NITROGEN MANAGEMENT OF TEMPORARY WATERLOGGED SOIL TO IMPROVE CORN PRODUCTION AND REDUCE ENVIRONMENTAL N LOSS

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Abstract

During the 2011 growing season excessive soil moisture in the Unites States accounted for at least 30% of the total crop loss to environmental stresses resulting in more than $3 billion dollars in insurance indemnities paid to farmers. The objectives of this study were to: (i) assess grain yield and N silage uptake for both rescue and non-rescue treatments of different enhanced efficiency products, (ii) determine soil N content among treatments throughout the growing season, and (iii) evaluate PCU release during waterlogging conditions, (iv) quantify soil nitrous oxide and carbon dioxide emissions among N treatments during soil waterlogging and initially after soils began to dry. A three-year study of N loss of enhanced efficiency products during waterlogging durations planted to corn (*Zea mays* L.) was initiated in 2012 in Northeast Missouri. Fertilizer treatments were urea (NCU), urea plus nitrapyrin (NCU+NI), and polymer coated urea (PCU) (N-Serve®, Dow AgroSciences) (ESN® Agrium, Inc.) applied at 168 kg N ha^{-1}. Waterlogging durations of 0, 24, 48, and 72 hours were initiated at the V6 growth stage. A rescue N application of 83 kg N ha^{-1} of urea plus N-(n-butyl) thiophosphoric triamide (NBPT) was applied at V10 to half of all treatments (NCU+UI) (Agrotain®, Koch Agronomic Services). In the severe drought year of 2012 there were no differences in yield among fertilizer treatments, but a significant grain yield increase did occur from with the rescue N application in the NCU and NCU+NI treated plots after 72 hours of waterlogging. There were no significant increases in the release rate of PCU under waterlogged or no waterlogged conditions. Nitrous oxide emissions were greater with PCU and NCU+NI. This research will be continued through the 2013 and 2014 growing seasons.

Introduction

Corn production losses due to temporarily flooded or saturated soils are a persistent problem in Missouri and can occur in both upland and low-lying areas. During 2011, the combination of rain and snowmelt temporarily flooded 207,000 acres of agricultural land, resulting in $176 million in lost revenue in Missouri. Row crop agriculture in floodplain soils in the Missouri and Mississippi River Basins as well as its tributaries in Missouri are highly productive systems and represent a large land area in the state of Missouri. For example, 67% of the Upper Mississippi River Basin is in managed agricultural land covering an area of approximately 4.9 million acres.

The extent to which flooding injures corn is determined by several factors including: 1) timing of flooding during the life cycle of corn, 2) frequency and duration of flooding, and 3) air-soil temperatures during flooding. Corn younger than about V6 is more susceptible to ponding damage partly because the corn plant's growing point remains below ground until about V6 (Nielsen, 2011). Other impacts of flooding that affect corn growth after flooding include deposition of mud and crop residues on plants, sand deposition, formation of soil crusts, and development of plant diseases.

Nitrogen deficiencies and losses due to flooding may occur because of denitrification and leaching losses as well as reduced crop N uptake resulting from low oxygen levels in flooded soils. Denitrification rates under saturated soil conditions in Illinois ranged from 1 to 2 % per day at soil temperatures less than 55 ºF, and up to 5 % per day at soil temperatures greater than 65 ºF (Hoeft, 2004). Yield losses with flooding have also been reduced in plots treated with high N fertilizer rates compared to those of low N fertilizer applications (Ritter and Beer, 1969). Little is known if enhanced efficiency N fertilizers such as polymer-coated urea (PCU) or addition of a nitrification inhibitor may reduce N loss with short-term flooding and improve recovery of corn after flooding. Previous research in Missouri has shown that application of PCU in lower landscape positions in upland agricultural fields where soils are generally wetter had over 20 bu/acre increase in grain yield compared to the yield of conventional urea and an estimated gross profit increase of between $20 to $260/acre with use of PCU (Noellsch et al., 2009).

Development of an N fertilizer strategy for temporarily flooded or saturated soils may help to increase corn production and reduce environmental N loss. This strategy may include N fertilizer recommendations combined with economic cost-benefit analysis for both pre-flood and post-flood conditions.

Approach

The overall goal of this research is the development of an economically profitable N fertilizer strategy for both pre- and post-flood conditions that will increase corn production and decrease environmental N loss. Specific objectives include:

1. To determine the effects of duration of flooding on corn growth and N use efficiency (NUE).

2. To assess the use of different N sources including PCU and nitrification inhibitor and a post-flood N fertilizer treatment.

3. To evaluate the economic costs and benefits of using these fertilizer sources under different flooding conditions.

Materials and Methods

A three-year field trial was established in 2012 at the University of Missouri Greenley Experiment Station in Northeast Missouri. The specific field was chosen because of its flat topography which would allow for a uniform ponding of water on the soil surface. Soil classification for the field is a Putnam silt loam (fine, smectitic, mesic Vertic Albaqualfs). Soil samples were collected in increments of 0-4, 4-8, and 8-12 inch depths before fertilizer application and incorporation and corn planting to characterize initial soil conditions (Table 1). Some differences in initial soil characteristics, especially soil pH_s and neutralizable acidity (NA) were observed among the three replicates in the field so an experimental design was implemented to account for this variation.

The field was separated into 15 by 100 foot plots of six 30-inch rows of DEKALB Corn Seed 62-97 planted at 30,000 seeds/acre on April 3rd. Nitrogen fertilizer treatments of a control (CO) and 150 lbs N/acre of urea (NCU), urea plus nitrapyrin nitrification inhibitor (NCU + NI) (N-Serve®, Dow AgroSciences, Indianapolis, Indiana), and polymer coated urea (PCU) (ESN®, Agrium, Inc., Calgary, Alberta). All fertilizer N treatments were incorporated immediately after application with a cultivator. The experimental design is a randomized split-split block with 3 replications.

Ponding of water occurred for durations of 0, 24, 48, and 72 hours at V6 corn growth stage on June 1st using temporary soil levees to surround each flooding block (Figure 1). Levees were knocked down to allow ponded water to escape after intended flooding duration had ceased. On June 21st, a rescue N fertilizer application of 75 lbs N acre^{-1} of urea plus NBPT (N-(n-butyl) thiophosphoric triamide) urease inhibitor (NCU + UI) at 1 gal/ton was applied to half of each original fertilizer treatment (Agrotain®, Koch Agronomic Services, Wichita, Kansas). Following rescue application each 15 by 100 foot fertilizer treatment was split into two 15 by 50 foot plots, one being with the rescue application and the other without the rescue application. A rescue application of 75 lbs N acre^{-1} was applied as an estimate of an economical optimal N rate for yield response at corn growth stage V10 determined from SPAD 502 chlorophyll meter readings (Konica Minolta, Hong Kong) taken after flooding on June 12th (Scharf *et al*., 2006) (Table 2). Percent of polymer coated urea release was monitored throughout the growing season among the 0 and 72 hour flooding regimes by placing mesh packets with ten grams of ESN in the soil (Figure 3). The remaining weight in each packet was recorded after removal and divided by its original weight. This value was then subtracted from one to determine the percent of urea lost.

Results and Discussion

The chlorophyll meter readings taken after flooding on June 12th in 2012 showed an increase in chlorophyll content with N fertilizer application compared to the control. At the 24 and 72 hour flooding, PCU had a higher chlorophyll content compared to urea (Table 2). This result suggests an effect of the fertilizer source on plant N content. No consistent effects of flooding duration were observed on plant chlorophyll content.

Corn grain harvest occurred on August 30th. Corn grain yields were harvested from the total row length of the two center rows from each N treatment. Figure 2 shows there were significant yield increases of 12 and 10.4 bu/acre among PCU and NCU + NI, respectively, versus the control where no N was applied for the 72 hour flooded plots. The rescue application of urea + UI had significant yield increases in all flooding durations compared to the control were no N was applied. Yield increases of 11 bu/acre occurred as a result of the rescue application with NCU fertilizer plots of 48 and 72 hour flooding durations. An increased yield of 10 bu/acre occurred with rescue N application in the NCU + NI treated plots at a 72 hour flooding duration. No significant yield increases we observed with a rescue N application in PCU treatments (Fig. 2).

Corn silage was collected from 20 foot of one row and total biomass dry weight, tissue N and N uptake were determined (Table 3 & 4). Silage yield increases occurred among PCU versus the control with no N fertilizer for 0, 24, and 72 hour flooding durations where no rescue N application was applied. There were no significant increases among PCU and the control where no N was applied in these flooding duration plots with the rescue application as a result of decreases in biomass. Plants in the 24 and 48 hour flooding plants had more N uptake with PCU and NCU + NI than where no N was applied. There was no significant difference between the amounts of N uptake with NCU in comparison with no N application.

All yields and N uptake results among the treatments were reduced during the 2012 research season because of the severe drought that occurred during the summer months (Fig. 3). The cumulative precipitation total from planting to harvest was 10.7 inches at the Greenley Research Station. The prior ten year average for this time period at Greenley Research Station was 27.5 inches. The drought reduced corn response to all N fertilizer treatments

Soil samples were collected from N fertilizer treatments before (May 30th) and after (June 11th) temporary flooding events (Table 5 and 6 A & B). These samples were taken from 0-4, 4-8, and 8-12 inch depths and analyzed for soil inorganic N (ammonium and nitrate-N). The PCU treatment generally maintained higher soil ammonium-N and nitrate-N concentrations among all the N treatments. There was a significant decrease in soil NO_3^- -N concentration from all plots treated with enhanced efficiency N fertilizers from 0 to 24 hours of soil saturation at a depth from 0-4 inches (Figure 4). The PCU treatment was the only N fertilizer treatment to continue significantly decreasing in soil NO_3^- -N concentration between 24 to 48 hours of soil saturation at a depth from 0-4 inches. No decrease in NH_4^+ concentration occurred as a result of saturated soils.

Percent of PCU was monitored throughout the 2012 growing season among the 0 and 72 hour flooding durations by placing mesh packets with ten grams of ESN into the soil (Figure 5). The remaining weight in each packet was recorded after removal and divided by its original weight. This value was then subtracted from one to determine the percent of urea lost. The results show a no significant PCU release between the 0 and 72 hour flooding treatments.

Soil surface effluxes of nitrous oxide and carbon dioxide gases were measured prior, during, and after soil saturation events to determine changes in gas loss from the soil under different flooding durations and enhanced efficiency N treatments (Figures 5 & 6). Gases were collected using small sealed chambers fitted with rubber septa for sample extraction using a syringe and placed into sealed vials. These gases were analyzed using gas chromatography and an automated sampler. The results show higher emissions of soil nitrous oxide under the saturated soil conditions versus when soils were not saturated (Fig. 5 A & B). The results also indicate that PCU had higher efflux of soil nitrous oxide at some times during the 72 hour saturation period compared to NCU and NCU + NI possibly due to the higher initial pre-flood soil nitrate-N in the PCU-treated plots compared to the other N fertilizer treatments (Table 5A).

Summary

- First year results from a three-year trial indicate that there was no significant effect of enhanced efficiency fertilizer treatment on grain yield, but this response was possibly due the effects of the extended drought conditions experienced in 2012.
- The rescue N fertilizer application (NCU + UI) caused a significant increase in grain yield compared to the non-rescue treated plots only in the 72 hour flooding duration areas

after initial fertilizer treatments of NCU and NCU + NI. However, corn N uptake was not significantly different among those treatments.

- The release rate of urea from PCU was not increased over the 72 hour flooding event.
- Fertilizer treatments of pre-plant PCU and NCU + NI had increased soil nitrous oxide flux compared to NCU over a 72 hour flooding duration possibly due to higher soil nitrate concentrations at the time of flooding.
- This research will be conducted for two more years and a 7 day flooding duration treatment will be added starting the second year.

Acknowledgments

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Table 1. Initial soil test for 2012 field study site at the Greenley Research Station by replicate and soil depth.

Replicate	Depth	pH_s	NA	OM	Bray 1 P	Exch. Ca	Exch. Mg	Exch . K	CEC	B.D.
	inches		meq/ 100 g	- % -	--------------- lbs/acre			----------------	meq/ 100 g	g/cm^3
1	0-4	6.4	1.0	2.8	53	5098	388	295	15.7	1.47
	4-8	6.5	1.0	2.2	22	5058	329	163	15.2	1.56
	8-12	5.5	3.5	1.6	9	4377	464	172	16.6	1.45
2	0-4	6.3	1.0	2.4	68	4403	315	383	13.8	1.38
	4-8	6.6	1.0	1.7	24	4938	343	185	15.0	1.32
	8-12	5.9	3.0	1.6	8	4477	455	182	16.3	1.46
3	0-4	5.6	3.0	3.0	53	4295	356	413	16.2	1.44
	4-8	5.9	2.1	2.1	16	4379	347	189	15.1	1.55
	8-12	5.0	1.9	1.9	6	4844	609	210	20.4	1.46

†Abbreviations: NA, Neutralizable Acidity; OM, Organic Matter; P, Bray-1 Phosphorus; Exch. Ca, Exchangeable Calcium; Exch Mg, Exchangeable Magnesium; Exch. K, Exchangeable Potassium; CEC, Cation Exchange Capacity; B.D, Bulk Density.

Figure 1. Ponding of water in a 72 hour flooding duration block on June 1st.

Table 2. Average SPAD chlorophyll readings on June 12th after flooding to determine an economically optimum N rate for rescue N application of urea plus urease inhibitor according to N treatments and temporary flooding durations.

N Fertilizer Treatment	Saturation Duration			
	0	24	48	72
	------------------------------ SPAD units -----------------------------			
Control	42.7	41.2	40.1	37.8
Urea	47.4	45.7	47.2	45.1
Urea + NI[†]	48.3	48.6	46.0	45.1
PCU[‡]	49.0	51.8	48.7	48.6
$LSD_{(0.05)}$ [††]	--------------------------------- 3.2 ---------------------------------			

[†]Urea + nitrification inhibitor

[‡]Polymer coated Urea

[††]Fisher's protected least significant difference at $p<0.05$.

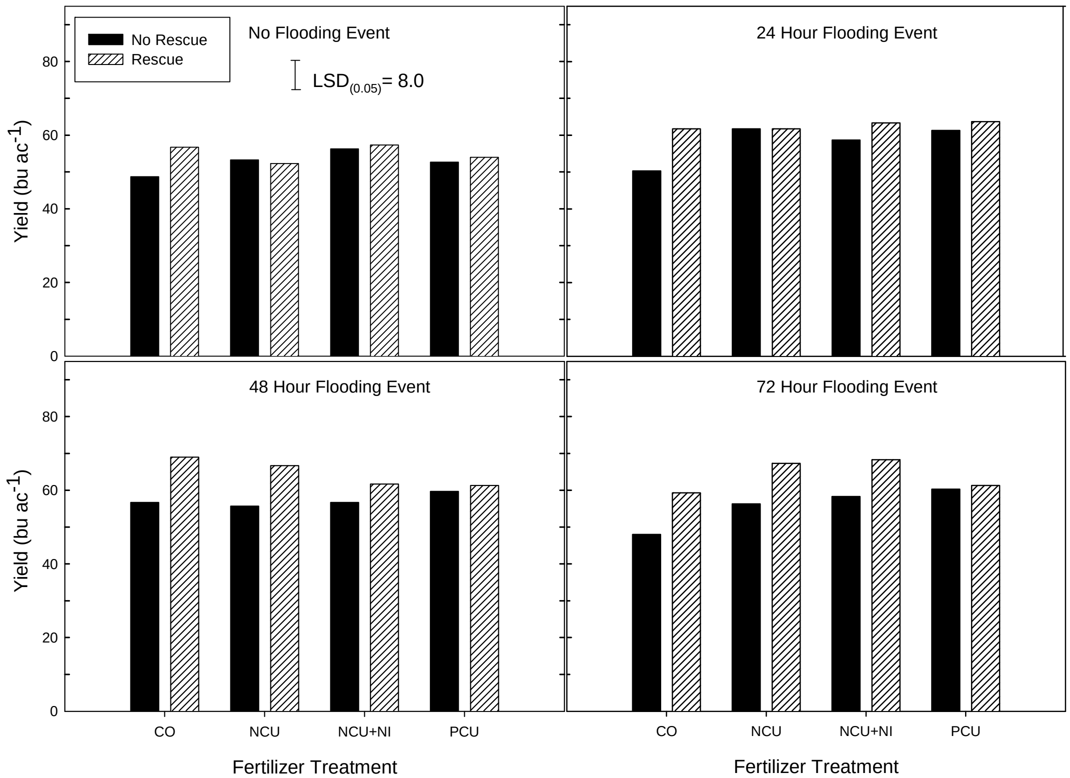


Figure 2. Average corn grain yield comparing no rescue N plus urease inhibitor with rescue N plus urease inhibitor for each N treatment and flooding duration. (†Abbreviations: CO, Control; NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea; LSD, least significant difference at $p < .05$ between no rescue N plus urease inhibitor and with rescue N plus urease inhibitor.)

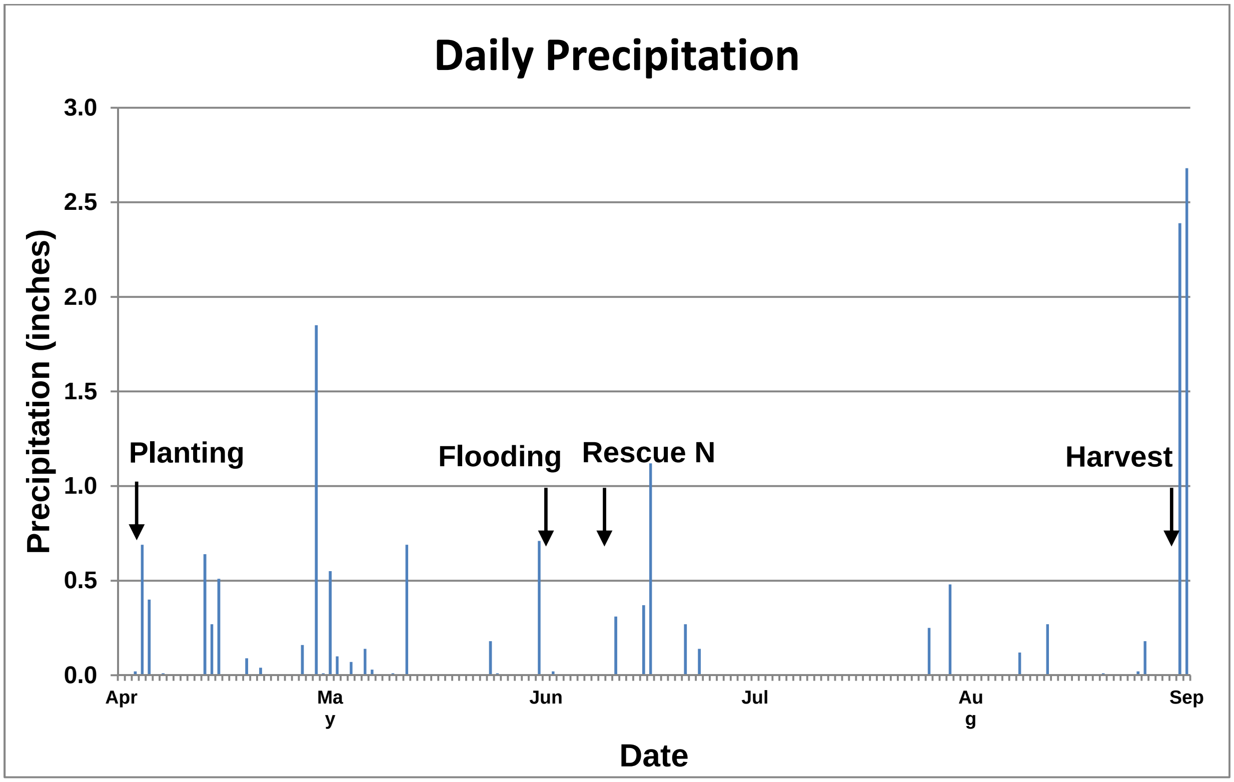


Figure 3. Daily precipitation values for the field research growing season from April 1st – August 28th, 2012 at the Greenley Research Station. Cumulative total for this time period was 10.7 inches. The prior ten year average from this time period at Greenley Research Station as 27.5 inches.

Table 3. Average corn silage yield with corresponding N treatments and temporary flooding durations with and without rescue N plus urease inhibitor application.

N Fertilizer Treatment	Saturation Duration 0	24	48	72
	------------------------ tons dry matter/acre -----------------------			
Without Rescue N				
Control	1.84	1.36	1.72	1.25
Urea	2.14	1.82	1.85	1.77
Urea + NI†	2.07	2.06	1.75	2.05
PCU‡	2.43	2.18	2.01	1.90
With Rescue N				
Control	1.98	1.60	1.83	1.49
Urea	1.67	1.94	1.97	2.01
Urea + NI†	1.59	1.97	1.89	1.90
PCU‡	1.81	2.02	2.52	1.84
$LSD_{(0.05)}$ ††	------------------------------------ 0.53 -------------------------			

†Urea + nitrification inhibitor
‡Polymer coated Urea
††Fisher's protected least significant difference at p<0.05.

Table 4. Average plant N uptake with corresponding N treatments and temporary flooding durations without and with rescue N plus urease inhibitor application.

N Fertilizer Treatment	Saturation Duration 0	24	48	72
	--------------------------- lbs N uptake/acre -----------------------			
Without Rescue N				
Control	24.0	16.4	19.5	15.3
Urea	28.3	19.1	26.5	24.9
Urea + NI†	33.2	28.2	21.5	23.9
PCU‡	34.6	29.8	29.1	23.2
With Rescue N				
Control	30.4	25.7	24.8	28.4
Urea	31.6	30.6	32.4	35.7
Urea + NI†	30.0	36.2	33.3	28.8
PCU‡	36.9	38.8	42.7	30.4
$LSD_{(0.05)}$ ††	------------------------------------- 12.2 ---------------------------			

†Urea + nitrification inhibitor
‡Polymer coated Urea
††Fisher's protected least significant difference at p<0.05.

Table 5 A & B. Average pre-flood (May 30th) inorganic soil N for (A) nitrate-N and (B) ammonium-N with corresponding N treatments, temporary flooding durations and sampling depths.

A.

N Fertilizer Treatment	Depth	Saturation Duration 0	Saturation Duration 72
	inches	mg NO_3^--N/kg	
Control	0-4	13.6	12.2
	4-8	5.4	4.5
	8-12	4.6	3.2
Urea	0-4	29.1	24.3
	4-8	7.5	7.6
	8-12	6.8	7.0
Urea + NI†	0-4	28.4	29.6
	4-8	5.8	6.4
	8-12	3.8	5.1
PCU‡	0-4	47.3	33.6
	4-8	11.5	6.1
	8-12	7.3	4.7
LSD $_{(0.05)}$ ††		9.5	

B.

N Fertilizer Treatment	Depth	Saturation Duration 0	Saturation Duration 72
	inches	mg NH_4^+-N/kg	
Control	0-4	6.1	6.1
	4-8	6.5	5.7
	8-12	4.7	4.9
Urea	0-4	5.7	5.9
	4-8	5.5	5.2
	8-12	4.0	5.3
Urea + NI	0-4	7.1	6.2
	4-8	5.4	5.0
	8-12	4.9	4.4
PCU	0-4	10.4	8.1
	4-8	5.6	5.5
	8-12	4.9	4.5
LSD $_{(0.05)}$		1.6	

†Urea + nitrification inhibitor

‡Polymer coated Urea

††Fisher's protected least significant difference at $p<0.05$.

Table 6 A & B. Average post-flood (June 11th) inorganic soil N for (A) nitrate-N and (B) ammonium-N with corresponding N treatments, temporary flooding durations and sampling depths.

A. N Fertilizer Treatment	Depth	Saturation Duration 0	24	48	72
	inches	mg NO_3^--N/kg			
Control	0-4	13.5	6.2	2.3	4.8
	4-8	1.7	1.5	0.8	1.3
	8-12	1.7	1.6	0.9	1.7
Urea	0-4	32.5	12.4	13.9	10.9
	4-8	3.6	3.1	4.8	4.3
	8-12	3.2	3.6	3.6	3.3
Urea + NI†	0-4	33.3	19.6	10.2	15.2
	4-8	4.7	4.5	3.6	4.1
	8-12	3.4	3.8	4.2	3.8
PCU‡	0-4	49.0	29.2	13.2	16.8
	4-8	2.6	3.8	2.8	4.7
	8-12	2.4	3.4	3.0	3.9
$LSD_{(0.05)}$ ††		9.7			

B. N Fertilizer Treatment	Depth	Saturation Duration 0	24	48	72
	inches	mg NH_4^+-N/kg			
Control	0-4	6.4	6.7	6.3	7.0
	4-8	5.5	5.9	6.5	6.7
	8-12	5.7	7.3	7.3	5.6
Urea	0-4	8.0	6.2	8.5	7.3
	4-8	6.4	6.0	5.6	7.3
	8-12	5.4	5.7	5.8	5.5
Urea + NI	0-4	6.9	7.4	7.0	7.1
	4-8	6.0	6.6	6.0	8.8
	8-12	6.0	6.4	6.5	6.3
PCU	0-4	11.3	10.4	9.1	8.1
	4-8	6.6	6.1	5.6	7.4
	8-12	4.9	5.4	5.3	5.7
$LSD_{(0.05)}$		2.5			

†Urea + nitrification inhibitor
‡Polymer coated Urea
††Fisher's protected least significant difference at $p<0.05$.

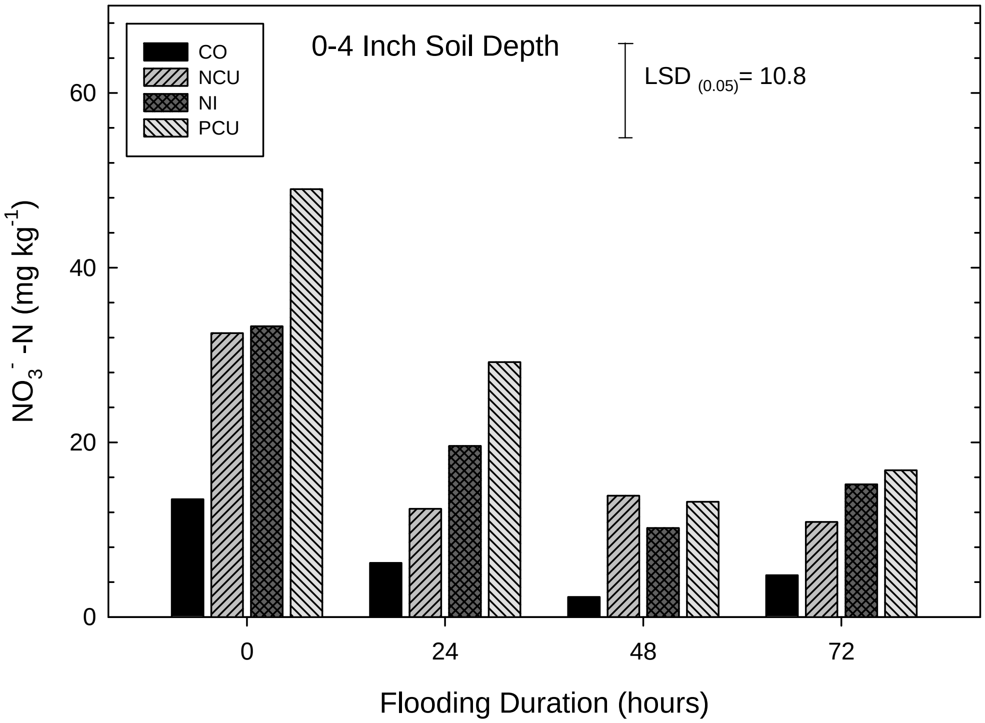


Figure 4. Average post-flood (June 11th) soil NO_3^- -N concentrations at a depth from 0-4 inches with respect to its N treatment and flooding duration. (†Abbreviations: CO, Control; NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea; LSD, least significant difference at $p < 0.05$).

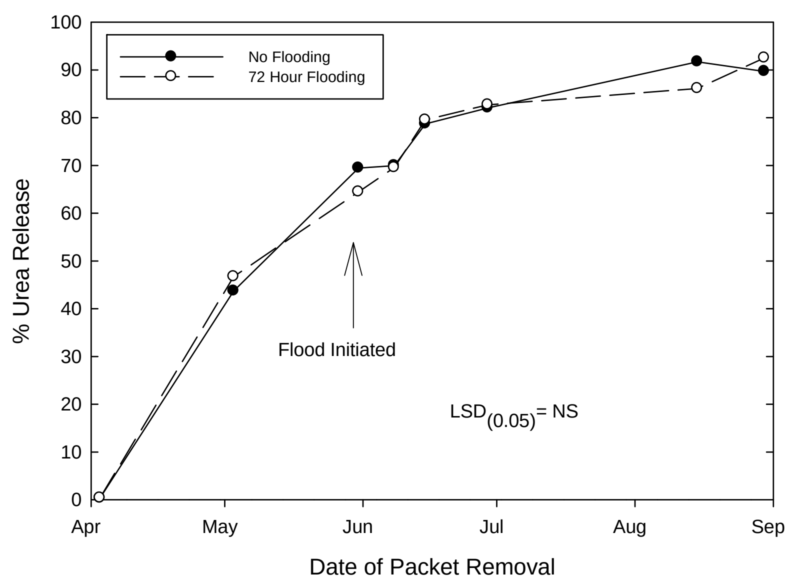


Figure 5. Percent of polymer coated urea release throughout the 2012 growing season between 0 and 72 hour flooding durations. (†Abbreviations: LSD, least significant difference at $p < 0.05$).

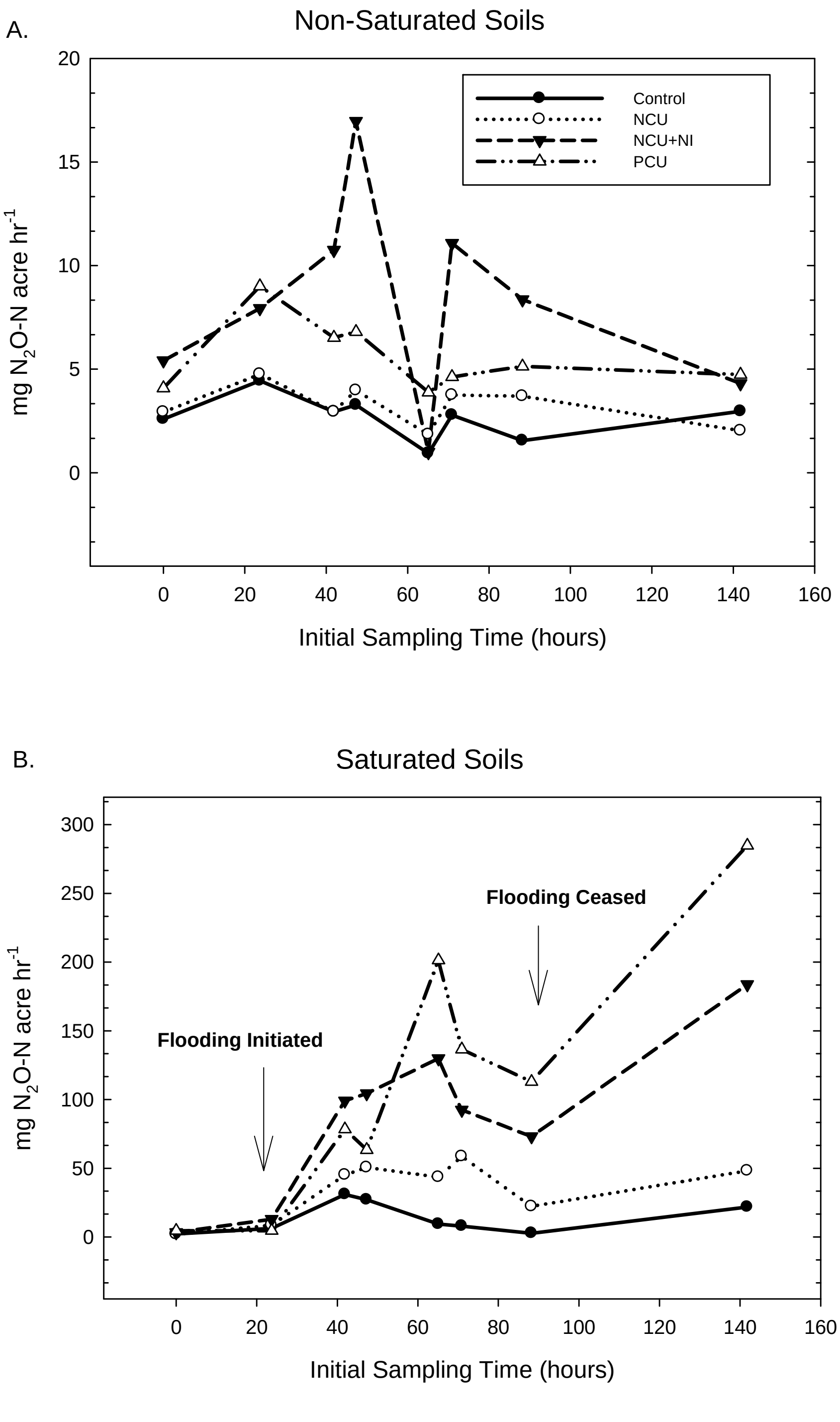
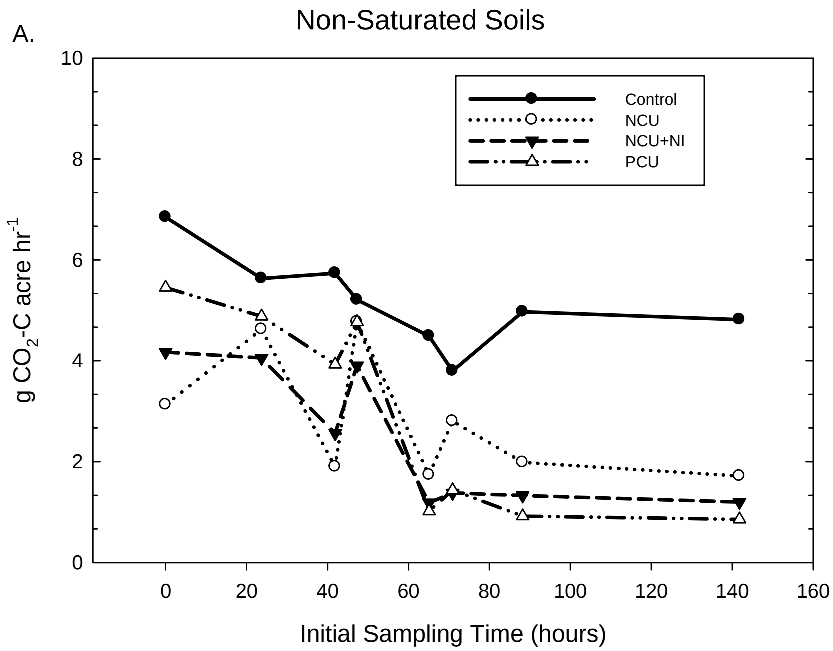


Figure 5 A & B. Average soil nitrous oxide emissions between (A) non-saturated and (B) saturated soils before, during, and after flooding event. Each point is the initial sample time with respect to the cumulative elapsed time from when the sampling period began. (†Abbreviations: CO, Control; NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea). Note scale change between both figures.

A.



B.

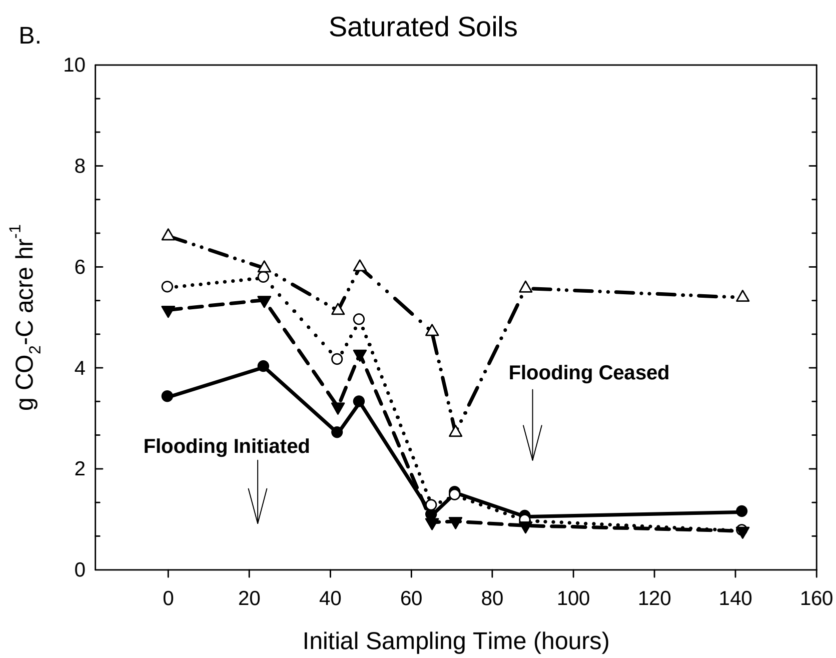


Figure 6 A & B. Average carbon dioxide emissions between (A) non-saturated and (B) saturated soils before, during, and after flooding event. Each point is the initial sample time with respect to the cumulative elapsed time from when the sampling period began. (†Abbreviations: CO, Control; NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea).

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