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Effects of nitrogen application timing and source on nitrate-nitrogen leaching and crop yields

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Introduction

Subsurface drainage systems have been intensively installed in the Midwest to enhance agricultural production by removing excess water from naturally poorly drained and somewhat poorly drained agricultural soils. However, despite positive aspects, numerous studies have reported artificial subsurface drainage as one of the primary pathways for nitrate-nitrogen (nitrate-N) loss from agricultural fields to surface water (Skaggs et al. 1994; David et al. 1997; Gilliam et al. 1999; Jaynes et al. 1999; Blann et al. 2009). Nutrient reduction strategies were developed and are being implemented across the Midwest to reduce nutrient loading to local and downstream waters. State-wide strategies were developed in response to the 2008 Gulf Hypoxia Action Plan. In order to reduce nitrate-N leaching through subsurface drainage systems, the Iowa Nutrient Reduction Strategy suggests implementation of nitrogen management practices including nitrogen application timing, source of nitrogen fertilizer, nitrogen application rate, and use of a nitrification inhibitor. The objectives of this study were to document the effects of nitrogen application timing and source on nitrate-N leaching and crop yield. Findings from this study can be used to evaluate the applicability of nitrogen management practices for local conditions, as well as describe the environmental and producer benefits of practices investigated.

Materials and methods

Field experiments were conducted at the Agricultural Drainage and Water Quality Research and Demonstration site located near Gilmore City in Pocahontas County, Iowa, from 2011 to 2014. Predominant soils at the site were Nicollet, Webster and Canisteo clay loams with 3-5% organic matter content and average slope of 0.5-1.5%. The research site was divided into 78 separate 0.14 ac plots and been managed in a randomized complete block design. The five treatments of interest in this study consisted of 40 experimental plots with both phases of a corn (*Zea mays* L.) and soybean (*Glycine max* [L.] Merr.) rotation to simulate a typical cropping system for Iowa conditions. Furthermore, each of five treatments consisted of 8 plots with a corn-soybean rotation, where 4 plots were in corn and 4 in soybean each year.

Each plot was drained separately and had subsurface drains installed at a depth of approximately 3.5 ft with a drain spacing of 25 ft. To prevent lateral water flow and cross contamination, subsurface drains were installed on the border between plots, and only the center drain was monitored for drainage volume and nitrate-N concentration. Subsurface drain flow was monitored continuously using water flow meters and effluent pumps. Composite water samples were collected on a flow-proportional basis as dictated by flow patterns. Nitrate-N loss (lb/ac) with subsurface drainage water was calculated by multiplying nitrate-N concentration (mg/l) with drainage volume (in) measured between sampling dates. This loss was divided by annual flow to determine an average annual flow-weighted nitrate-N concentration to be used for comparison.

Precipitation was recorded at the weather station located at the site and compared with long-term average (1960-2010) from the National Climate Data Center (NOAA) weather station located nearby in Pocahontas, Iowa.

The effects of nitrogen application timing was studied using three treatments involving the application of aqua-ammonia in the fall (CP-FA-150), spring (CP-SP-150) and as a late season side-dress (CP-SIDEDRESS-150). The other practice examined in this study is the source of nitrogen fertilizer, which included the application of aqua-ammonia (CP-SP-150), urea (CP-SPUREA-150), and poly-coated urea (CP-SPPOLY-150). In all years of this study, the same nitrogen application rate of 150 lb/acre was used for all treatments being investigated. As typical in a corn-soy rotation, only the corn phase (C) of the treatments received nitrogen, while the soybean phase (S) of production received no nitrogen.

Primary tillage was performed using a chisel plow in the fall after corn harvest for the plots being planted in soybeans the next year. Secondary tillage for seedbed preparation was performed using a field cultivator in the spring before planting for both corn and soybean plots. Spring disking was only necessary a few times after primary tillage, when field conditions required additional tillage. Weeds were controlled with annual application of herbicides. The grain yield for each plot was measured using a plot-scale combine with all stover left in the field. Agronomic field activities were carried out according to local conditions and timetables. The detailed schedule of field activities is given in Table 1.

Table 1. Field activities at the study site.

Field operations	2011	2012	2013	2014
Primary tillage	29 Nov*	17 Nov*	13 Nov*	21 Nov*
Secondary tillage	9 May	8 May	13 May	7, 22 May
Corn planting	9 May	10 May	14 May	7 May
Soybean planting	11 May	16 May	6 Jun	22 May
Corn harvest	14 Oct	4 Oct	29 Oct	8 Oct
Soybean harvest	6 Oct	25 Sep	21 Oct	16 Oct
Fall aqua-ammonia application	29 Nov*	11 Nov*	16 Nov*	20 Nov*
Spring aqua-ammonia application	16 Jun	19 Jun	13 Jun	25 Jun
Side-dress aqua-ammonia application	29 Jun	21 Jun	14 Jun	26 Jun
Urea application	6 May	25 Apr	13 May	6 May
Poly-coated urea application	6 May	25 Apr	13 May	6 May

* Field operation completed in the previous year.

Statistical analyses were conducted using Statistical Analysis System software, version 9.3 (SAS 2011) to study treatment effects on subsurface drainage, flow-weighted nitrate-N concentration, and crop yield. The general linear model procedure (PROC GLM) was used to determine the statistical significance, and the mean values for the variables investigated were separated using a least significant difference (LSD) test at p=0.05. The statistical analyses were conducted separately for corn and soybean yield data.

Results

Precipitation data show that 2011, 2012 and 2013 were drier, while 2014 was slightly wetter than the long-term average for the study area (Table 2). Overall, 2012 was the driest year during the study period with total annual precipitation of 34% below normal. Differences in monthly rainfall totals were found when values observed in the long-term and study period were compared. Precipitation in January, March, July, September, November and December of every year of this study was substantially less than in the corresponding months in the long-term. In contrast, precipitation amounts received at the research site in April of every year were above the long-term norm. Most of the annual precipitation occurred during the potential growing season (April to October). Growing season precipitation for the long-term average was 80% of the annual total, while in the period of monitoring (2011-2014) it ranged from 78% in 2012 to 97% in 2014. In addition, three of the four years of this study received at least 88% of total annual precipitation within the growing season months.

Table 2. Precipitation at the research site during the study period and long-term normal from local NOAA weather station.

	2011	**2012**	**2013**	**2014**	**Normal (1960-2010)***
Month			*inches*		
January	0.0	0.1	0.2	0.0	0.8
February	1.2	1.6	0.3	0.3	0.8
March	0.3	1.8	0.7	0.2	2.0
April	3.4	4.9	7.8	4.8	3.1
May	4.0	2.0	7.3	3.4	3.9
June	7.3	3.7	3.2	11.9	4.5
July	2.9	1.2	1.8	1.4	4.1
August	0.9	1.0	1.4	6.1	4.4
September	0.9	2.1	0.4	3.1	3.1
October	0.2	1.5	2.1	1.5	2.1
November	0.3	0.5	1.4	0.3	1.5
December	1.0	0.6	0.0	0.0	1.1
Year	22.3	20.8	26.6	33.0	31.5

*From Climatological Data for Iowa, National Climate Data Center for Pocahontas, Iowa.

During the period of the study, average subsurface drainage volume from all treatments represented from 4% to 43% of the annual precipitation in 2012 and 2011, respectively. In general, drainage volumes were affected by temporal distribution of precipitation and intensity of individual rainfall events, as well as the precipitation from the previous year since it influences antecedent soil water content. As an example, years 2011 and 2012 received similar amounts of annual precipitation of 22.3 and 20.8 inches, respectively, but annual drainage volumes were considerably different with all treatments averaging 9.6 inches in 2011 and 0.9 inches in 2012. Subsurface drainage volumes by year and treatment with statistical significance are shown in Table 3. Treatments included in this study did not show consistent statistical effects of drainage. Overall, the corn phase of the treatments investigated tended to have higher subsurface drainage than the soybean phase. Although, in most cases, this difference was not statistically significant.

Table 3. Average annual subsurface drainage from the treatments investigated.

	2011	2012	2013	2014	4-year average
Treatment			*inches*		
CP-FA-150-S	8.6ab	0.8ab	5.3c	9.4a	6.0d
CP-FA-150-C	8.0ab	0.4b	8.9ab	8.9a	6.5bcd
CP-SIDEDRESS-150-S	10.2ab	1.3ab	6.3bc	8.6a	6.6abcd
CP-SIDEDRESS-150-C	13.4a	0.9ab	7.9abc	9.0a	7.8ab
CP-SP-150-S	10.3ab	1.8a	8.6ab	9.1a	7.4abc
CP-SP-150-C	10.2ab	1.2ab	10.0a	10.6a	8.0a
CP-SPUREA-150-S	7.7b	1.4ab	5.0c	9.6a	5.9d
CP-SPUREA-150-C	10.4ab	0.5b	7.6abc	8.9a	6.9abcd
CP-SPPOLY-150-S	7.9ab	0.5b	6.4bc	9.0a	5.9d
CP-SPPOLY-150-C	9.5ab	0.5b	6.8bc	8.7a	6.4cd

Note: Means within years (i.e., columns) with a different letter are significantly different (p = 0.05).

Average annual flow-weighted nitrate-N concentrations for the nitrogen application timing and nitrogen source treatments are summarized in Tables 4 and 5, respectively. Fertilizer application timing had different impacts on nitrate-N concentrations for corn and soybean phases. The four-year average nitrate-N concentration for the soybean phase with fall applied nitrogen to the previous corn crop had significantly lower nitrate-N concentrations when compared to the spring and side-dress applications of nitrogen. This could be due to longer time between two sequential nitrogen applications when nitrogen is available for leaching, crop uptake and denitrification processes. For the corn phase the side-dress application of aqua-ammonia resulted in significantly reduced nitrate-N concentrations when compared with the fall and spring treatments. When averaged over the four-year study period, no significant differences in the flow-weighted nitrate-N concentrations were observed between nitrogen source treatments. However, treatments under the application of poly-coated urea tended to have lower nitrate-N concentrations for both corn and soybean phases.

Table 4. Average annual flow-weighted nitrate-N concentration for the nitrogen application timing treatments.

	2011	2012	2013	2014	4-year average
Treatment			*Nitrate-N concentration (mg/l)*		
CP-FA-150-S	10.1b	9.2b	15.8c	14.1c	12.3c
CP-FA-150-C	11.4b	14.3ab	25.5a	22.1a	18.3a
CP-SIDEDRESS-150-S	12.1ab	9.7ab	23.7ab	16.6bc	15.6ab
CP-SIDEDRESS-150-C	9.8b	9.8ab	17.8bc	16.6bc	13.5bc
CP-SP-150-S	12.7ab	14.9a	21.9abc	18.0b	16.9a
CP-SP-150-C	15.4a	14.3ab	21.3abc	18.1b	17.3a

Note: Means within years (i.e., columns) with a different letter are significantly different (p = 0.05).

Table 5. Average annual flow-weighted nitrate-N concentration for the nitrogen source treatments.

	2011	2012	2013	2014	4-year average
Treatment	---------------- *Nitrate-N concentration (mg/l)* ----------------				
CP-SP-150-S	12.7ab	14.9a	21.9a	18.0b	16.9ab
CP-SP-150-C	15.4a	14.3a	21.3a	18.1b	17.3ab
CP-SPUREA-150-S	12.1ab	13.0a	23.1a	18.0b	16.6ab
CP-SPUREA-150-C	11.7ab	14.3a	19.6a	25.3a	17.7a
CP-SPPOLY-150-S	10.6b	13.8a	16.8a	15.5b	14.2b
CP-SPPOLY-150-C	11.5ab	12.8a	19.0a	20.5ab	16.0ab

Note: Means within years (i.e., columns) with a different letter are significantly different (p = 0.05).

When flow-weighted nitrate-N concentrations are averaged over the corn-soybean rotation, there are no statistical differences in the four-year average concentrations between treatments either for nitrogen application timing or source of nitrogen fertilizer (Tables 6 and 7).

Table 6. Four-year (2011-2014) average annual flow-weighted nitrate-N concentration for the nitrogen application timing treatments averaged over the corn-soybean rotation.

	2011	2012	2013	2014	4-year average
Treatment	---------------- *Nitrate-N concentration (mg/l)* ----------------				
CP-FA-150	10.7b	11.7ab	20.7a	18.1a	15.3a
CP-SIDEDRESS-150	11.0b	9.7b	20.8a	16.6a	14.5a
CP-SP-150	14.1a	14.6a	21.6a	18.0a	17.1a

Note: Means within years (i.e., columns) with a different letter are significantly different (p = 0.05).

Table 7. Four-year (2011-2014) average annual flow-weighted nitrate-N concentration for the nitrogen source treatments averaged over the corn-soybean rotation.

	2011	2012	2013	2014	4-year average
Treatment	---------------- *Nitrate-N concentration (mg/l)* ----------------				
CP-SP-150	14.1a	14.6a	21.6a	18.0ab	17.1a
CP-SPUREA-150	11.9ab	13.7a	21.3a	21.6a	17.1a
CP-SPPOLY-150	11.1b	13.3a	17.9a	17.7b	15.1a

Note: Means within years (i.e., columns) with a different letter are significantly different (p = 0.05).

There were few significant differences in crop yields between treatments (Figures 1, 2, 3, and 4). Significant differences in soybean yield were observed among nitrogen application timing treatments in 2012, when significantly lower soybean yield was measured for the fall applied nitrogen treatment when compared to the side-dress treatment. Notably, in 2012 soybean yields were reduced consistently for all treatments included in this study due to severe drought conditions, but corn yields were not affected. The four-year average soybean yield for the poly-coated urea treatment (CP-SPPOLY-150-S) was statistically higher than the urea treatment (CP-SPUREA-150-S). Overall, the results indicate limited yield impacts between treatments being studied. This might be due to large variability in crop yields among the experimental plots, treatments, and years.

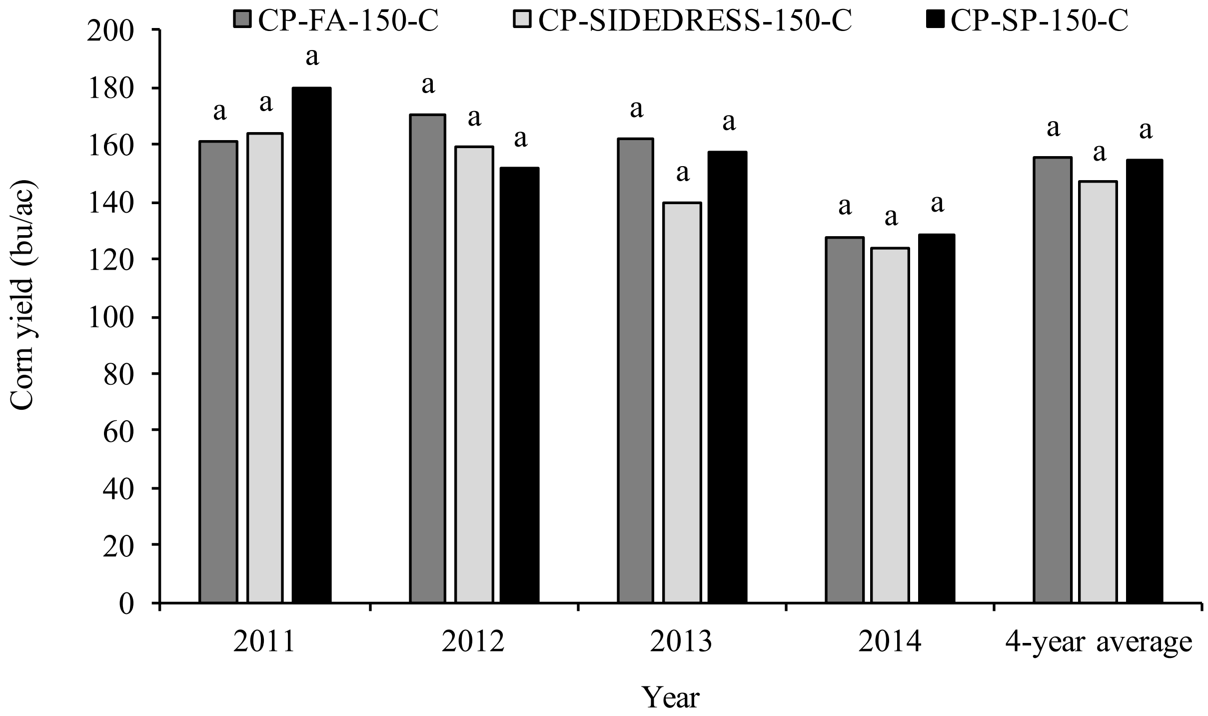

Figure 1. Corn yields (bu/ac) for the nitrogen application timing treatments. Means within years with a different letter are significantly different (p = 0.05).

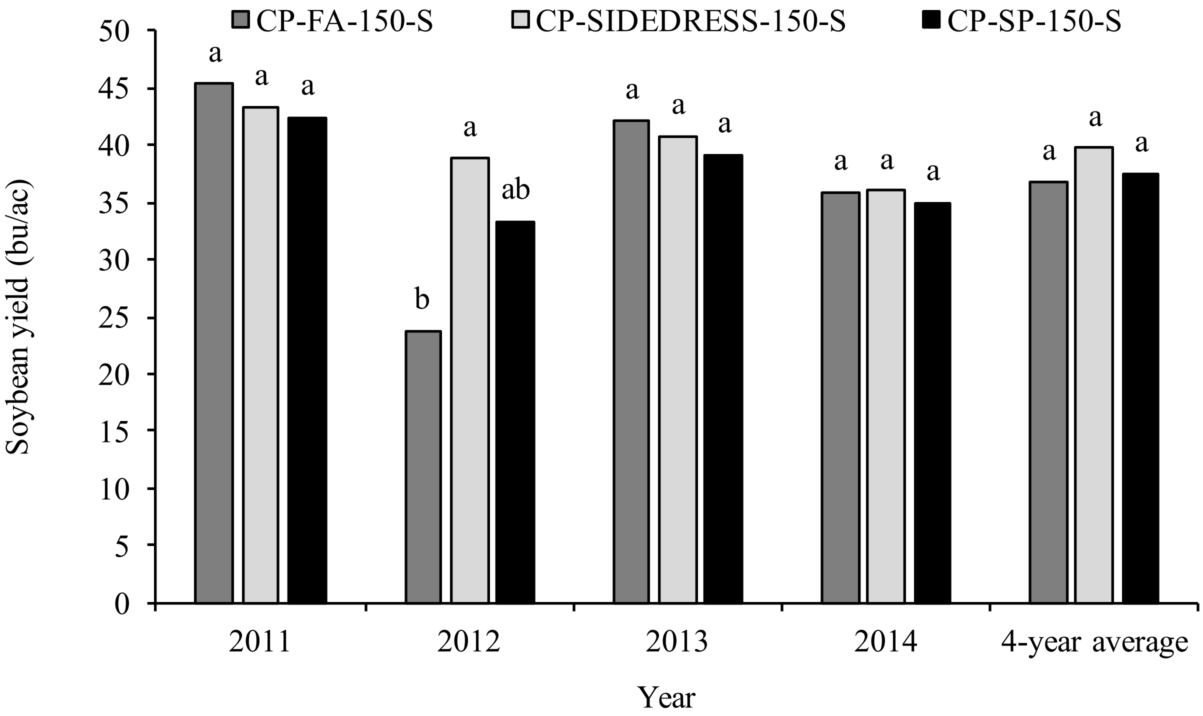

Figure 2. Soybean yields (bu/ac) for the nitrogen application timing treatments. Means within years with a different letter are significantly different (p = 0.05).

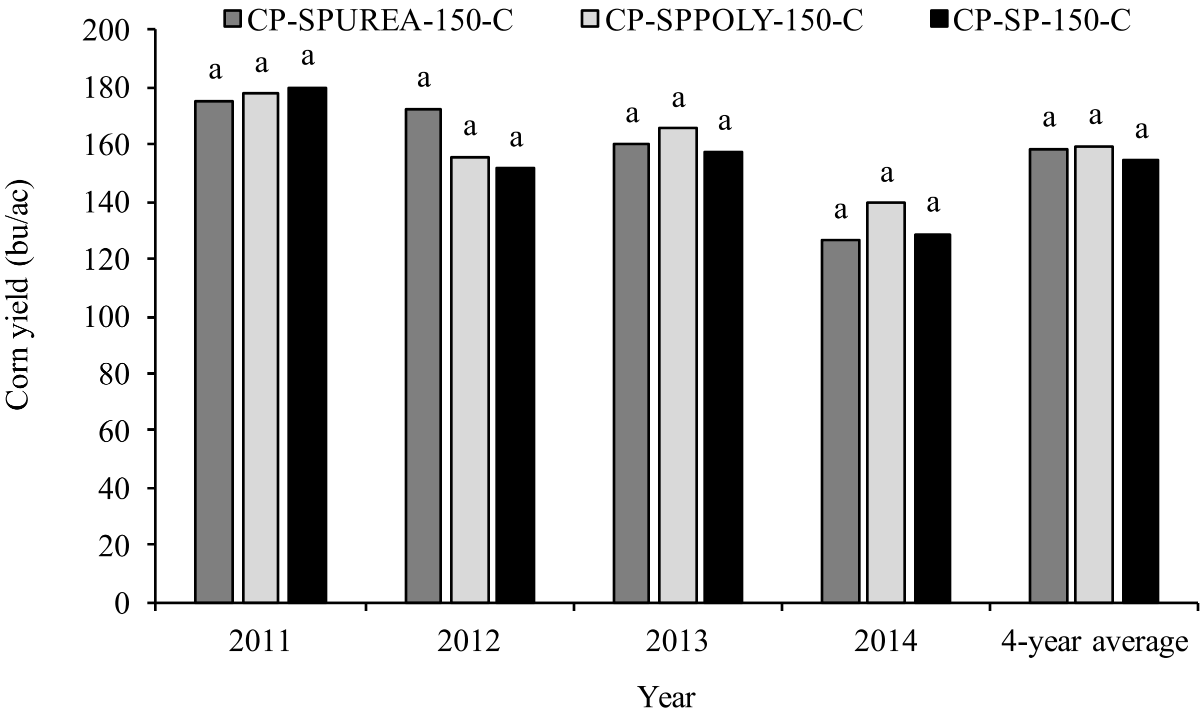

Figure 3. Corn yields (bu/ac) for the nitrogen source treatments. Means within years with a different letter are significantly different (p = 0.05).

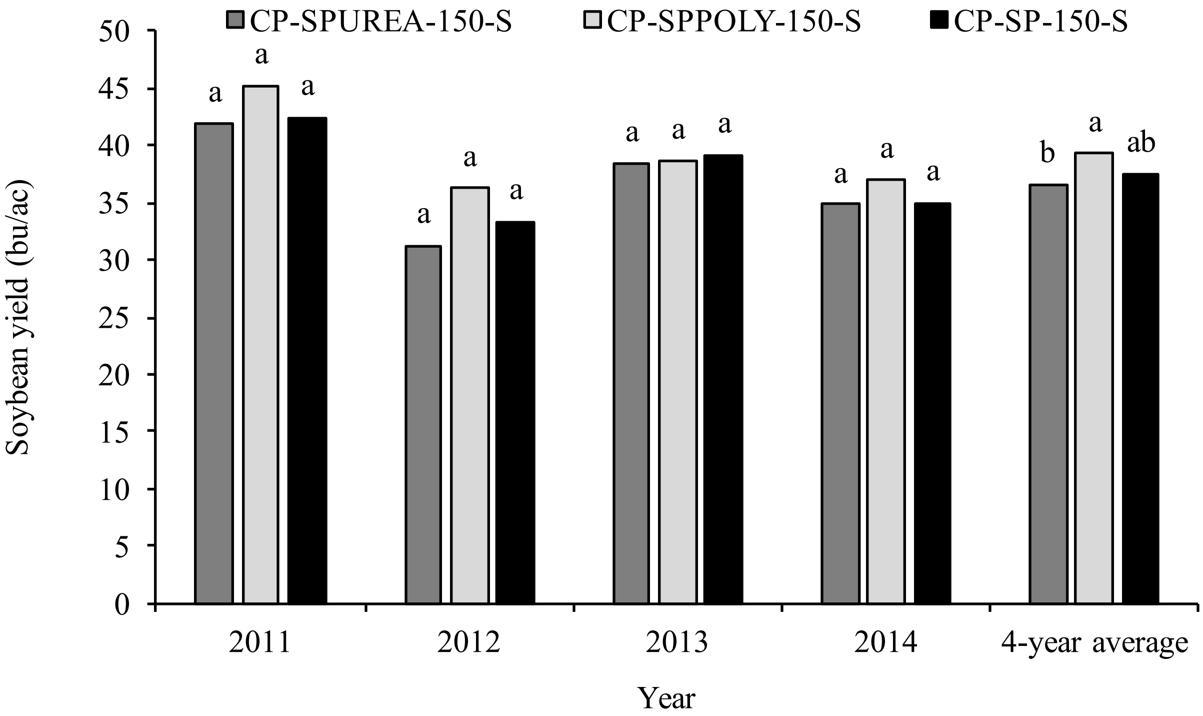

Figure 4. Soybean yields (bu/ac) for the nitrogen source treatments. Means within years with a different letter are significantly different (p = 0.05).

Conclusions

This study showed limited impact of nitrogen application timing on nitrate-N concentrations. The use of poly-coated urea as a source of nitrogen fertilizer showed some potential to reduce nitrate-N concentrations in subsurface drainage.

Year-to year variations in total annual precipitation and seasonal distribution of rainfall events affected drainage volumes and nitrate-N concentrations in subsurface drain flow. A wet spring in 2013 that was preceded by an extremely dry year in 2012 resulted in increased nitrate-N concentrations for all treatments included in this study.

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