ELUCIDATING HOW N MANAGEMENT PRACTICES AND EXCESS WATER CONDITIONS AFFECT CORN N UPTAKE AND GRAIN YIELD

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ABSTRACT

Flooding and waterlogging events have been more frequent in the Midwest region, causing corn yield penalty and nitrogen losses through leaching and denitrification processes. Improving N fertilizer recommendations for areas prone to flood conditions is necessary to minimize N losses and optimize corn yield. This research aimed to determine how N application practices before and after waterlogging events impact corn growth and grain yield. A field experiment was initiated in 2021 in Custar, Ohio using a split-plot randomized complete block design with four replications. The whole plot factor was waterlogging regime implemented at the V4 corn growth stage: zero days (0-d), three days (term 1), or repeated waterlogged conditions (term 2; three days of water applied, followed by three days of drying and three additional days of water applied). The subplot factor was N treatment applied pre-plant with 0 or 100 lbs N ac^{-1}, and one of four rates applied post-waterlogging (0, 60, 120, and 180 lbs N ac^{-1}). Biomass and total soil inorganic N (nitrate-N and ammonium-N) were measured at zero, six, thirteen, and eighteen days after waterlogging initiation. Ear leaf N was measured at the R1 growth stage. Stalk nitrate and grain yield were measured at the R6 growth stage. Data were analyzed using mixed models (repeated measures and GLIMMIX procedures in SAS). Linear plateau regression analyses using PROC NLIN were performed using total soil inorganic N to predict ear leaf N content and yield. Biomass was reduced with term 2 waterlogging. Pre-plant and post-waterlogging applications of N increased biomass more rapidly after waterlogging was alleviated. Generated regressions using soil inorganic N to predict ear leaf N content resulted in R^2 of 0.14-0.50 and R^2 of 0.23-0.58 when predicting yield. Ear leaf N content was greatest when pre-plant with 120 or 180 lbs N ac^{-1} post-waterlogging was applied. Stalk nitrate levels did not indicate luxurious consumption of N in any treatment. Corn exposed to waterlogging had maximum yield production with pre-plant with 60, 120, or 180 lbs N ac^{-1} applied post-waterlogging. This trial will be repeated in 2022 and 2023 at more Ohio locations to ensure responsible N recommendations can be developed.

INTRODUCTION

Precipitation has been increasing in the Midwest (Dai et al., 2016). There is also an increase in extreme weather events in the region, potentially exacerbating the N-loss pathways (Iqbal et al., 2018). In the US, flooding and waterlogging were responsible for up to 34% of corn grain yield loss, which is comparable to the 37% loss from drought (Li et al., 2019). For the Midwest, in 2011, flooding caused an economic damage of $1.6 billion for corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] (Bailey-Serres et al., 2012). Waterlogging and flooding can also cause environmental impacts such as leaching in nitrate (NO_3^-) form and greenhouse gas emission as nitric oxide (NO) and nitrous oxide (N_2O) emissions due to denitrification (Motavalli et al., 2008; Bailey-Serres et al., 2012; Bowles et al., 2018).

The N management recommendations in the Midwest are derived from Maximum Return to Nitrogen (MRTN) approach, which is an economic tool that considers the fertilizer prices of nitrogen fertilizers and corn grain (ISU, 2020). However, the MRNT was not designed to account for split N application or excess soil water. Moreover, N application management in much of the Midwest consists of a single fall post-harvest application or spring pre-plant application (Gramig et al., 2017). Although this approach allows for N mineralization in NO_3^- form (Cassman et al., 2002), it also makes the N susceptible to environmental losses in case of flooding or waterlogging (Iqbal et al., 2018; Bowles et al., 2018). Adapting the N recommendations to account for waterlogging could reduce economic and environmental losses. This research aimed to determine how N application practices before and after waterlogging events impact corn growth and grain yield. The specific objective of this research was to measure soil inorganic, N uptake by plants, and corn yield following waterlogging conditions.

MATERIALS AND METHODS

Study site

This experiment was conducted at Northwest Agricultural Research Station (NWARS; 41° 12' 53'' N, 83° 45' 34'' W) in Custar, Ohio, in 2021. The NWARS soil type is Hoytville clay loam (Fine, illitic, mesic Mollic Epiaqualfs).

Experimental Design

The experimental design was a split-plot randomized complete block design with four repetitions (rep). The whole plot factor was waterlogging duration (WD): zero days of waterlogging (0-day); three days of waterlogging (term 1); and repeated waterlogging (term 2; three days of water applied, followed by three days of drying, and three additional days of applied water). Using overhead irrigation, waterlogging was imposed at the V4 corn growth stage to maintain soil saturation. The sub-plot consisted of two factors. The first factor was urea that was pre-plant incorporated at 0 or 100 lbs N ac^{-1}. The second factor was topdressed N applied post-waterlogging. The post-waterlogging rates were 0, 60, 120, and 180 lbs N ac^{-1}. The post waterlogging application was urea combined with N-(n-butyl) thiophosphoric triamide (NBPT) (N-save, PCT Sunrise). The NBTP is a urease inhibitor that prevents the urease enzyme's action, thus helping minimize ammonia volatilization and slow the conversion of ammonium to nitrate (Motavalli et al., 2008). Nitrogen was manually and evenly distributed in the subplots three days after the waterlogging event ended. Each subplot was 10 ft x 30 ft. There was a 20 ft buffer between waterlogging treatment in the same rep. Between reps, there was another buffer of 40 ft (Fig. 1). A commercial corn hybrid of common maturity for Ohio was used (DKALB DK C61-88) and seeded at 34,000 seeds ac^{-1} in 30-in rows.

Eight eight-inch depth soil cores were collected at 0, 6, 13, and 18 days after the first waterlogging initiation (DAWI) for NO_3-N and NH_4-N. A total of ten ear leaves from the middle row of each plot were collected at the R1 growth stage to quantify ear leaf N concentration. Six stalk segments were collected at R6 in the border rows of each subplot to quantify stalk nitrate. For ear leaf N and stalk nitrate, materials were dried using a conventional air drier (Blue M Electric, model DC-966RI-E, New Columbia, PA), grounded using a grinding mill (Thomas Scientific, model 3379-K05, Swedesboro, NJ), and sent to

A&L Great Lakes laboratory for analysis. Each subplot was harvested at the R6 growth stage and moisture was adjusted to 15%.

Statistical Analysis

The statistical analyses were performed using SAS 9.4 (SAS Institute, Cary, NC). The ANOVA assumptions of normality of residuals distribution and equal variance (homogeneity of variance) were checked for all analyses. If the residuals were normally distributed, an ANOVA analysis was conducted with an alpha level of 0.05.

Plant biomass was analyzed using repeated measures. The MIXED procedure was used. The fixed factors were WD, N pre-planting, N post-waterlogging, and days after waterlogging initiation (DAWI). The random factors were rep and the interaction of rep with the fixed factors. DAWI was used for repeated measures statements. The covariance structure was chosen using the smallest Akaike information criterion (AIC). The means were calculated using LSMEANS. For soil sample at thirteen and eighteen DAWI, linear plateau regression analyses using PROC NLIN were performed using total soil inorganic N to predict ear leaf N content and yield. A mixed model's effect using GLIMMIX procedure was employed for ear leaf nitrogen, stalk nitrate, and yield. For GLIMMIX, the fixed factors were WD, N pre-plating, and N post-waterlogging, and the interaction between whole plot and sub-plot factors. The random factors were rep and the interaction of rep and WD. If the global F-test were significant, LSMEANS was used for means calculation, and pairwise means comparisons were performed using paired t-test. Letter separations were performed using the PDIFF statement.

RESULTS AND DISCUSSION

Biomass

Repeated waterlogging (term 2) negatively impacted plant growth, reducing biomass (data not shown). At 18 DAWI, term 2 had 45% less plant biomass than 0-day while term1 had 27% less biomass than 0-day (F-value =30.01; p-value = <0.0001). At 18 DAWI, the use of 100 lbs N ac^{-1} pre-planting increased biomass by 32% compared to no pre-planting across WD (F-value = 17.05; p-value = <0.0001). Dill et al. (2020) reported lower shoot biomass for 6, 4, and 2 days of flooding compared to no flooding. They also reported an increase in biomass with the application of N pre-planting. Kaur et al. (2019) reported lower shoot biomass for hybrids following 14 and 21 days of flooding compared to no flooding in a greenhouse experiment.

Inorganic N

The use of soil inorganic N at 18 DAWI resulted in greater R^2 values than those from 13 DAWI (Tables 1-2). The use of soil inorganic N was poorly correlated with ear leaf N (R^2 0.11 - 0.50) and yield (R^2 0.19 - 0.58).

Table 1. Soil inorganic N as a predictor of ear leaf N content (%). DAWI is days after first waterlogging initiation. WD is waterlogging duration.

DAWI	WD	a	b	joint	Plateau	R^2	F	Prob
13	0-day	1.85	0.04	25.99	2.76	0.11	1.52	0.238
13	Term 1	2.01	0.03	25.39	2.89	0.19	3.15	0.060
13	All	2.01	0.03	25.39	2.81	0.14	4.47	0.016
18	0-day	1.46	0.06	25.87	2.92	0.49	13.87	<0.001
18	Term 1	0.28	0.17	15.30	2.89	0.50	14.64	<0.001

18	Term 2	1.14	0.11	16.35	2.89	0.42	9.96	0.001
18	All	1.11	0.10	17.70	2.87	0.42	33.57	<0.001

Table 2. Soil inorganic N as a predictor of yield in bu ac^{-1}. DAWI is days after first waterlogging initiation. WD is waterlogging duration.

DAWI	WD	a	b	joint	Plateau	R^2	F	Prob
13	0-day	69.44	4.79	27.63	201.77	0.19	2.86	0.077
13	Term 1	107.13	3.09	29.97	199.86	0.23	3.80	0.036
13	all	115.19	2.49	35.97	204.85	0.21	6.93	0.002
18	0-day	-136.80	19.99	17.18	206.58	0.58	20.44	<0.001
18	Term 1	31.70	8.49	19.99	201.53	0.34	7.59	0.002
18	Term 2	15.18	9.93	18.67	200.67	0.49	13.43	<0.001
18	all	-0.67	11.12	18.18	201.41	0.49	43.87	<0.001

Ear Leaf Nitrogen and Stalk Nitrate

The pre-planting N application had a significant effect on ear leaf N content across WD (Fig. 1a). The application of pre-planting led to higher N concentration; however, it was below the sufficiency range of 2.9 to 3.5% (Vitosh et al., 1995). There was a significant interaction between WD and post-waterlogging applications across the pre-plant applications (Fig. 1b). Nitrogen post-waterlogging applications of 120 and 180 post-waterlogging irrespective of WD, were in the sufficiency range for ear leaf N content.

There was a triple interaction between the WD, N pre-plant, and N post-waterlogging for stalk nitrate content, though all treatments were below the optimum range (250 to 2000 ppm; Vitosh et al. 1995) (data not shown). The highest corn stalk nitrate concentration was observed at 0-day WD, with pre-plant, and 180 lbs N ac^{-1}, thus the treatment more likely to have consumed most of the available N available and have excess uptake (Zhang et al. 2013). The lower stalk nitrate across treatments can be attributed to the wet conditions posed by waterlogging, leading to lower availability of N and no surplus on N consumption (Varvel et al. 1997; Tao et al. 2018).

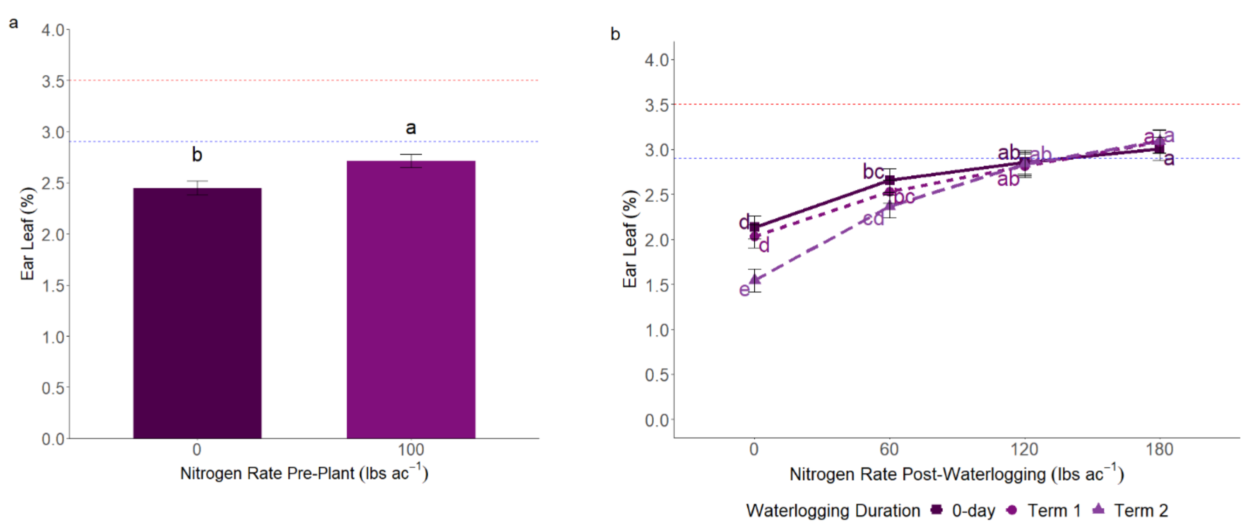

Figure 1. Mean and standard error for ear leaf N content. Blue and red dashed lines represent the optimum range for ear leaf N content according to Vitosh et al. (1995) **a.** Ear leaf N content across WD. Differences bar graphs represent different N pre-plant

rates. Different letters indicate treatment significant different at p<0.05 using paired t-test. **b.** Interaction between WD and N post-waterlogging. Different lines represent different WD. Different letters are significant different at p<0.05 using paired t-test.

Yield

There was a significant interaction between WD and N post-waterlogging across N-plant (Fig. 2a). The use of 180 lbs N ac^{-1} for all WD and 120 lbs N ac^{-1} for 0-day WD showed the highest yield. There was an interaction between pre-plant and post-waterlogging application across WD (Fig. 2b). The use of 180 lbs N ac^{-1} irrespective of pre-plant application and 120 lbs N ac^{-1} with pre-plant led to the highest yield (Fig. 2b). Other research studies also observed a positive response to N applying pre-planting or sidedress (Kaur et al. 2017; Dill et al. 2020). For this study, using 60 lbs N ac^{-1} did not result in higher yield for term 1 and 0-day, which differs from Dill et al. (2020), that showed a higher yield using 60 lbs N ac^{-1} as sidedress after 120 lbs N ac-1 was applied pre-plant incorporated. In Dill et.al study, yield for four days and six days of flooding were 207 bu ac^{-1} and 165 bu ac^{-1} compared to 246 bu ac^{-1} non-flooded. Kaur et al. (2018) showed that sidedress of 75 lbs N ac^{-1} only led to a higher yield for one season when comparing seven days of waterlogged and non-waterlogged treatments.

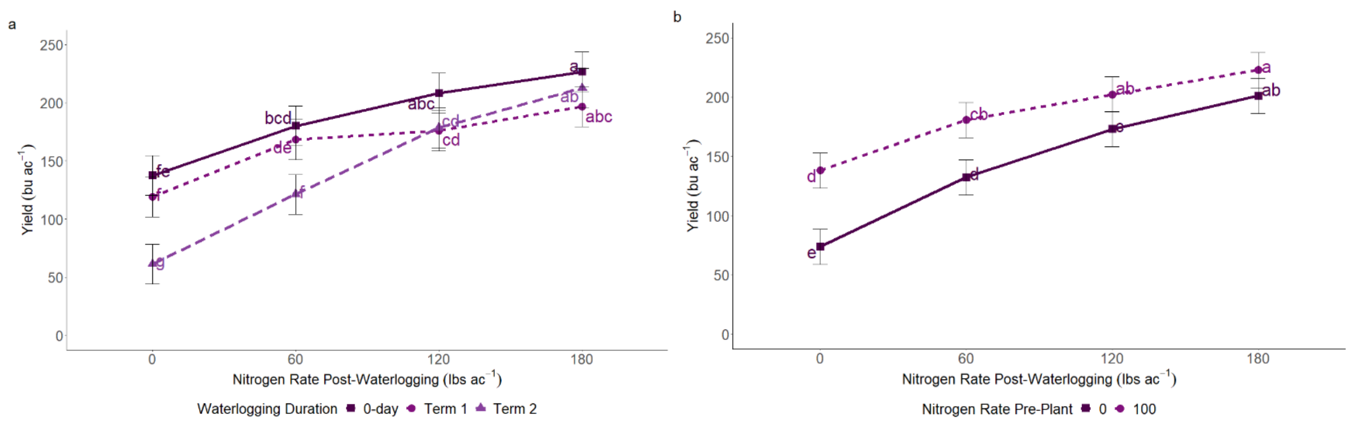

Figure 2. Mean and standard error of yield in bu ac^{-1}. **a.** Interaction between WD and N post-waterlogging application. Different lines represent different waterlogging treatments. Different letters indicate treatment significant different at p<0.05 using paired t-test. **b.** Interaction between nitrogen pre-plant and DAWI across WD. Different lines represent different nitrogen rate treatments. Different letters indicate treatment significant different at p<0.05 using paired t-test.

IMPLICATIONS

Pre-plant N application has a positive effect during early growth vegetative stages; however, post-waterlogging applications have a greater effect on yield. Repeated waterlogging causes a negative impact on corn growth. Nitrogen post-waterlogging can minimize the adverse effects of single flooding (term 1) or repeated flooding (term 2). For areas prone to waterlogging, it is recommended to use a post-waterlogging application (sidedress) at 180 lbs N ac^{-1} to maximize yield and reduce potential losses due to nitrate leaching. This research trial will be repeated in 2022 and 2023 at more Ohio locations to ensure responsible recommendations for farmers and growers in areas prone to soil water excess.

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