placed at fertilizer band depth as a function of cumulative soil growing degree days (GDD, base of 5°C) after fertilizer application.



Disease Severity and Adventitious Roots

There were no statistically significant findings with disease severity (DS) ratings over the course of this study. In 2005, the average disease rating was 6.6, which is equivalent to the vascular system being affected, but the tap root is still in tact. The disease ratings in 2006 and 2007 were 5.3 and 5.1, respectively, which indicate that root rot was moving into the vascular system. It is not surprising that DS ratings were relatively high in the field trials, due to the previous history of root rot. Differences in DS due to tillage and N treatment were not found. These results agree with the conclusions of Burke et al. (1972) where deep tillage before seedbed preparation failed to affect DS. However, deep tillage after seedbed preparation to break up the compacted plow layer did significantly reduce crop damage from fusarium root rot. Other studies have found varying results of tillage on DS. Estevez de Jensen et al. (2004) found that DS was not affected by moldboard plowing when compared with minimal tillage in a soil similar to the present study. It is unlikely that moldboard plowing broke up the Bt layer, however. Harveson et al. (2005) reported that zone tillage (a type of strip tillage) significantly reduced DS over no-tillage in a soil with a compacted layer. No-tillage was not tested in the current study, and may need further evaluation.

A rating system for the presence of adventitious roots was also employed to determine the effect of tillage practices and N management on disease. Adventitious roots often form above the initial infection area in order to maintain the function of dying roots (Hagedorn and Inglis, 1986; Meronuck et al., 1993). Adventitious roots were not affected by N treatment in any year. In 2005, tillage depth significantly affected the presence of adventitious roots (Table 5). Deep tillage resulted in a higher rating, indicating that on average adventitious roots were present more often than with shallow tillage. In the same year, adventitious root ratings were not correlated with DS ratings, which suggests other factors affected their growth. Severe root rot will affect adventitious roots over time, and given the high average DS rating (6.6 on a scale of 9) and the later timing of measurements in 2005 (77 DAP compared with approximately 44 DAP in 2006/2007), adventitious root growth may have been affected by disease. Roman-Aviles et al. (2004) found that while root rot symptoms were expressed by 30 DAP, root weights were not affected until approximately 60 DAP.

Table 5. Adventitious root ratings as affected by tillage and year.

	Adventitious Root Ratings	
	2005	2006/2007
Tillage		
Deep	0.3 a	2.2 a
Shallow	0.2 b	2.3 a
Year		
2006	---	2.6 a
2007	---	1.9 b

[1]Means followed by the same letter are not significantly different (p>0.10).

Adventitious roots were not significantly affected by tillage in 2006 and 2007, but years were significantly different (Table 5). In 2006, the average plant contained 5-15 adventitious roots, while the average per plant in 2007 ranged from 0-5. These values are slightly lower than those reported in Michigan, where the variety Montcalm grew 15 adventitious roots on average under field conditions (Roman-Aviles et al., 2004).

Adventitious root ratings were inversely correlated with DS ratings in 2006/2007, although variation was high (rho = -0.13, $p<0.05$). Roman-Aviles et al. (2004) also found a negative correlation between adventitious roots and DS, but the study included many varieties with varying levels of susceptibility to root rot. They also found that Montcalm kidney beans had fewer adventitious roots on average compared with more resistant varieties. This suggests that Montcalm (a variety that is highly susceptible to root rot) is less adapted to dealing with root rot via adventitious roots, which may explain the high variability found in our study.

Drought stress in 2006 and 2007 may have affected adventitious root development, regardless of DS. The initiation of adventitious roots was inhibited at a relative humidity of 93% or less in water stressed white clover in a study by Stevenson and Laidlaw (1985). Manschadi et al. (1998) found that root densities of faba bean (*Vicia faba* L.) in upper soil levels were much lower under water stress compared with those of well watered plants. Both 2006 and 2007 had below normal precipitation levels, but the rain deficit in 2007 was more pronounced. The drought conditions in both years also limited irrigation water supplies, especially in 2007. This may explain the low adventitious root ratings compared with other studies and the significant difference between years.

Nodule Ratings

Nodule ratings in 2005 were significantly affected by N treatment (Table 6). In 2005, all N treatments were not significantly different than the control, except the highest rate of PCU (101 kg N ha^{-1}), which produced significantly lower nodule ratings. In the 2006/2007 analysis, the addition of N did not significantly affect nodulation. Moisture stress may adversely affect nodule numbers and size, especially at important growth stages (Sprent, 1976; Peña-Cabriales and Castellanos, 1993), and drought conditions due to inadequate water supply for irrigation in 2006 and 2007 may have limited nodulation.

Table 6. Nodule ratings as affected by N source, rate and timing.

Treatment #	N Source	N Rate	Timing (P,E,S)[1]	Nodule Ratings[2] 2005[3]	2006/2007
1	None	0	0,0,0	0.8 a b	1.8 a
2	WSPCU	67	67,0,0	---	1.3 a
3	Urea	67	67,0,0	---	1.4 a
4	PCU	67	67,0,0	0.7 b c	1.3 a
5	Urea	34	0,34,0	1.2 a	1.7 a
6	PCU	34	0,34,0	1.0 a b	1.9 a
7	Urea	67	0,34,33	0.8 a b	1.5 a
8	PCU	67	0,67,0	0.6 b c	1.7 a
9	Urea	101	0,34,67	0.8 a b	1.6 a
10	PCU	101	0,101,0	0.3 c	1.8 a

[1] P,E,S = applied at planting, emergence and pre-bloom sidedress, respectively

[2] Nodule ratings methods differ between 2005 and 2006/2007

[3] 2005 did not include treatments 2 and 3 in the experimental design

[4] Means with the same letter are not significantly different (p>0.10).

The addition of N to dry bean is reported to decrease N_2 fixation and nodulation (both in nodule mass and number present per plant) (Graham, 1981; Da Silva et al., 1993; Leidi and Rodriguez-Navarro, 2000). This study supports these findings to some degree, since nodule ratings were reduced by some N treatments, especially at the higher N rates.

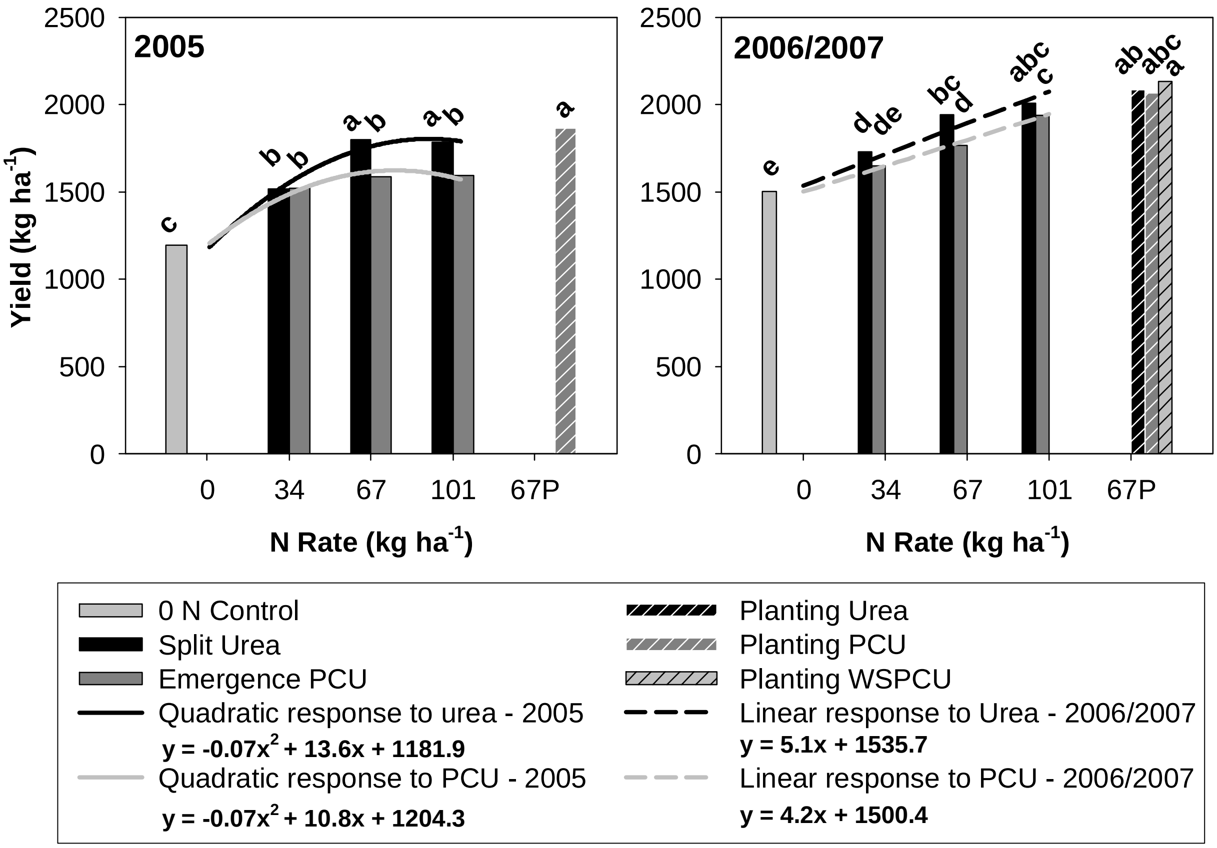
Bean Yields

In 2005, N treatment significantly affected dry bean yields although tillage treatments did not. The addition of N significantly increased yields over the 0 N control, and yield response was a quadratic function of N rate (Figure 3). At the low N rate (30 kg N ha^{-1}), there was no yield difference between N sources, but split urea at 67 and 101 kg N ha^{-1} resulted in significantly higher yields compared with emergence PCU. Bean yields with planting PCU were similar to split urea at the equivalent rate, however.

With N applications at emergence or later, bean yield was a quadratic function of N rate. Slopes and intercepts of the quadratic functions were not significantly different between emergence PCU and split urea, which suggests that yields responded similarly to N source. Since yield responses were a quadratic function, the N rate that would have produced the highest yield can be obtained for 2005. The optimum N rates as calculated from the quadratic equations were 92 and 78 kg N ha^{-1} for split urea and emergence PCU, respectively. Although the two values vary between N sources, the quadratic lines were not significantly different and therefore optimum N rates cannot be assumed to be different either.

Dry bean yields in 2005 were lower when compared with yields in 2006 and 2007, most likely due to excessive moisture conditions early in the season. In 2006 and 2007, N treatments significantly affected dry bean yields. The addition of N significantly increased yields over the 0 N control, except at the lowest N rate (34 kg N ha^{-1}) of emergence PCU (Figure 3). Yield response was a linear function of urea and PCU N rate. This suggests that an optimum rate was not reached within the parameters of this study or that additional N may have increased yields further. Slopes and intercepts for each N source were not significantly different. Split urea generally resulted in higher yields compared with emergence PCU, although differences were only significant at the 67 kg ha^{-1} N rate. N applied at planting resulted in the highest yields, but there were no differences between N sources. Planting WSPCU resulted in significantly higher yields than all other emergence applied N treatments except split urea applied at 101 kg N ha^{-1}. Yields with planting PCU were similar to yields with emergence applied PCU and split urea at the highest N rate (101 kg N ha^{-1}) and split urea at 67 kg N ha^{-1}, but were significantly higher than yields with all other emergence PCU applications. In contrast to the current study, Henson and Bliss (1991) found that applying soluble N at planting generally reduced yields due to nodule inhibition compared with later N applications. In the present study, bean nodule ratings were not affected by N timing treatments, although moisture stress may have limited their growth.

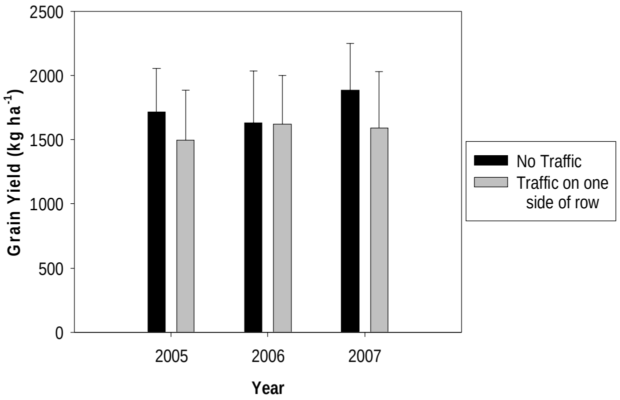
Figure 3. Dry bean grain yield as affected by N source, rate and timing. Yield response to N rate (for N applied at emergence or later is also presented. Bars with the same letter (2005 and 2006/2007 are considered separately) are not significantly different (p>0.10).



Several studies have concluded that tillage practices affected dry bean yields. Estevez de Jensen et al. (2004) reported increased grain yields with moldboard plowing compared with disking on a soil similar to the one in the present study. A deep tillage method was not used to break up the Bt horizon, however, such as in the current study. Harveson et al. (2005) found that zone tillage to break up a compacted layer significantly increased bean yields over no-tillage. Burke et al. (1972) found that yields were not affected by subsoiling before seedbed preparation, but were significantly increased with subsoiling between the rows after seedbed preparation. In the current study, yields were not significantly different between tillage treatments in all three years, which suggests preparation of the seedbed may have resulted in re-compaction even though the Bt layer was broken up. Further research needs to be conducted to determine optimal tillage timing in combination with field preparation.

Further examination of the yield data found that another factor may have affected grain yield. Yields were determined separately from each harvest row in order to determine if there was an effect of wheel traffic on grain production. Of the two center rows of beans used for harvest, one row had wheel traffic on one side while there was no traffic adjacent to the other harvest row. The tractor used for planting had single wheels that were approximately 46 cm in width, which left approximately 15 cm between the wheel and the row. While the experimental design of this study did not allow for statistical analysis, general trends were found. Averaged over tillage and N treatments in each year, there tended to be a decrease in grain yield when the row was next to wheel traffic compared with the row without any traffic nearby (Figure 4). The difference in yield was more pronounced in 2005 and 2007 than in 2006 and may be due to soil moisture conditions. Wet soils are more susceptible to increased compaction than dry soils (DeJong-Hughes et al., 2001), and there was little precipitation in the first half of the growing season in 2006. Wet field conditions occurred during post-emergence field operations in 2005 and at planting in 2007, respectively.

Figure 4. Kidney bean yields averaged over tillage and N treatments as affected by wheel traffic in three years.



Averaged over three years, there was generally a 9% yield loss due to traffic. With an 8 row planter, approximately 50% of the yield will be reduced since 4 rows are adjacent to wheel traffic. To reduce the proportion of the yield affected, a larger planter should be used. Many have reported that compaction of a sandy soil with wheel traffic significantly reduced yields of various crops (Mamman and Ohu, 1997; Dauda and Samari, 2002; Nevens and Reheul, 2003). These studies have typically compacted entire plots with wheel traffic which is not practiced in traditional crop production. The current study, however, found that there may be an effect of wheel traffic on kidney bean yields as it applies to conventional kidney bean production practices.

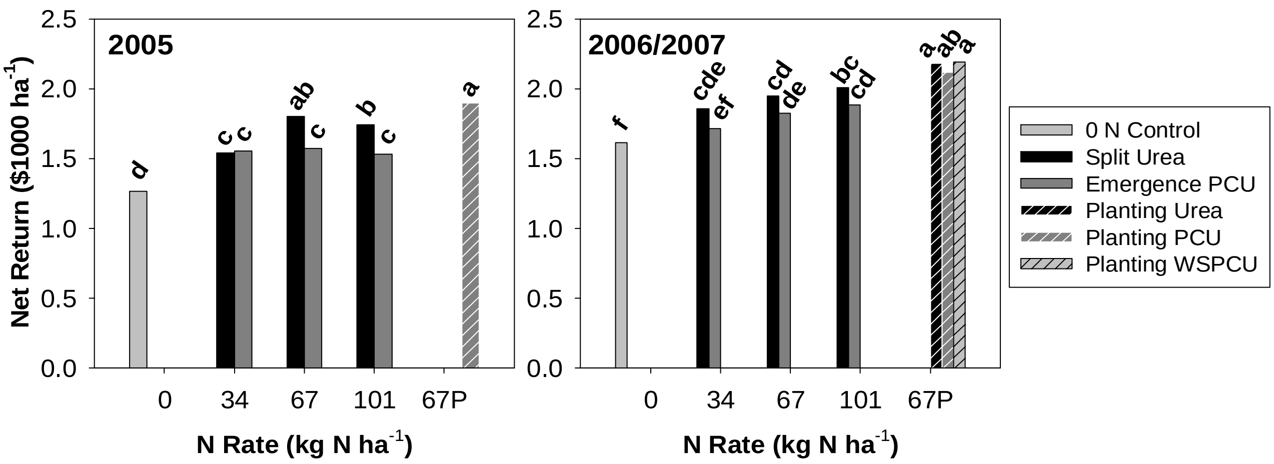
Economic Analysis

An economic analysis of the current study was conducted to show net monetary returns based on fertilizer prices, application costs, tillage costs and dry bean yields. Net returns in 2005 (\$1263 – \$1896 ha^{-1}) were generally lower compared with 2006 and 2007 (\$1614 – \$2189 ha^{-1}), mainly due to lower yields. In 2005 and 2006/2007, N treatments significantly affected net monetary returns for bean production (Figure 5). In 2005, the addition of N significantly increased returns over the zero N control. Planting PCU and split urea at equivalent rates resulted in the highest net returns, although split urea at 67 kg N ha^{-1} was not significantly different from split urea at 101 kg N ha^{-1}. Increasing N rate with emergence PCU did not result in an increase in net return. Net returns with split applied urea significantly increased between 34 and 67 kg N ha^{-1} and then remained statistically the same at 101 kg N ha^{-1}. At the lowest N rate, there were no differences in returns between N sources, but at 67 and 101 kg N ha^{-1}, split urea resulted in a significantly higher net return than emergence PCU.

In 2006 and 2007, the addition of N significantly increased net returns over the zero N control, except at the lowest rate of emergence PCU. Planting applied N significantly increased monetary returns over all emergence or later applied N, and all planting N sources resulted in similar returns. In general, net returns were increased as N rate applied at emergence increased, although split urea treatments did not result in significantly different returns. The highest rate of emergence PCU (101 kg N ha^{-1}) resulted in a significantly higher net return compared with the lowest rate (34 kg N ha^{-1}), while 67 kg N ha^{-1} was similar to both. Split urea resulted in higher net returns than emergence PCU, although these differences were not significant.

Overall, emergence applied PCU resulted in reduced net returns in a wet year compared with uncoated urea, but planting applied PCU was comparable at equivalent rates. Under dry conditions, emergence PCU and split urea resulted in similar returns, but the highest returns were with planting N applications, regardless of N source. Tillage depth did not affect net returns in any year, due to the lack of a yield response and the low cost of tillage compared with net returns.

Figure 5. Net monetary returns as a function of N source, rate and timing. Bars with the same letters (2005 is separate from 2006/2007) are not significantly different (p>0.10).



CONCLUSIONS

This study was conducted to examine different tillage techniques and polymer coated ureas on irrigated dry bean production in Minnesota. In general, tillage treatments did not affect disease severity ratings, nodulation, kidney bean yields, or net monetary returns. The current study conducted tillage before seedbed preparation however, and others have reported that only tillage after preparation of the seedbed resulted in yield differences (Burke et al., 1972). Future research should focus on timing of tillage to find the optimal treatment for bean production.

Emergence applied PCU resulted in lower grain yields compared with split applications of urea at emergence and prebloom. The N release study of PCU suggested that emergence applied PCU had released less than 50% of N when maximum plant N accumulation began. When applied at planting, PCU resulted in similar yields and net returns as split applied and planting urea at equivalent rates over three years. Based on these results, we conclude that emergence applications of PCU may release N too late for the period of maximum N uptake in dry beans, but planting applications of PCU have shown promising results. WSPCU applied at planting also resulted in similar yields and net returns as planting applied urea over 2 years. Further research should focus on finding the optimal N rate for planting applied PCU or WSPCU or test other PCU formulations that release N more quickly.

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