FATE OF ^{15}N-LABELED UREA APPLIED IN-SEASON FOR CORN IN EASTERN NORTH DAKOTA

M.M. Culpitt[1], and K.L. Griesheim[1]
[1]North Dakota State University, Fargo, ND
kelsey.griesheim@ndsu.edu (701) 231-1890

ABSTRACT

Nitrogen (N) fertilizers represent a major investment for North Dakota cropping systems as evidenced by the 890,000 tons of N used by producers in 2024 alone. If these inputs are to be beneficial to the producer and not harmful to the environment, they must be managed efficiently. To evaluate the efficacy of split-N applications, ^{15}N-labeled fertilizer was applied to three different soil types in eastern North Dakota, including an irrigated sand, a smectite-rich clay, and clay loam developed on glacial till above a marine bedrock unit of shale. Treatments included a single application of 140 lbs ac^{-1} broadcasted at planting and two treatments with 30% applied at planting and 70% applied in-season as a surface dribble, where the entirety of one treatment (Split-^{15}N) is ^{15}N-labeled and only the first application of another treatment is ^{15}N-labeled (Split-1st^{15}N). With 2025 being the first year of the study, only yield data is reported here and averaged 200 bu ac^{-1} for Oakes, 181 bu ac^{-1} for Gardner, and 192 bu ac^{-1} for Langdon. All three of these sites were responsive to the addition of N, though there were no significant differences in yield between fertilized treatments. The complete dataset will include total-N and -^{15}N uptake in both grain and stover so that fertilizer ^{15}N uptake efficiency and percent of N derived from fertilizer and soil can be calculated.

INTRODUCTION

Nitrogen (N) is an essential plant nutrient and especially important for corn (*Zea mays L.*) production where growers often supplement crop needs with synthetic N fertilizers that contribute to input costs. Nitrogen must be managed efficiently for maximum return on investment, but predicting N availability for cropping systems can be complicated due to the inherent dynamics of the N cycle. Though Nitrogen uptake efficiency (NUE) is an important tool to evaluate N management, fertilizer N uptake efficiency (FNUE) focuses on the fertilizer addition alone and allows producers to make informed decisions about inputs (Hauck et al., 1994). The project detailed here was conducted on three sites in North Dakota and involved production systems located in Cavalier, Cass, and Dickey counties, where fertilizer N usage in 2024 was 45,400 tons, 41,800 tons, and 8,500 tons, respectively (Novak, 2025). Considering this, an increase in FNUE would result in substantial savings for producers in years of high input cost and low commodity price, in addition to reducing environmental pollution.

Split-applying N can increase FNUE and reduce N loss by supplying the input during periods of peak uptake (Bender, 2013), but is not a common practice in North Dakota. Several studies throughout the U.S. using FNUE by the difference method ($FNUE_{diff}$) have evaluated fertilizer timing and concluded that there can be a positive (e.g., Eckert, 1990; Fernandez, 2016), negative (Jokela & Randall, 1989; Clark, 2020) or negligible (e.g., Davies et al., 2020; Preza-Fontes, 2021) impact of in-season N applications. These findings are also consistent where the isotopic method has been used (Spackman, 2024; Wang et al., 2016), though numerous studies have found that the efficacy of split applications is often dependent on site-specific factors such as soil texture and precipitation. Trials evaluating in-season application conducted in wet years often report an increase in efficiency or yield (Davies et al., 2020), whereas dry years do not (Rutan & Steinke, 2018), likely due to the exacerbating impact of added rainfall on N loss. Regardless of precipitation, N loss occurs in all soil textures with denitrification being more common for finer textured soils (Aulakh et al., 1991) and leaching for coarse textured soils (Korsaeth et al., 2001).

This research will provide locally relevant data on corn uptake of fertilizer ^{15}N for key areas and soil types in eastern North Dakota. Field studies in locations with vastly different soil types, including an irrigated sandy loam, a dryland expanding clay, and a clay loam developed on shale with potential to fix NH_4^+, were established utilizing ^{15}N-labeled urea to determine FNUE. The data reported herein are preliminary and future work is detailed below.

MATERIALS AND METHODS

Three field trials were established on crop production fields in Gardner, Oakes, and Langdon, ND having been under row crop production for 50+ years. All three sites can be categorized as conventional-till systems receiving spring cultivation with either a field cultivator (Gardner and Langdon) or a disk (Oakes), while only the Gardner site received vertical tillage in the fall. Based on initial fertility measurements, each site received 50 lbs of phosphorus pentoxide (P_2O_5) ac^{-1} as monoammonium phosphate (MAP) and only Oakes received 80 lbs of potassium chloride (KCl) ac^{-1} to ensure P and K were not limiting. At each site before any fertilizer was applied, a composite of nine soil cores were taken from the 0-6, 6-12, 12-24, 24-36 in depths, dried, ground, and analyzed for soil parameters reported in Table 1.

Table 2: Characterization of study sites

Location & Soil Series[1]	Sampling Depth	Textural Class[2]	CEC	pH	Total N	Potentially Mineralizable N
	in		meq/100g		g kg^{-1}	mg/kg^{-1}
Oakes, ND	0-6	sl	12.89	7.62	1.239	163.77
Embden	6-12	sl	11.31	7.50	0.817	122.34
(C-S)	12-24	ls	7.56	7.93	0.375	59.00
	24-36	ls	6.12	8.22	0.195	30.37
Gardner, ND	0-6	c	41.25	7.72	2.336	245.00
Fargo	6-12	c	38.35	7.79	1.451	158.56
(C-S)	12-24	c	38.18	8.04	0.889	91.32
	24-36	c	34.56	8.41	0.706	68.98
Langdon, ND	0-6	cl	31.52	7.46	2.573	314.52
Vang	6-12	cl	24.76	7.31	2.232	334.48
(C-S-B)	12-24	cl	28.09	7.82	0.902	135.79
	24-36	cl	21.74	8.39	0.444	60.74

[1]Crop rotation indicated in parentheses: C, corn (*Zea mays* L.); S, soybean (*Glycine max* L. Merr.); B, barley (*Hordeum vulgare* L.).
[2] As determined by the hydrometer method: sl, sandy loam; ls, loamy sand; c, clay; cl, clay loam.

At each site, 75 ft^2 plots were arranged in a randomized complete block design with four treatments and four replications including ample border to prevent cross contamination of ^{15}N. The N rate used was determined with the North Dakota N Rate Calculator, developed by NDSU Extension (Franzen, 2022), which is based on maximum economic yield (Goettl, 2024). Rate windows generated for each site included a rate of 140 lbs N ac^{-1}, and was thus used as the total rate for all locations.

The four treatments are detailed in Table 2, and include a zero-N check (UTC), a 100% rate of ^{15}N-labelled urea broadcasted at planting (Single-^{15}N), and two treatments with 30% applied at planting and 70% applied in-season as a surface dribble, where the entirety of the Split-^{15}N treatment is ^{15}N-labeled and only the first application of the Split-1st^{15}N treatment is ^{15}N-labeled. For broadcast applications made at planting, liquid urea was applied with Excellis Maxx at a rate of 25 oz. liquid ton^{-1}, which includes the nitrification inhibitor *dicyadiamide* (DCD) and the urease inhibitor *N-(n-butyl) thiophosphoric triamide* (NBPT). To ensure consistent and accurate application, a calibrated boom back-pressured with CO_2 was used for the initial additions at Gardner and Oakes on May 14th and 18th, respectively. Applications were accomplished prior to a rain event the following day, except at Langdon, where incorporation was provided via chisel plow to planting on May 27th.

Table 2. Treatment summary

Treatment	1st application[1]	2nd application[2]
UTC	None	None
Single-^{15}N	140 lbs ^{15}N ac^{-1}	None
Split-^{15}N	42 lbs ^{15}N ac^{-1}	98 lbs ^{15}N ac^{-1}
Split-1st^{15}N	42 lbs ^{15}N ac^{-1}	98 lbs ^{na}N ac^{-1}

[1]applied as surface broadcast
[2]applied as surface dribble

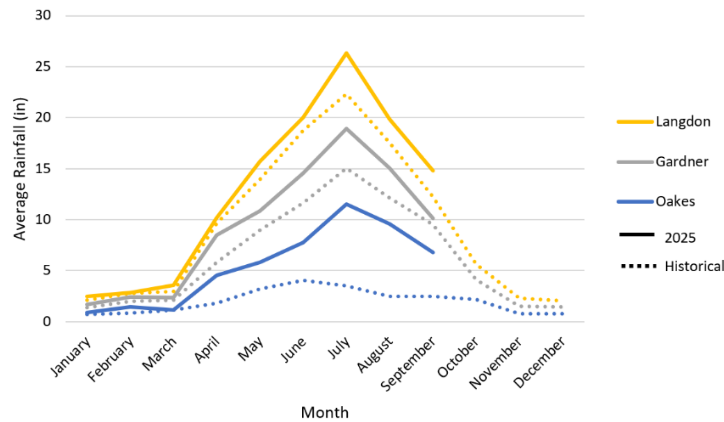
The in-season applications of fertilizer took place on July 2nd, July 2nd, and July 7th, for Oakes, Gardner, and Langdon, respectively, when the crop reached the V6 growth stage. At all sites, the remaining 98 lbs N ac^{-1} for Split-^{15}N and Split-1st^{15}N was applied with the same CO_2 back pressure system modified to accommodate a surface-band application. Similar to the first application, sites were fertilized just before a rain event to aid in incorporation.

Post R6, all ears in the center two rows were harvested by hand, shelled, and thoroughly mixed before taking a subsample, which was tested for moisture content using a commercial moisture tester. Preliminary data was analyzed using a linear mixed model with site and treatment as fixed effects and replication as a random effect. Mean separations were performed using Tukey's HSD and residuals were inspected using Shapiro-Wilks's test.

PRELIMINARY RESULTS AND DISCUSSION

While temperatures in the growing season of 2025 were consistent with historical norms at each site, precipitation was above average for all three sites, even without inclusion of irrigation that was carried out in Oakes (Fig. 1). For both historical and 2025 precipitation, the quantity received was highest for Langdon, then Gardner, then Oakes. As depicted in Table 3, there were significant yield differences between the Oakes and

Figure 1. Rainfall during the study period, as reported by the North Dakota Agricultural Network (NDAWN) alongside historical norms. Oakes, ND 2025 totals include irrigation. Gardner historical norms are reported from Galesburg, ND (16 km NW of Gardner).



Gardner sites, but not the Langdon site. All three sites were responsive to the 140 lbs N ac^{-1}, regardless of application timing. There were no significant differences in yield between the single and split applications, which is unsurprising considering the numerous other studies finding yield to be unaffected by timing (Davies et al., 2020; Preza-Fontes, 2021). Similarly, there was no significant difference between Split-^{15}N and Split-1st^{15}N treatments, validating the assumption that ^{15}N content did not impact yield.

Table 3. 2025 Yield

Site	Treatment	Yield[1] (bu a^{-1})
Oakes	Single-^{15}N	222 (70)
	Spilt-^{15}N	224 (72)
	Split-1st^{15}N	225 (72)
	UTC	131
Gardner	Single-^{15}N	190 (51)
	Spilt-^{15}N	196 (56)
	Split-1st^{15}N	212 (69)
	UTC	125
Langdon	Single-^{15}N	205 (33)
	Spilt-^{15}N	201 (30)
	Split-1st^{15}N	209 (35)
	UTC	154
Statistics		
Treatment	< 0.0001	
Site	0.006	
Treatment x Site	NS	
Treatment effect		
	Single-^{15}N	206a
	Spilt-^{15}N	207a
	Split-1st^{15}N	215a
	UTC	137b
Site effect		
	Oakes	200a
	Gardner	181b
	Langdon	192ab

[1]Percent fertilizer N response indicated in parentheses, calculated as 100 x (fertilized yield – unfertilized yield) / unfertilized yield.

FUTURE WORK

The strength of the project detailed comes from the ^{15}N component that will allow for the distinction between soil- and plant-N. Isotopic analyses are currently underway for the first growing season and will be carried out for all grain and biomass samples to determine total N and fertilizer ^{15}N uptake. These data will be used to calculate FNUE by both the difference and isotopic method, as well as the percent of N derived from the fertilizer (NDFF) and soil (NDFS). This project will be replicated during the 2026 growing season to include six site-years in eastern North Dakota. To understand the impact of soil properties on single- versus split-N applications, additional characterization measurements will be made and include organic carbon (C), bioavailable P and K, smectite:illite ratio, as well as inorganic N (NO_3^-, exchangeable NH_4^+, and fixed NH_4^+).

REFERENCES

Aulakh, M. S., Doran, J. W., Walters, D. T., & Power, J. F. (1991). Legume residue and soil water effects on denitrification in soils of different textures. *Soil Biology and Biochemistry*, *23*(12), 1161–1167. https://doi.org/10.1016/0038-0717(91)90029-J

Bender, R. R., Haegele, J. W., Ruffo, M. L., & Below, F. E. (2013). Nutrient uptake, partitioning, and remobilization in modern, transgenic insect-protected maize hybrids. *Agronomy Journal*, *105*(1), 161–170. https://doi.org/10.2134/agronj2012.0352

Clark, J. (2020). When to use a single or split application of nitrogen fertilizer in corn. *Crops & Soils*, *53*(5), 20–24. https://doi.org/10.1002/crso.20070

Davies, B., Coulter, J. A., & Pagliari, P. H. (2020). Timing and rate of nitrogen fertilization influence maize yield and nitrogen use efficiency. *PLOS ONE*, *15*(5), e0233674. https://doi.org/10.1371/journal.pone.0233674

Eckert, D. J. (1990). Ridge planting for row crops on a poorly drained soil. 2. Anhydrous ammonia and UAN management for maize following soybean. *Soil and Tillage Research*, *18*(2–3), 189–194. https://doi.org/10.1016/0167-1987(90)90059-M

Fernández, F. G., Venterea, R. T., & Fabrizzi, K. P. (2016). Corn nitrogen management influences nitrous oxide emissions in drained and undrained soils. *Journal of Environmental Quality*, *45*(6), 1847–1855. https://doi.org/10.2134/jeq2016.06.0237

Franzen, D. W. (2022). *Soil fertility recommendations for corn* (Extension Circular No. SF722; pp. 1–14). North Dakota State University.

Goettl, B. J. (2024). *Improving nitrogen management, including the use of cover crops, in North Dakota cropping systems* [Doctoral Dissertation]. North Dakota State University.

Hauck, R. D., Meisinger, J. J., & Mulvaney, R. L. (1994). Practical Considerations in the Use of Nitrogen Tracers in Agricultural and Environmental Research. In R. W. Weaver, S. Angle, P. Bottomley, D. Bezdicek, S. Smith, A. Tabatabai, & A. Wollum (Eds.), *SSSA Book Series* (pp. 907–950). Soil Science Society of America. https://doi.org/10.2136/sssabookser5.2.c40

Jokela, W. E., & Randall, G. W. (1989). Corn yield and residual soil nitrate as affected by time and rate of nitrogen application. *Agronomy Journal*, *81*(5), 720–726. https://doi.org/10.2134/agronj1989.00021962008100050004x

Korsaeth, A., Bakken, L., & Riley, H. (2003). Nitrogen dynamics of grass as affected by N input regimes, soil texture and climate: Lysimeter measurements and simulations. *Nutrient Cycling in Agroecosystems*, *66*(181–199).

Novak, L., & Timmer, C. (2025). *2024 Fertilizer tonnage teports*. North Dakota Department of Agriculture. www.ndda.nd.gov/divisions/pesticide-fertilizer-division/fertilizer-program.

Preza-Fontes, G., Pittelkow, C. M., Greer, K. D., Bhattarai, R., & Christianson, L. E. (2021). Split-nitrogen application with cover cropping reduces subsurface nitrate losses while maintaining corn yields. *Journal of Environmental Quality*, *50*(6), 1408–1418. https://doi.org/10.1002/jeq2.20283

Rutan, J., & Steinke, K. (2018). Pre-plant and in-season nitrogen combinations for the northern corn belt. *Agronomy Journal*, *110*(5), 2059–2069. https://doi.org/10.2134/agronj2018.03.0153

Spackman, J. A., Fernández, F. G., Paiao, G. D., Venterea, R. T., & Coulter, J. A. (2024). Corn^{15} N uptake and partitioning in response to fertilizer application rate and timing. *Agronomy Journal*, *116*(4), 1991–2006. https://doi.org/10.1002/agj2.21577

Wang, S., Luo, S., Yue, S., Shen, Y., & Li, S. (2016). Fate of ^{15}N fertilizer under different nitrogen split applications to plastic mulched maize in semiarid farmland. *Nutrient Cycling in Agroecosystems*, *105*(2), 129–140. https://doi.org/10.1007/s10705-016-9780-3