Cover Crop and Nitrogen Fertilizer Rate Effects on Mitigating Soil Nitrate Leaching in Irrigated Sandy Soils in Corn and Soybean Production

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ABSTRACT

Coarse textured soils are very productive when supplemented with irrigation and nitrogen (N); however, they are susceptible to nitrate (NO_3–N) leaching. Nitrate leaching not only reduces fertilizer efficiency but has costly environmental impacts to the groundwater supply. The majority of NO_3–N loss occurs in the fall and spring or when nutrient and water uptake from corn (*Zea mays* L.) and soybean (*Glycine max* Merr. L.) is limited but precipitation is frequent. Cover crops, such as winter rye (*Secale cereal* L.), show promise as a tool to reduce NO_3–N loss by taking up water and nutrients during these critical loss periods. The objectives of this study were to determine if a rye cover crop reduced season cumulative NO_3–N load and measure what effect a rye cover crop had on corn and soybean production. The study compared N rate treatments with and without fall planted rye into continuous–corn (CC) and both the corn (CSb) and soybean (SbC) phases of a corn–soybean rotation. When fall seeded into soybean, rye reduced NO_3–N leaching by 46 lbs N ac^{-1} (P>F 0.0491) only in 2016 and rye had no impact on NO_3–N leaching when seeded into corn. A rye cover had no impact on corn yield and had no impact on EONR in CC. In 2016, the CSb EONR with Rye-Cover was 52 lbs N ac^{-1} less than No–Cover, but in 2017 the Rye–Cover EONR was 47 lbs N ac^{-1} more than No–Cover. The results of this study indicate that rye has the most potential as a beneficial practice when seeded into the soybean phase of a corn–soybean rotation.

INTRODUCTION

More than 95 million acres of the Midwest landscape produce the majority of the U.S. corn and soybean supply (USDA, 2015), and in Minnesota there are approximately 500,000 acres of irrigated, coarse textured soils in row crop cultivation (USDA, 2012). Production on coarse textured soils continues to expand because high yields are achievable when supplemented with nutrients and water. Concerns associated with coarse soils are water movement below the root zone and nutrient loss. The majority of nutrient loss occurs in the spring when precipitation is high but uptake is limited (Struffert et al., 2016).

As the above–mentioned challenges intensify, there is renewed interest in determining best management practices (BMP's) for N in sandy soils. The BMP's for corn production on irrigated sandy soils were updated by University of Minnesota Extension in 2015 (Lamb et al., 2015). One of the changes in the 2015 revision was an increase in the economic optimal N rate (EONR), which raised concerns over increase environmental contamination of NO_3–N in groundwater. However, Struffert et al. (2016) showed that merely decreasing N rate below the EONR did not adequately reduce NO_3–N leaching and that notable leaching occurs in check plots (Beaudoin et al., 2005). These results highlight that standard BMP's may not be enough to substantially reduce NO_3–N leaching and that alternative management strategies are needed.

Cover crops have been associated with many desirable benefits such as reduced soil erosion, scavenging and recycling residual soil NO_3–N, and improved soil organic matter (Dabney et al., 2001; Jewett, 2008). Inversely cover crops can increase management, suppress yield, and have allelopathic characteristics (Dabney et al., 2001). For coarse textured soils under irrigation in corn and soybean production in the upper Midwest, a winter rye cover crop is a suitable option (Stoskopf, 1985). While rye is an effective N scavenger, is winter hardy, and can be chemically or mechanically terminated, more research is needed to determine the extent to which rye, as a cover crop, enhances nutrient management and crop production. Corn grain and silage yields managed with a rye cover have been reported to decrease (Raimbault et al., 1990; Johnson et al., 1998; Vaughan and Evanylo, 1998), increase (Ball-Coelho and Roy, 1997; Andraski and Bundy, 2005), or have no difference in yield (Dhima et al., 2006; Krueger et al., 2011). Similarly, soybean yields when planted with rye were observed to decrease (Reddy, 2003), increase (Moore et al., 1994), or have no difference to no cover management (Pantoja et al., 2015). Furthermore, most of the above mentioned studies come from warmer regions of the Midwest and are exclusively on fine textured soils. Less is known regarding the impact of a rye cover crop on the yield and N needs of corn and soybean in cooler regions of the upper Midwest and on coarse textured soils. Therefore, this study was conducted on an irrigated, sandy soil under continuous corn (CC) and both phases of a corn–soybean (CSb and SbC) rotation in the upper Midwest.

The objectives of this study were to (1) evaluate rye biomass and N uptake in CC, CSb and SbC, (2) evaluate the impact of a rye cover crop on corn and soybean yield and corn EONR, and (3) evaluate the impact of cover and N rate on NO_3–N leaching.

MATERIALS AND METHODS

The study was conducted during 2016 and 2017 at the Rosholt Research Farm in Westport, Minnesota (45°42’49.1” N, 95°10’16.2” W) on an Arvilla sandy loam soil (sandy, mixed, frigid Calcic Hapludolls). This study was part of a long–term project established in 2011 with three adjacent rotations: continuous corn (CC) and both phases of a corn–soybean rotation, corn (CSb) and soybean (SbC). In 2015, the site received uniform applications of N to remove previous treatment effects.

Ten treatments were arranged in a randomized complete block design with 4 replications and each treatment applied to plots measuring 15 ft. wide (six crop rows 30 in apart) by 40 ft. long. Treatments were winter rye (Secale cereal L.) and no rye with 0, 90, 180, 225, and 270 lbs N ac^{-1} applied to the CC and CSb rotations and no N applied to the SbC rotation. The N rates were divided in four equal split applications at corn development stages V2, V6, V8, and V12 (Abendroth et al., 2011). Nitrogen was applied as urea (46–0–0) (N–P–K) treated with a urease inhibitor [N–(n–butyl) thiophosphoric triamide (NBPT)].

Rye was seeded on 17 Sept. 2015 at 75 lbs ac^{-1} into only the SbC rotation. The method of hand broadcasting rye at corn development R6 and at soybean 50–75% leaf drop and then incorporating with irrigation proved effective and was adopted for the remainder of the study. In 2016 rye was seeded into corn and soybean on 1 Sept. 2016 and in 2017 into soybean on 29 Sept. and into corn on 12 Oct. at 112 lbs ac^{-1}. Depending on precipitation, irrigation was also applied after rye germination to prevent plant loss from water stress. Each spring, 21 Apr. 2016 and 9 May 2017, rye was terminated chemically with glyphosate, N–(phosphonomethly) glycine at 1.2 kg a.i. ha^{-1} plus 4.7 L ha^{-1} non-ionic surfactant (NIS) at 2.5% v/v. After rye termination in 2016, a disk and field cultivator were used for seedbed preparation and in 2017 the fields were strip tilled to better accommodate other crops present in the larger long–term study that are not part of this study. Rye treatments remained in the same plots across years.

Corn hybrids and soybeans varieties were planted 3 May 2016 and 25 May 2017. Corn was harvested 6 Oct. 2016 and 26 Oct. 2017 and soybean was harvested 7 Oct. 2016 and 17 Oct. 2017. Other than N, standard agronomic practices were used to maximize yield. Irrigation was scheduled using an irrigation checkbook (Steele et al., 2010) and was applied with a linear irritation system. In both years, the irrigation system was run 7 times, 4 inches were applied in 2016 and 4.5 inches were applied in 2017.

Rye biomass was sampled before termination each spring at tillering (Zadoks et al., 1974). Corn whole plant samples were collected at V8, R1, and R6 by collecting 6 whole plant samples per plot. At harvest, grain sub–samples were collected from each corn and soybean plot.

Soil samples were collected from the 0–12 and 12–24 inch depth increment at corn V8, R1 and at post–harvest Soil samples were dried in a forced–air oven at 90°F, ground through a sieve, and analyzed for NO_3–N and NH_4–N.

Economic optimum N rate (EONR), the point where the return from grain yield is adequate to compensate the cost of N inputs, was calculated with an N fertilizer to corn price ratio of 0.1. Treatment efficiency was calculated using fertilizer recovery efficiency (FRE) which measures the percent of applied fertilizer used by the crop and agronomic efficiency (AE) which measures lbs of yield increase per unit of N applied (Fixen et al., 2012).

Suction–tube lysimeters were sampled every 7–10 days April–October to collect cumulative NO_3–N leachate samples from 1.2 m below the soil surface. A pressurized vacuum system (32 centibars) was used to collect 30 – 50 ml of sample from each lysimeter. The samples were analyzed for NO_3–N concentration using a Hach DR 6000 spectrophotometer. Known standards were analyzed every 20–24 samples to ensure equipment accuracy. From each batch, duplicate samples and standards were sent to an independent lab to maintain a 10% QA/QC. Six passive capillary lysimeters, two in each rotation, were measured to provide mean seasonal drainage value across all rotations and treatments.

Daily drainage was calculated from a modified water–balance model were if $TSW_{t-1}+P_t+I_t-$ $Et > TSW_{FMC}$, then $D_t=P_t+I_t-Et-TSW_{FMC}$ (Steele et al., 2010): where $TSW_{(t-1)}$ is the total stored water in the 1.2 m soil profile at the end of the previous day (t-1 where “t” is in days), Pt is the present–day water inputs from precipitation, It is the present–day water inputs from irrigation, Ett is the present–day water loss from evapotranspiration, TSWFMC is the total stored water in the 1.2 m profile at field moisture capacity (FMC, 33 kPa), and D_t is the present–day water loss through drainage. Each year the initial soil profile was at 88 mm, the TSW_{FMC} for an Arvilla sandy loam. Season long drainage in 2016 was 13.6 inches under soybean and 12.1 inches under corn and in 2017 was 14.7 inches under soybean and 13.3 inches under corn.

Data were analyzed with SAS software version 9.4 (SAS Institute, 2012) using MIXED and GLMMIX procedures. Year and rotation were run independently, replication was a random effect, and rate and cover were fixed effects. Differences between treatment means were determined using the PDIFF function and were considered significant at $P<0.05$.

RESULTS AND DISCUSSION

Corn-Soybean

Crop rotation seemed to play an integral role in the success of rye establishment and its interaction with NO_3–N leaching and crop agronomics. Factors that may have influenced rye establishment but were not directly measured were crop maturity, canopy light penetration, crop residue, and seed predation (Ball-Coelho and Roy, 1997; Sivy et al., 2011). The rye biomass in CSb was previously seeded into the soybean phase of the rotation in the fall. The CSb rye had the greatest biomass and N uptake compared to the other rotations (Table 1). Rye seeded into soybean accumulated 70% more biomass and N than the CSb and 80% more than CC. These results were similar to those in Pantoja (2016) where spring rye biomass was greater following soybean than corn at three of four locations. Seeding into soybean may have provided a more ideal environment for rye establishment than corn rotations. Rye was seeded into soybean when leaf–drop was between 50 and 75%. In 2016 leaf drop coincided with corn R6 and rye was seeded into both crops on the same day; however, in 2017 the corn crop maturity was delayed and rye was seeded into soybean two weeks earlier than corn. Early rye seeding would allow rye to utilize as much time for development as possible which is usually the limiting factor for cover crop establishment in northern climates (Snapp et al., 2005). Additionally, at leaf drop the canopy begins to open as more leaves fall and more sunlight can reach the soil surface which would benefit rye development. It is possible that once the rye was seeded, that the remaining soybean leaves also covered the seeds. This would potentially protect the seeds from predation while also providing moisture and an environment conducive to germination. Finally, soybean leaves and plant biomass are recorded to have low C:N (20:1) and are rapidly decomposed (Mannering, J.V., 1981). These characteristics would likely not inhibit rye roots and shoots from developing through the soybean residue. When rye biomass and N uptake were compared to treatment N rate there were no significant interactions (data not shown) suggesting that there was no residual treatment effect from previous corn rotations and that uptake is dependent on biomass. These N uptake findings are supported by similar results discussed in Wilson et al, (2013) where N uptake was correlated with rye biomass.

Rye–Cover had no impact on corn yield in CSb (Table 2). The potential negative impacts of allopathy or high C:N of rye on corn yield noted by others (Raimbult et al., 1991; Tollenaar et al., 1993) were not observed in this study likely because the termination of rye two weeks prior to planting has been shown to reduce these negative interactions (Duiker and Curran, 2005).

Corn yield typically increased as N rate increased with a quadratic plateau response to N across years in both CC and CSb crop rotations (Table 3). The quadratic plateau response indicated that in 2016 under CSb Rye–Cover the EONR was 52 lbs N ac^{-1} lower than for No–Cover and differences in grain yield were minimal (4.8 bu ac^{-1} less with Rye–Cover). In contrast, the EONR for the 2017 CSb Rye–Cover was 47 lbs N ac^{-1} greater than for No–Cover with no difference in yield. Rye biomass production was 53% greater in 2016 than 2017 and accumulated 63% more N (Table 1). There was adequate moisture both years of the study but 2016 had a warmer spring and fall than 2017. In contrast, 2017 experienced a wet spring which may have leached mineralized N and a cool fall delayed crop maturity. These factors, along with full residue incorporation from the disk and field cultivator tillage operations in 2016 compared to 2017 where strip–tillage only incorporated approximately half of the residue, likely resulted in greater N immobilization in 2016 ultimately impacting the EONR.

Early season immobilization could be advantageous because it can reduce concentrations of soil NO_3–N that is subject to loss. As emphasized in a related study (Struffert et al., 2016), greatest NO_3–N leaching losses take place in early spring when corn is not capable of accumulating large quantities of N and excess precipitation forces soil NO_3–N below the root zone. One potential drawback of immobilization is if mineralization from the rye residue is delayed and limits N availability at the time when corn has large N demands (Abendroth, LJ; Elmore, RW; Boyer, 2011). In 2016 full incorporation of rye residue with a low C:N ratio (15:1) likely resulted in accelerated decomposition and mineralization. The substantially lower EONR for the Rye–Cover in 2016 is likely a result of reduced N loss by early–season immobilization followed by rapid mineralization. These results illustrate that rye can be an effective tool to manage N. However, as contrasted by the 2017 results, there are many variables that may hinder a consistent response.

Rye–Cover reduced cumulative NO_3–N load by 46 lbs N ac^{-1} in 2016 (Table 4). Due to greater variance in 2017, the reduction of 37 lbs N ac^{-1} was not statistically significant. N rate was significant in 2016 but was not significant in 2017. This may have been an artifact from the blanket N application applied in 2015. The Rye–Cover may have reduced the NO_3–N load by taking up water and nutrients following the soybean crop but rapidly releasing N for corn use through mineralization after the rye was terminated in the spring. Rye likely tied up residual NO_3–N when it was most vulnerable to leaching, thus helping reduce N loss. The rye biomass N uptake values support this possibility; in 2016 average rye N uptake was 63 lbs N ac^{-1} and the difference in NO_3–N load was 46 lbs N ac^{-1} and in 2017 rye N uptake was 38 lbs N and the difference in NO_3–N load was 37 lbs N ac^{-1}. While there are variables such as weather and tillage that contribute to N mass balance, rye uptake seems to account for some of the load difference between the No–Cover and Rye–Cover treatments.

Continuous–Corn

Under CC, rye had very poor establishment in both years of the study (Table 1). The poor establishment in CC was most likely due to the abundance of crop residue in and on the soil which may have created a vegetative barrier that inhibited rye root and shoot growth. Corn reside typically has a C:N of 70:1 (Mannering, J.V., 1981) which would cause slow decomposition and enable a buildup of crop residue (Broder and Wagner, 1988). The seeds that did successfully germinate may also have been smothered with residue after harvest. Without an established root system, the rye may have had limited survivability in this environment. Under CC, N rate significantly impacted rye biomass where biomass increased as N rate decreased. This is best explained by examining corn R6 biomass, there was statistically less corn biomass in the 0N plots and the canopies were visually thinner (LAI was not measured). These conditions would lead to more light penetration and potentially better rye development in the CC 0N plots as compared to N rate plots where biomass was greater and the canopy may have intercepted more light from reaching the soil surface.

In CC, rye had no interaction with crop yield and there minimal differences in EONR between Rye–Cover and No–Cover in both 2016 and 2017 (Table 2 and 3). Rye–Cover EONR required an additional 12.5 lbs N ac^{-1} in 2016 and 17.8 lbs N ac^{-1} in 2017. A lack of differences in EONR were likely due to corn residue overshadowing any artifact of N mineralization from the rye biomass.

Like EONR, there were no differences in leaching due to cover crop. Rye–Cover likely had little impact on leaching reduction in CC because of very poor rye establishment and little N uptake. Additionally, the corn residue may have tied up potentially leachable N. If corn residue was constantly stimulating immobilization then the agronomic or environmental benefits of Rye–Cover may not have been detectable. Leaching would still occur because mineralization takes place throughout the spring and growing season. The available nutrients from mineralization or fertilizer that are not taken up by the corn crop may be lost during a precipitation event that creates drainage. In 2017, N rate significantly impacted N leaching load in CC with 0N leaching an average load of 30 lbs N ac^{-1} compared the 225N and 270N rates which leached 58 and 78 lbs

N ac^{-1} respectively. In contrast, N rate was not significant in 2016, and like was likely due to the uniform N application the previous year. These results reiterate the importance of N rate management but again illustrate that N loss occurs even when no N is supplied. Factors affecting uniformity in the study, such as tillage and weather, may have also impacted results but specific interactions were not detectable in CC likely due to the abundance of crop residue that may have overshadowed any small contribution from the rye biomass.

Soybean–Corn

The rye biomass in SbC previously seeded into the corn phase of the rotation in the fall. Rye establishment was poor in SbC but was greater than in CC (Table 1). Similarly to CC, corn residue likely inhibited rye establishment but the integration of the soybean phase reduces the amount of crop residue in the system. Soybean residue typically has a C:N of 20:1 and decomposes rapidly (Broder and Wagner, 1988). This would explain the visual difference of residue in the corn rotation prior to harvest. When seeded into the corn phase, initial rye growth was not limited by a buildup of residue in the soil but some of the rye may have been smothered by the residue after harvest. This would help to explain the improved rye biomass compared to CC. The trend of increased rye biomass with 0N rate was not seen in this rotation and was likely due to the 0N plot in CSb having a fuller canopy compared to CC because of the N credit from the soybean phase (Lamb et al., 2015). The fuller canopy would not have given the rye under 0N the increased light advantage as seen in CC.

In SbC, Rye–Cover produced small and inconsistent yield results with numerical differences of 1.5 bu ac^{-1} between Rye–Cover and No–Cover in both years. Rye–Cover was statistically significant in 2016 but likely due to low variance within the replicates (Table 2). There was no yield response to residual N rate from the previous corn crop from either year as was observed in a related study (Rubin et al., 2016).

Cumulative NO_3–N load in SbC averaged 55 lbs N ac^{-1} in 2016 and 62 lbs N ac^{-1} in 2017 (Table 4). Cover was not significant either year but residual N rate was significant only in 2017 where load increased as N rate increased. This is likely due to the blanked N application in 2015 which eliminated residual treatment effects in 2016. Under SbC the cumulative drainage was 13.6 inches in 2016 and 14.7 inches in 2017 as compared to the corn rotations where drainage in 2016 was 12.1 inches and in 2017 was 13.3 inches. The 1.4 and 1.5 inch increased drainage in soybean compared to corn is likely due to corn having greater evapotranspiration than soybean. Leaching findings were similar to results in Struffert et al. (2016) and indicate that even under no added N conditions mineralization can contribute to NO_3–N leaching. In 2017, the residual 0N treatment had an average load of 38 lbs N ac^{-1} compared 180N and 270N rates that leached 66 and 83lbs N ac^{-1} respectively. These data highlight the necessity for proper N rate and N management but they also indicate that even when there is no added N, leaching can occur.

The differences in weather, with more precipitation in 2017 than 2016 contributed to the differences in drainage but likely not rye establishment or yield and differences due to tillage practices were not evident likely because soybeans were able to supply their own N through their symbiotic relationship with rhizobia to counter long term N immobilization and N loss (Ott et al., 2005).

SUMMARY

A winter rye cover crop may prove to be a beneficial N management tool on irrigated sandy soils; specifically when seeded into the soybean phase of a corn–soybean rotation. Under these conditions, rye accumulated the most biomass and N uptake compared to when seeded into a corn rotation. Rye cover in CSb reduced NO_3–N leaching by 46 lbs (49%) while also reducing EONR. The 2016 results were encouraging but in 2017 leaching was not reduced significantly and Rye-Cover required a greater EONR, these results indicate that more research is needed to truly understand how well this system can work. Under CC and SbC Rye–Cover did not impact crop yield, EONR, or NO_3–N leaching suggesting that rye may not be an optimal N management tool under those systems. This research confirmed that NO_3–N leaching occurs even when no N is added to a system such as in soybean and check plots. This phenomenon stresses the importance of a multifaceted N management strategy. A rye cover crop seeded into the soybean phase of a corn–soybean rotation could be used as an N management tool on coarse texted soils; however, more information is needed to understand its true potential to reduce NO_3–N and especially its impact on EONR.

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Table 1. Aboveground rye cover crop biomass in dry matter basis.

Year	Rotation	Biomass	N Uptake
		lbs ac^{-1}	lbs N ac^{-1}
2016	CSb†	2573	62
	CC	391	11
	SbC‡	518	15
2017	CSb	1358	38
	CC	327	8
	SbC	527	14

† Rye biomass in CSb was fall seeded into standing soybean.

‡Rye biomass in SbC was fall seeded into standing corn.

Table 2. Corn and soybean yield averaged per rotation and cover crop by N rate. Rate for soybeans is the residual N rate from the previous year.

		2016		2017	
Rotation	N Rate	Rye–Cover	No–Cover	Rye–Cover	No–Cover
	lbs N ac^{-1}	bu ac^{-1}			
CSb	0	155.7	163.5	103.0	86.6
	90	235.7	229.5	175.4	190.4
	180	252.6	252.2	203.4	200.8
	225	256.2	269.2	192.1	190.6
	270	262.4	259.8	205.5	206.5
CC	0	94.0	95.7	56.5	63.4
	90	183.1	189.5	112.8	128.7
	180	253.8	250.9	171.8	164.9
	225	250.3	251.2	179.0	174.1
	270	260.4	257.9	174.4	182.8
SbC	0	64.7	67.5	55.7	59.4
	90	64.4	68.3	57.7	57.6
	180	64.6	66.1	55.8	57.5
	225	66.8	67.8	57.2	55.3
	270	67.4	67.6	58.3	57.1

	P>F†			P>F			P>F	
CSb	2016	2017	CC	2016	2017	SbC	2016	2017
Rate	<.0001	<.000	Rate	<.0001	<.0001	Rate	0.2417	0.8229
Cover	0.6470	0.253	Cover	0.8991	0.8403	Cover	0.0106	0.6519
RatexCover	0.7383	0.188	RatexCover	0.9849	0.3306	RatexCover	0.4743	0.3758

† Significantly different at P = 0.05

Table 3. Quadratic-plateau regression models for grain yield (y) in relation to N fertilizer rate (x), EONR at N:Corn price ratio of 0.1, and yield at EONR.

Year	Rotation–Cover	Regression Model	P>F	EONR	Yield at EONR
				lbs N ac^{-1}	bu ac^{-1}
2016	CSb - Rye	y = 155.70 + 1.219x - 0.004x2	<0.0001	152.8	256.5
	CSb - No	y = 164.50 + 0.849x - 0.002x2	<0.0001	204.6	261.6
	CC - Rye	y = 92.349 + 1.298x - 0.003x2	<0.0001	237.7	258.5
	CC - No	y = 94.840 + 1.331x - 0.003x2	<0.0001	224.6	255.6
2017	CSb - Rye	y = 103.00 + 1.071x - 0.003x2	<0.0001	165.1	199.6
	CSb - No	y = 86.575 + 1.804x - 0.007x2	<0.0001	118.0	198.9
	CC - Rye	y = 53.089 + 0.831x - 0.001x2	<0.0001	266.7	177.2
	CC - No	y = 64.185 + 0.824x - 0.001x2	<0.0001	249.5	179.4

Table 4. Season-long NO_3–N load leached below the root zone for various N rates in continuous–corn, corn following soybean, and soybean following corn with the residual N rate from the previous corn crop.

		2016			2017		
Rotation	Rate	Rye–Cover	No–Cover	Mean	Rye–Cover	No–Cover	Mean
	lbs N ac^{-1}	load lbs N ac^{-1}					
CSb	0†	36	81	59b	22	71	47ns
	180	56	101	79a	39	78	58ns
	270	54	103	79a	56	79	68ns
	Mean	49B‡	95A	-	39NS	76NS	-
CC	0	25	28	26ns	25	35	30c
	225	61	33	47ns	59	56	58b
	270	62	98	80ns	87	68	78a
	Mean	49NS§	53NS	-	57	53	-
SbC	0	42	64	53ns	37	38	38c
	180	70	58	64ns	78	54	66b
	270	53	43	48ns	82	85	83a
	Mean	55NS	55NS	55NS	66 NS	59NS	62NS

†Lysimeters were placed in the 0N, EONR, and 270N rate plots. For CSb, and the SbC residual, the EONR was 180 lbs N ac^{-1} and in CC the EONR was 225 lbs N ac^{-1}.

‡Same lowercase letters within column are not significantly different while same uppercase letters across rows are not significantly different at P = 0.05.

§ NS/ns, not significant.