Corn production losses due to temporarily flooded or saturated soils often occur in Missouri in both upland and low-lying areas. Several factors affect the severity of damage to corn including: 1) the timing of flooding during the life cycle of corn, 2) the 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). However, a comparison of recent studies at the Greenley Center suggests that corn is more susceptible to temporary waterlogging damage at the V6 and later stages of corn growth compared to waterlogging at the V3 growth stage (see report by Kaur). 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. 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. 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.

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

A three-year field trial was established in 2012 at the University of Missouri Greenley Experiment Station in Northeast Missouri and this report provides the results for the 2013 growing season. The specific field chosen was adjacent to the field used in the 2012 growing season. 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 pre-plant fertilizer application and incorporation to characterize initial soil conditions (Table 1). Some differences in pre-fertilization soil characteristics compared to the 2012 growing season were lower pHs and greater inorganic N concentrations. This could possibly be due to residual N from the exceptionally dry growing season of 2012. These inorganic N concentrations also increase with depth suggesting higher than normal N concentrations might be present below the sampling depth.

The field was separated into 15 by 100 foot plots of six 30-inch rows of DEKALB 62-97VT3 planted at 32,000 seeds/acre on 14 May. 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 was a randomized complete block with a split-split plot arrangement replicated three times.

Since no flooding treatment effect occurred during the 2012 growing season, an extended flooding duration treatment of 7 days was added to replace the 2 day treatment. Therefore, flooding durations imposed in 2013 were 0, 1, 3, and 7 days at the V6 corn growth stage on 18 June using temporary soil levees to surround each flooding block (Figure 1). Levees were removed to allow ponded water to escape after the intended flooding duration had ceased. On 8 July, a rescue N fertilizer application of 75 lbs N/acre of urea plus NBPT (N-(n-butyl) thiophosphoric triamide) urease inhibitor (NCU + UI) at 1 gal/ton was applied to half of each pre-plant fertilizer treatment (Agrotain®, Koch Agronomic Services, Wichita, Kansas). Following the rescue application each 15 by 100 foot fertilizer treatment was split into two 15 by 50 foot plots, one being with the rescue application plus urease inhibitor and the other without the rescue application. The 2013 rescue application of 75 lbs N/acre was consistent to the amount applied in 2012 for an economical optimal N rate for yield response at corn growth stage V10 determined from SPAD 502 chlorophyll meter readings (Konica Minolta, Hong Kong) (Scharf et al., 2006).

**Results**

Chlorophyll content was measured in all plots after the 7 day flooding treatment had ended to assess any impacts of pre-plant N treatments and flooding stress on corn plants (Figure 2). Pre-plant fertilizer treatments of NCU+NI and PCU had significantly higher chlorophyll content than the non-fertilized pre-plant treatment of 5.5 and 4.2 SPAD units, respectively. There were no significant chlorophyll content differences among the non-fertilized and NCU treatments. Urea, NCU+NI, and PCU had significantly greater chlorophyll content compared to the non-fertilized pre-plant treatment when 3 and 7 days of flooding occurred. Chlorophyll content also generally decreased as flooding durations increased for all pre-plant N treatments. There were no statistically significant differences between pre-plant N treatments with a 7 day
flood duration. These results suggest that flooding can temporarily decrease the amount of leaf chlorophyll measured using the SPAD meter. A possible explanation for this result could be due to soil NO$_3^-$ loss with flooding, and less corn N uptake since oxygen depleted soils can result in a decrease in plant transpiration.

Corn grain yields were determined on 23 Sept. from the total row length of the two center rows from each N treatment. There was an effect of flooding duration on the grain yield in 2013 (Figure 3). Significant yield reductions of 15.7 and 44.6 bushels/acre occurred as a result of 3 and 7 days of flooding, respectively, when compared to the non-flooded control. An average loss of 6.6 bushels/acre occurred with each day of flooding. No effect of pre-plant or rescue N plus a urease inhibitor occurred on grain yield for the 2013 growing season. The lack of corn grain yield response to N fertilizer treatments could possibly be due to the combination of residual soil N in the soil profile deeper than 1 foot, and late season “flash” drought conditions during the seed-filling period (Figure 4).

Corn silage N uptake was measured when corn plants reached physiological maturity (Figure 5). As was observed with the decrease in grain yield with increased flooding duration, silage N uptake significantly declined with 3 and 7 days of flooding when compared to the non-flooded control. There was also significantly lower silage N uptake when comparing the 7 day flooding event 1 and 3 days of flooding. A significant increase in silage N uptake of 17.4 pounds/acre did occur with the rescue N plus urease inhibitor application.

Pre-plant N and flooding treatments had an effect on grain quality (Figure 6 A & B and 7). As flooding duration increased the concentration of grain protein decreased. All three pre-plant N treatments had greater protein concentration than the non-fertilized pre-plant N treatment with no-flooding and 1 day of flooding. After 3 days of flooding, PCU had 0.25 % more protein content than the non-fertilized pre-plant treatment. In contrast to the protein content, extractable starch and oil content generally increased as flooding durations increased.

Soil samples were collected from the 0-4, 4-8, and 8-12 inch depths from pre-plant N fertilizer treatments before (18 June) and after the temporary flooding events (1 July) and analyzed for soil inorganic N (ammonium-N and nitrate-N) (Figure 8 A & B, 9, and 10). Prior to flooding, PCU and NCU+NI had 3.6 and 2.8 more pounds of NH$_4^+$-N per acre, respectively, than the NCU pre-plant N treatment at a depth of 8-12 inches (Fig 8A). After flooding, PCU maintained significantly greater NH$_4^+$-N than all other pre-plant N treatments at a depth of 0-12 inches (Figure 9). Nitrate content prior to flooding was significantly greater for all pre-plant N treatments compared to the non-fertilized N control (Fig 8B). Soil samples collected after the temporary flooding durations and analyzed for NO$_3^-$-N showed that when no flooding occurred the PCU and NCU+NI treatments had 51.3 and 47.1 more pounds/acre of NO$_3^-$-N, respectively, than NCU (Figure 10). Significant losses of soil NO$_3^-$-N occurred even after 1 day of flooding especially with the PCU and NCU+NI-treated soils which had initially higher soil NO$_3^-$-N concentrations compared to the control and NCU treatments when no flooding occurred (Figure 10).

Soil samples were also collected from pre-plant N fertilizer treatments with and without rescue N plus urease inhibitor treatments following corn grain harvest and analyzed for NH$_4^-$-N.
and NO$_3^-$-N (Figure 11 A & B). Polymer-coated urea maintained the highest soil NH$_4^+$-N and NO$_3^-$-N content of the pre-plant N fertilizer applications that received the rescue N application plus urease inhibitor. Both the PCU and NCU+NI treatments had greater NO$_3^-$-N content than the NCU treatment when comparing the pre-plant N treatments without the rescue N application.

The field study was repeated in 2014 to assess variation in climate on corn response to enhanced efficiency N fertilizers and rescue N application following soil saturation periods of 0, 1, 3, and 7 days. An economic analysis will be included using fluctuations in fertilizer and enhanced efficiency prices between the three years to determine whether use of enhanced efficiency products and a rescue application of N are cost effective after 0, 1, 3, and 7 days of soil saturations.

References

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

Table 1. Soil test collected prior to pre-plant fertilization for the 2013 field study site at the Greenley Research Center averaged over three replications by soil depth.

<table>
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<tr>
<th>Depth</th>
<th>pHs</th>
<th>NA (meq/100 g)</th>
<th>OM (%)</th>
<th>Bray 1 P</th>
<th>Exch. Ca</th>
<th>Exch. Mg</th>
<th>Exch. K</th>
<th>CEC</th>
<th>B.D. (g/cm³)</th>
<th>NO₃⁻-N</th>
<th>NH₄⁺-N</th>
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†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; NO₃⁻-N, Nitrate Nitrogen; NH₄⁺-N, Ammonium Nitrogen.

Figure 1. Flooding treatments on 11 July 2013 which was 16 days after the 7-day flooding treatment was drained.
Figure 2. SPAD chlorophyll readings on 28 June 2013 after all flooding treatments were drained to determine effects of flooding duration and pre-plant N fertilizer on chlorophyll content. (Abbreviations: CO, Control; NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea; 0, No-flooding; 1, 1 day of flooding; 3, 3 days of flooding; 7, 7 days of flooding; LSD, least significant difference at $P < 0.10$).

Figure 3. Average corn grain yield decline per day of flooding for all pre-plant N treatments. (Abbreviations: LSD, least significant difference at $P < 0.10$ between grain yield means of different flooding durations).
Figure 4. Daily and cumulative precipitation with from 1 April – 1 October 2013 at the Greenley Research Center. The ten-year average from 2002 to 2011 at the Greenley Research Center was 38.8 inches for this time period.
Figure 5 A & B. Average plant N uptake at physiological maturity comparing plants that experienced different flooding durations, and with and without rescue N application plus urease inhibitor. Rescue N application was applied at growth stage V10 on 8 July, 2013. (Abbreviations: LSD, least significant difference at $P<0.10$ between N uptake and different flooding durations, and without and with rescue N application plus urease inhibitor).
Figure 6 A & B. Average grain protein and extractable starch concentration by pre-plant fertilizer treatments and flooding durations. (Abbreviations: CO, Control; NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea; LSD, least significant difference at \( P < 0.10 \)).
Figure 7. Average grain oil concentration with increasing time of flooding durations. (Abbreviations: CO, Control; NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea; LSD, least significant difference at $P < 0.10$).
Figure 8 A & B. Average (A) NH$_4^+$-N (A) and (B) NO$_3^-$N to a depth of 12 inches with different pre-plant fertilizer applications. Sampling occurred prior to flooding on 17 June 2013. (Abbreviations: CO, Control; NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea; LSD, least significant difference at $P < 0.10$).
**Figure 9.** Average $\text{NH}_4^+$-N to a depth of 12 inches with different pre-plant fertilizer applications. Sampling occurred after the flooding durations on 1 July 2013. (Abbreviations: CO, Control; NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea; LSD, least significant difference at $P < 0.10$).

**Figure 10.** Average $\text{NO}_3^-$-N to a depth of 12 inches with different pre-plant fertilizer applications and flooding durations. Sampling occurred after the flooding durations on 1 July 2013. (Abbreviations: CO, Control; NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea; LSD, least significant difference at $P < 0.10$).
Figure 11 A & B. Average (A) NH$_4^+$-N and (B) NO$_3^-$-N to a depth of 12 inches designated by pre-plant fertilizer applications with and without rescue N application plus urease inhibitor. Sampling date occurred after harvest on 10 October 2013. (Abbreviations: CO, Control; NCU, Urea; NCU + NI, Urea + nitrification inhibitor; PCU, polymer coated urea; LSD, least significant difference at \( P < 0.10 \)).