USE OF NITROGEN FERTILIZER SOURCES TO ENHANCE TOLERANCE AND RECOVERY OF NEW CORN HYBRIDS TO EXCESSIVE SOIL MOISTURE

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In the United States, losses in crop production due to drought and flooding accounted for more than 70% of the yield reductions in 2011, and the frequency of these climate extremes is increasing in farming regions (Bailey-Serres et al., 2012). Incidence of excessive rainfall events in the Midwest region has increased over 30% from 1958 to 2007 and is expected to increase more in the future, especially during the spring. In 2011 alone, a year characterized by excessive flooding, monetary losses for corn and soybean production in the Midwest were calculated to be more than $1.6 billion. However, few seed companies have been developing corn hybrids that have been identified to be tolerant to excessive soil moisture despite large areas in corn production in Missouri and the Midwest region that experience temporarily saturated soil conditions. Moreover, few studies have been conducted to determine the use of different sources and rates of nitrogen (N) fertilizer to promote increased flood tolerance and recovery in interaction with different corn hybrids.

Corn plants have several possible adaptive mechanisms for conditions of excessive soil moisture both under conditions of waterlogging or submergence. Among these mechanisms are formation of air space (aerenchyma) in the root cortex, stem enlargement (hypertrophy), adventitious root formation especially near the soil surface (Zaidi et al., 2004) and early root tip death (Subbiaah and Sach, 2003).

Application of N fertilizer for increased tolerance to excessive soil moisture may have several functions and management advantages both with initial N fertilizer applications and post-flooding rescue N applications. First, N 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 waterlogged soils (Nielson, 2011). Second, added N fertilizer may enhance and accelerate plant adaptive mechanisms to waterlogging such as adventitious root growth and root re-growth after flooding. Evidence for this beneficial effect of N fertilizer has been observed with lower yield losses with flooding in plots treated with high N fertilizer rates compared to those of low N fertilizer applications (Ritter and Beer, 1969). This research will develop N fertilizer management strategies in conjunction with screening corn hybrids at early stages of growth for flood tolerance. This early crop stage has a higher probability and vulnerability for soil waterlogging in Missouri due to normally high spring rains. This management will include the possible use of enhanced efficiency N fertilizers, such as polymer-coated urea (PCU), urea plus nitrification inhibitor (NI) or urea plus urease inhibitor (UI) that have been shown to improve corn yields and N use efficiency (NUE) under wet soil conditions (Nelson et al., 2010).

Objectives

The overall goal of this research is to develop a combination of N fertilizer management and hybrid selection for growers to increase corn production and reduce environmental N loss under temporary soil waterlogging. This strategy will include N fertilizer recommendations for both pre- and post-waterlogging conditions. The objectives of this study are:

1. To evaluate a selection of new corn hybrids for tolerance to soil waterlogging at early growth stages.
2. To assess the interactive effects of corn hybrid and pre- and post-waterlogging applications of different N fertilizer sources (e.g., PCU and NI) on corn yields and NUE.
3. To determine the effects of the treatments and excessive soil moisture conditions on plant available soil inorganic N during the growing season.
4. To evaluate the economic costs and benefits of using these fertilizer sources under waterlogged conditions.

Procedures

A greenhouse experiment was conducted prior to the field season in 2013 to determine the relative waterlogging tolerance of eight corn hybrids recommended by agronomists and breeders. None of these hybrids have been field tested to determine waterlogging tolerance in interaction with improved N fertilizer management systems. The results of the greenhouse screening experiment were presented in the 2013 Greenley Center field day report bulletin. A three-year field experiment was established in 2013 at the Greenley Experiment Station on the same poorly-drained claypan soil (Putnam silt loam) that was used in the greenhouse screening. Initial soil samples were collected at depths of 0-4, 4-8 and 8-12 inches before fertilizer application and planting to characterize initial soil conditions (Table 1).

The experimental design was a split-split-split plot in a randomized complete block arrangement with 3 replications. Main plots included flooding treatments of 0 and 7 days accomplished by setting up berms. The flood was initiated on 3 June 2013 and ended on 10 June 2013. The subplots consisted of N fertilizer treatments of a control or 150 lbs N/acre as pre-plant-applied urea (NCU), polymer-coated urea (PCU; ESN®, Agrium, Inc), and urea plus a nitrification inhibitor (NCU+NI) (Instinct®, Dow AgroSciences) and two corn hybrids. The two corn hybrids, Hybrid #1 and Hybrid #2, were selected based on the results of the greenhouse screening trial to provide one hybrid that showed tolerance and another that was less tolerant to flooded soil conditions. The fertilizers were applied on 14 May and then incorporated using vertical till . The hybrids were planted on 15 May at 33,000 seeds per acre in 30 inch rows. These subplots measured 10 x 80 ft. There were 4 rows of corn in each subplot. After the flooding treatment, subplots were divided into two parts of 40 ft length and one of them was treated with 75 lbs N/acre of a rescue post-flood broadcast application of urea plus NBPT (N-(n-butyl) thiophosphoric triamide) urease inhibitor (1 gal/ton urea; Agrotain®, Koch Agronomic Services) while the other subplot did not receive additional N. Corn plants averaged approximately 40 inches tall at V7-V8 at the time of the rescue N application.

Results

Soil conditions during the flooding were measured by determination of changes in soil redox potential (E_h), soil pH, soil temperature and bulk density at the soil surface. Soil redox potential (E_h), soil pH and soil temperature were measured on alternate days during flooding. No significant differences were observed in bulk density and soil pH between flooded and non-flooded conditions (Table 2 and 3). The soil redox potential decreased as the duration of flooding increased. The soil redox potential was significantly different on the 1st, 3rd and 6th day during flooding (Table 3). Soil temperature was significantly higher in flooded versus non-flooded treatments (Table 4).

Soil samples were collected from from 0-4, 4-8 and 8-12 inch depth of all N treatments before and after flooding as well as after harvest at the end of season. These samples were analyzed for soil inorganic N (ammonium and nitrate N). No significant differences were found in pre-flood nitrate and ammonium N among both hybrids. The 0-4 inch depth had significantly different pre-flood inorganic N content compared to other two depths. The control treatment had lower nitrate N contents than the remaining fertilizer treatments (Table 5). At a depth of 0-4 inches, NCU+NI had higher ammonium N than the other fertilizer treatments (Table 6).

Fertilizer packets of PCU weighing 10 g each were placed on the soil surface before fertilizer application in the different treatments to evaluate PCU dissolution due to flooding and time. They were removed at 8 different times as shown in Figure 1. There was a greater release of urea fertilizer from the start of flooding to 2 weeks after flooding in flooded treatments compared to non-flooded treatments. Average plant chlorophyll content was significantly higher in flooded treatments compared to non-flooded treatments measured after the 7 days of flooding (Table 7). Hybrid #2 had higher chlorophyll content than Hybrid #1 in the non-flooded control. There was no significant effect of fertilizer sources and rescue N application on SPAD chlorophyll readings.

Corn silage was collected from 10 feet of one corn row on 6 September 2013. The silage yield was used for determining total aboveground dry biomass weight and total N uptake. In treatments having 7 day flooding without rescue N, Hybrid #1 had an increase of 2.11 tons/acre in silage yields with the NCU+NI treatment compared to the control treatment (Table 8). In contrast, an application of NCU+NI resulted in lower silage yield of 2.51 tons/acre as compared to that of PCU due to flooding in treatments with rescue nitrogen application. No significant differences in silage yield between hybrids were observed except for treatments having NCU and rescue N application with 7 days of flood (Table 8). Corn N uptake among the different fertilizer treatments was not significantly different overall. However, there was a significant increase in N uptake when PCU was applied compared to application of NCU for Hybrid #1 with the 7 day flood treatment (Table 9).

Corn was harvested on 18 September 2013. There was no significant effect of rescue N application on yield possibly due to low rainfall after rescue fertilizer application (Table 10). Both hybrids under 7 day flooding treatment resulted in significantly lower grain yields than the non-flooded control. Hybrid #1, under control fertilization and 7 day flooding, had losses of 26 and 29 bu/acre compared to no-flood without and with rescue nitrogen application, respectively. Hybrid #2 showed a reduction in yield ranging from 18 to 33 bu/acre due to 7 day flooding among the different fertilizer treatments (Table 10).

Hybrid #1 showed no significant losses in grain yield due to flooding in treatments having PCU, NCU, or NCU+NI fertilizer applications (Table 10). Hybrid #1 had a significant increase in yield among NCU, PCU and NCU+NI compared to control only with 7 day flooding in the presence or absence of rescue N application treatments. In contrast, a significant increase in grain yield was obtained with Hybrid #2 with NCU, PCU and NCU+NI in the non-flooded treatment and with the 7 day flood duration which was also applied with rescue N application.

The field study will be repeated for two more years to evaluate climatic variation on corn yields in response to different flooding durations and N treatments.

References

Bailey-Serres, J., S.C. Lee, and E. Brinton. 2012. Waterproofing crops: Effective flooding survival strategies. Plant Phys. Rev. doi:10.1104/pp.112.208173.

Motavalli, P.P., K.A. Nelson, and S. Bardhan. 2012. Development of a variable source nitrogen fertilizer management strategy using enhanced efficiency nitrogen fertilizers. Soil Sci 177:708-718.

Nelson, K.A., P.C. Scharf, W.E. Stevens, and B.A. Burdick. 2010. Rescue nitrogen applications for corn. Soil Sci. Soc. Am. J. 75:143-151.

Nielson, R.L. 2011. Effects of flooding or ponding on young corn. Dept. of Agronomy, Purdue University, West Lafayette, IN. http://www.kingcorn.org/news/timeless/PondingYoungCorn.html

Ritter, W.F., and C.E. Beer. 1969. Yield reduction by controlled flooding of corn. Trans. Am. Soc. Agric. Engineers 12:46-50.

Subbiah, C.C., and M.M. Sachs. 2003. Molecular and cellular adaptations of maize to flooding stress. Annals of Botany 90:119-127.

Zaidi, P.H., S. Rafique, P.K. Rai, N.N. Singh, and G. Srinivasan. 2004. Tolerance to excess moisture in maize (Zea mays. L): susceptible crop stages and identification of tolerant genotypes. Field Crops Res. 90:189-202.

Table 1. Initial selected soil properties of the study site at the Greenley Research Center in Northeast Missouri to a depth of 12 inches.

Depth	pH_s (0.01 M $CaCl_2$)	Neutralizable acidity	Organic matter	Bray-1 P	Exchangeable Ca	Exchangeable Mg	Exchangeable K	CEC	NH_4^+-N	NO_3^--N
-- in --		meq/100 g	%	-------------- lbs/acre --------------				meq/100 g	--------- mg/kg -----------	
0-4	6.0	2.0	2.8	70	3751	339	372	13	5.7	13.5
4-8	6.1	1.8	1.9	16	3831	263	123	13	6.4	14.2
8-12	5.4	4.0	1.8	14	3777	454	131	16	7.7	13.0

Table 2. Soil bulk density at different depths among flood durations.

Flooding duration	Depth (inches) 0-4	4-8	8-12	LSD$_{(0.05)}$[‡]
	-------------- g/cm^3	----------------		
0	1.41	1.38	1.34	NS
7	1.44	1.42	1.25	NS
LSD$_{(0.05)}$	NS	NS	NS	

[‡] LSD, Fisher's least significant difference ($P \leq 0.05$); NS, not significant.

Table 3. Soil redox potential and pH during flooding.

Days after flooding started	Redox potential	Soil pH
	------------ mV ----------	
1	266	6.2
3	130	6.1
4	90	6.2
6	-41	6.1
LSD $_{(0.05)}$[‡]	69	NS

[‡] LSD, Fisher's least significant difference ($P \leq 0.05$); NS, not significant.

Table 4. Soil temperature during flooding among flood durations.

Days after flooding starts	Flooding duration (In days) 0	7	LSD$_{(0.05)}$[‡]
	----------- °F ----------		
1	59	63	0.4
3	63	64	0.4
4	59	63	0.4
6	68	70	0.4
LSD $_{(0.05)}$	----------- 0.5 -----------		

[‡]LSD, Fisher's least significant difference ($P \leq 0.05$); NS, not significant.

Table 5. Average pre-flood soil nitrate N by depth due to N fertilizer treatments.

N fertilizer treatment	Depth	Corn hybrids	
		Hybrid #1	Hybrid #2
	inches	mg NO_3^--N/kg	
Control	0-4	3.9	6.6
	4-8	9.1	10.5
	8-12	8.7	12.4
NCU[†]	0-4	55.2	40.6
	4-8	14.3	10.8
	8-12	15.8	11.5
NCU+NI	0-4	43.9	35.7
	4-8	9.5	11.8
	8-12	10.8	11.5
PCU	0-4	50.8	37.2
	4-8	13.5	10.3
	8-12	11.4	12.6
$LSD_{(0.05)}$[‡]		4.8	4.8

[†] Abbreviations: NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea).

[‡] LSD, Fisher’s least significant difference ($P \leq 0.05$); NS, not significant.

Table 6. Average pre-flood soil ammonium N by depth due to N fertilizer treatments.

N fertilizer treatment	Depth	Corn hybrids	
		Hybrid #1	Hybrid #2
	inches	mg NH_4^+-N/kg	
Control	0-4	8.0	3.6
	4-8	9.8	6.9
	8-12	8.6	5.2
NCU[†]	0-4	5.9	4.5
	4-8	4.0	4.0
	8-12	3.3	2.6
NCU+NI	0-4	44.6	22.5
	4-8	2.8	8.3
	8-12	6.3	3.0
PCU	0-4	11.4	16.8
	4-8	8.5	4.3
	8-12	3.7	2.2
$LSD_{(0.05)}$[‡]		4.1	4.1

[†] Abbreviations: NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea.

[‡] LSD, Fisher’s least significant difference ($P \leq 0.05$); NS, not significant.

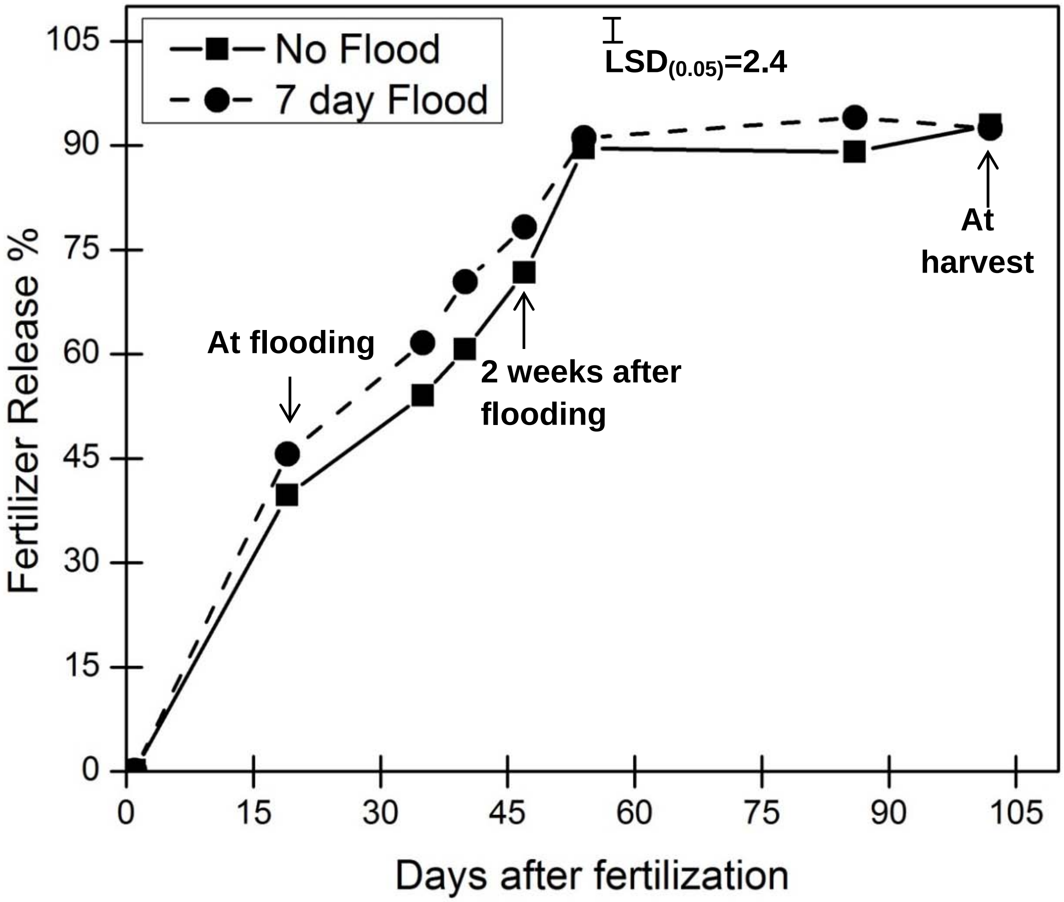

Figure 1. PCU fertilizer release at different times due to flooding.

Table 7. Average SPAD chlorophyll readings among the corn hybrids with and without flooding.

Flood duration (In days)	Corn hybrids		$LSD_{(0.05)}$ ‡
	Hybrid #1	Hybrid #2	
	-------------------- SPAD units ----------------------		
0	53	55	1
7	58	57	NS
$LSD_{(0.05)}$	------------------------------- 2 ------------------------		

‡ LSD, Fisher's least significant difference ($P \leq 0.05$); NS, not significant.

Table 8. Average silage yields with corresponding N treatments and flooding durations for corn hybrids.

	Flooding duration (in days)					
	0			7		
	Corn hybrids			Corn hybrids		
N fertilizer treatment	Hybrid #1	Hybrid #2	LSD $_{(0.05)}$	Hybrid #1	Hybrid #2	LSD $_{(0.05)}$
	tons/acre					
<u>Without Rescue N</u>						
Control	6.19	7.19	NS	4.72	6.21	NS
NCU[†]	7.70	7.38	NS	5.90	6.99	NS
NCU+NI	7.37	8.10	NS	6.83	6.52	NS
PCU	6.55	7.56	NS	6.35	6.16	NS
LSD $_{(0.05)}$ [‡]	NS	NS		1.95	NS	
<u>With Rescue N</u>						
Control	6.58	6.42	NS	5.68	5.92	NS
NCU	6.66	7.07	NS	4.62	7.57	1.88
NCU+NI	6.48	7.64	NS	4.75	5.90	NS
PCU	7.57	7.89	NS	7.26	7.41	NS
LSD $_{(0.05)}$	NS	NS		1.95	NS	

[†] Abbreviations: NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea.

[‡] LSD, Fisher's least significant difference ($P \leq 0.05$); NS, not significant.

Table 9. Average corn hybrid N uptake resulting from different N fertilizer treatments and flooding durations.

	Corn hybrids					
	Hybrid #1 Flooding duration (in days)			Hybrid #2 Flooding duration (in days)		
N fertilizer treatment	0	7	LSD $_{(0.05)}$	0	7	LSD $_{(0.05)}$
<u>Without Rescue N</u>	---------- lbs N/acre ----------					
Control	126	112	NS	166	154	NS
NCU[†]	178	167	NS	180	157	NS
NCU+NI	176	169	NS	141	169	NS
PCU	161	148	NS	170	141	NS
LSD $_{(0.05)}$ [‡]	NS	NS		NS	NS	
<u>With Rescue N</u>						
Control	141	143	NS	111	140	NS
NCU	168	116	NS	160	172	NS
NCU+NI	153	123	NS	164	129	NS
PCU	172	195	NS	177	191	NS
LSD $_{(0.05)}$	NS	72		NS	NS	

[†] Abbreviations: NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea.

[‡] LSD, Fisher's least significant difference ($P \leq 0.05$); NS, not significant.

Table 10. Average corn grain yields with corresponding N treatments and flooding durations for two hybrids.

N fertilizer treatment	Corn hybrids					
	Hybrid #1			Hybrid #2		
	Flooding duration (in days)			Flooding duration (in days)		
	0	7	LSD $_{(0.05)}$	0	7	LSD $_{(0.05)}$
	------------------------------------ bu/acre --------------------------------------					
Without Rescue N						
Control	108	82	17	122	124	NS
NCU[†]	125	108	NS	146	128	17
NCU+NI	124	115	NS	151	126	17
PCU	121	111	NS	146	127	17
LSD $_{(0.05)}$[‡]	NS	17		17	NS	
With Rescue N						
Control	113	84	17	132	103	17
NCU	127	104	17	154	123	17
NCU+NI	130	105	17	151	126	17
PCU	129	114	NS	156	123	17
LSD $_{(0.05)}$	NS	17		17	17	

[†] Abbreviations: NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea.

[‡] LSD, Fisher's least significant difference ($P \leq 0.05$); NS, not significant.