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Interseeded cover crops did not cause corn yield loss in eastern North Dakota

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Abstract

North Dakota is a transitional semiarid region with annual precipitation in the eastern part of the state of about 50–55 cm, mostly from rainfall. The moisture demand from interseeding cover crops into standing corn (*Zea mays*) early in the season has been a concern and is likely why most corn growers do not interseed cover crops. Corn grain yield was determined in response to interseeding of cereal rye (*Secale cereale*) or oat (*Avena sativa*), radish (*Raphanus sativus*), and camelina (*Camelina sativa*) and incremental fertilizer nitrogen (N) application rates for five site-years in the eastern North Dakota. Fifty-eight days and 35 days of leaf wetness from dew in 2019 and 2020, respectively, were recorded. Cumulative dew accumulation since cover crop emergence was 5.6 mm and 3.5 mm in 2019 and 2020, respectively. Interseeding and its interactions with fertilizer-N rate did not influence the grain yield. However, cereal rye produced the most biomass of the cover crop species, but the amount varied with site and growing season conditions. Late October, cereal rye biomass produced was 98.8 kg ha^{-1} in 2018, 352 kg ha^{-1} in 2019, and 70.3 kg ha^{-1} in 2020 at the Gardner site. Interseeding did not reduce grain yield loss compared to control. Outcomes will encourage corn growers to adopt cover crops without any changes in their fertilizer N application.

1 | INTRODUCTION

In eastern North Dakota, soils are exposed to erosion and loss of nutrients during fallow (October–April); adoption of cover crops to prevent these losses and promote soil health began in 2015 (Wick, 2020). Most North Dakota cover crops are established after harvest, which allows up to 3 months of growth in North Dakota following small grains; however, it allows almost no time, if any, following corn harvest to establish a cover crop. Interseeding cover crops into corn allow a better cover crop establishment compared to planting after harvest and provide sufficient time for significant cover crop biomass accumulation before killing frost. In Minnesota, Noland et al. (2018) found that interseeding cover crops into corn at the seven-leaf collar stage in the upper Midwest did not reduce yield of corn and subsequent soybean (*Glycine max*).

Since North Dakota is in a transitional semi-arid region, eastern North Dakota receives 50–55 cm of annual precipitation. Farmers in eastern North Dakota fear interseeding will cause a loss in grain yield of the main crop (Robinson & Nielsen, 2015). Deines et al. (2023) estimated an average corn grain yield loss of 5.5% on fields under cover crop compared to fields without cover crop across the US Corn Belt. Because cover crops need soil moisture, in a dry growing season, some yield reduction might result from interseeded cover crops under rainfed conditions. However, during the 2012 drought, the use of a cereal rye cover crop did not significantly lower soil water conditions compared to without cereal rye cover crop in a corn–soybean rotation (Daigh et al., 2014). We hypothesize that "non-rainfall" water or dew might have contributed to soil moisture under cover crop to account for the moisture loss due to cover crop biomass accumulation.

Dew is formed due to the phase transition of water vapor into liquid during close proximity to a soil surface. Since biblical times, dew has been considered a source of great fertility (Genesis 27:28; Deuteronomy 33:13; and Zechariah 8:12) (Agam & Berliner, 2006). A cover crop canopy can facilitate dew formation during the dry period without rainfall. Short grass becomes wet due to the partial condensation of water vapor evaporating from the soil during cool calm nights (Monteith, 1957). Xie et al. (2021) found that as plant height increased, dew formation also increased, but was limited within a species in grassland. Between species, the grass with slender leaf structure accumulated similar dew at lower leaf heights compared to broader leaf species, indicating that surface area is very important in dew formation. Dew events are most common and large in size during summer (July–September) (Yokoyama, Yasutake, Wang, et al., 2021). Atzema et al. (1990) measured dew using Leick plates at five height levels within the corn canopy and reported that accumulation of dew ranged from 0.01 to 0.41 mm per night under corn field over 16 nights. Although the amount of leaf wetting by dew might be minute (5.4% of the rainfall amount), it could reduce moisture stress of corn in semi-arid climates (Yokoyama, Yasutake, Minami, et al., 2021; Yokoyama, Yasutake, Wang, et al., 2021).

Growers also continue to question the impact of cereal rye cover crops on the optimal fertilizer nitrogen (N) rate and corn grain yield. With winter cereal rye cover crop, corn showed plant stand reduction, stress, and slower growth, ultimately causing grain yield loss by 6% at the economic optimum N rate (Pantoja et al., 2015). On the contrary, Quinn et al. (2023) reported that rye cover crop reduced corn grain yield by 20% at 0 kg N ha^{-1} due to N deficiency but did not reduce corn yield at the economic optimum N rate. A meta-analysis study showed that greater precipitation and N fertilizer inputs reduced the negative effects of grass cover crops on corn yield under humid temperate climate conditions (Bourgeois et al., 2022).

This on-farm study was conducted to convince corn growers that adoption of cover crop interseeding does not need to compromise corn grain yield. The inclusion of cover crops does not require additional fertilizer N to optimize the yield. Research objectives are to determine the (i) influences of cover crop interseeding on grain yield and (ii) interactions between cover crop and fertilizer-N application rate on agronomic optimum N rate in eastern North Dakota.

Core Ideas

- No yield was compromised due to cover crop interseeding.
- Fertilizer-N rate did not interfere with cover crop interseeding.
- In eastern North Dakota, cereal rye can be interseeded at corn V7 stage.

2 | MATERIALS AND METHODS

An on-farm field experiment was conducted at Rutland, ND (46.032681°N, 97.48782556°W) in 2018 and 2019 and at Gardner, ND (47.175679°N, 96.920338°W) during 2018–2020 growing seasons. Rutland soil is characterized as Astad clay loam, fine-loamy, mixed superactive, frigid Pachic Argiudolls, and Gardner soil is characterized as Fargo-Enloe complex, silty clay, fine, smectitic, frigid Typic, Epiaquerts. Before planting, soil samples were analyzed using recommended methods for initial soil properties, and recommended fertilizers were applied (Table 1).

For all site-years, the previous crop was spring wheat (*Triticum aestivum*). The tillage history of the Rutland site was long-term continuous no-till for about 40 years. The Gardner site was managed in a conventional tillage system, with chisel plows once or twice in the fall and spring field cultivators until 2016, when no-till management began. At both sites, the field experiment was laid out in a split-plot randomized complete block design with and without cover crop as main plot; and sub-plot treatments were six incremental fertilizer-N application rates: 0, 45, 90, 135, 180, and 225 kg N ha^{-1}, with three replications. Fertilizer-N was applied in the form of urea treated with N-(n-butyl)thiophosphoric triamide (NBPT) and N-(n-propyl)thiophosphoric triamide (NPPT) urease inhibitors (Limus, BASF Agricultural Products) at the rate of 3 mL kg^{-1} of urea. A mix of cover crop species, cereal rye (Dylan) seed at the rate of 45 kg ha^{-1}, forage radish (Daikon) seed at the rate of 2.2 kg ha^{-1}, and camelina seed at the rate of 2.2 kg ha^{-1}, were interseeded at 0.4 cm soil depth using an experimental Fargo-Air (Amity Technologies) seeder at V6–V8 corn growth stage, depending on the site and year (Figure 1). Individual experiment unit area was 12 m × 3.05 m.

Cover crop biomass was sampled using three sampling squares (0.31 m × 0.76 m) per experimental unit (Figure 1). At physiological maturity, corn was harvested by hand, removing

TABLE 1 Initial soil properties of experimental sites to study interseeding and incremental fertilizer nitrogen on corn production in the eastern North Dakota during the 2018–2020 growing seasons.

Year	Site	pH (1:1)	Organic matter content (g kg^{-1})	Nitrate nitrogen of 60 cm depth(kg ha^{-1})	Olsen-phosphorus (mg kg^{-1})	Available potassium (mg kg^{-1})
2018	Rutland	7.2	55	+Cover: 21 −Cover: 33	8	260
	Gardner	7.9	44	+Cover: 58 −Cover: 96	9	380
2019	Rutland	7.5	58	+Cover: 24 −Cover: 19	7	305
	Gardner	7.7	49	31	13	410
2020	Gardner	7.6	54	39	12	340

Note: +Cover: soil with cover crop; −Cover: soil without cover crop.

all ears from the whole middle row of the plot and leaving an alley ear at each end to avoid the border effect. Grain moisture and test weight were measured using Dickey John Grain Moisture tester (GAC 500 XT). Final grain yield was adjusted to 155 g kg^{-1} moisture concentration.

In 2019–2020, leaf wetness sensors (Campbell Scientific) were installed at a 10-cm height at the Gardner corn cover crop sites and attached to a weather station platform. Two sensors were placed within the cover crop and no-cover crop 225 kg ha^{-1} treatment plots with two replications. In days of dew formation analysis, days with rainfall were deleted from the dataset, and only dates that did not receive rainfall were included.

On June 23, 2020, a subplot (0.6 m × 0.6 m) with and without oat (*Avena sativa*) as cover crop was established in between corn rows within the plot receiving 225 kg N ha^{-1} at the Gardner site. Approximately 50 seeds were planted within subplot. Both subplots (with and without oats) were watered with 2 L water following seeding. After seeding as needed, an additional 2 L of water was applied to each area to keep the soil moist. At daybreak on mornings, dew accumulation was measured by holding down a section (27.5 cm × 15 cm) of paper towel (Bounty, Procter & Gamble) on the ground for 30 s, wearing latex gloves to avoid contamination by sweat (Kabela et al., 2009). A paper towel was transferred to a zip-lock bag and weighed to measure the moisture content. Gardner site was visited frequently for dew collection during July and August. Unfortunately, on most of the occasions, no moisture was gathered on the paper towel except August 30. The sky was hazy during most of this period due to smoke from California or Canadian forest fires.

Statistical analysis of corn grain yield was performed using cover crop, fertilizer-N rates, and their interactions as fixed factors and block and block × cover crop as random factors using the PROC Mixed procedure on the web-based SAS Studio (SAS Inc.) for individual site and growing year. Differences in least square mean values were adjusted using the "Tukey-Kramer" method at the 95% significance levels ($p < 0.05$). A quadratic fit was developed to relate the corn grain yield in response to fertilizer-N application rate separately for with and without cover crop treatments and separately for site and year using the PROC GLM procedure.

3 | RESULTS AND DISCUSSION

3.1 | Growing season conditions

Daily precipitation and average air temperature data were collected from nearby weather stations and the North Dakota Agricultural Weather Network (NDAWN, http://ndawn.ndsu.nodak.edu/) (Figure 1). During May 1 to October 31, normal rainfall is 449 mm for Rutland and 470 mm for Gardner. In 2018, May showed a deficit of 55 mm for Rutland and 24 mm for the Gardner site. In 2019, both sites were extremely wet in September, with an excess of 145 mm for Rutland and 79 mm for Gardner. In 2020, the Gardner site was extremely dry in May (−37 mm) and June, and again in late growing seasons of September (−56 mm) and October (−49 mm).

In 2018, during field visits in July and August, dew was noticed on cereal rye and radish after emergence between corn rows. In 2019, 58 days of dew formation were recorded, with a mean of 8 h of leaf wetness recorded at each event (not associated with rainfall). Cumulative dew accumulation was 3.5 mm. In 2020, 35 days of dew were recorded, with more than 7.1 h of leaf wetness recorded at each event, resulted in cumulative dew accumulation of 5.6 mm (Figure 2). We did not observe any differences in dew accumulation between with and without cover crop (based on leaf wetness sensors), probably because leaf wetness sensors were attracting dew even without cover crop treatment. On August 30, 2020, we observed a significant difference in paper towel from subplots with and without oat as cover crop. Cover crop treatment had 0.5 g of water per paper towel section, whereas no moisture was recorded without cover crop treatment (Figure 2).

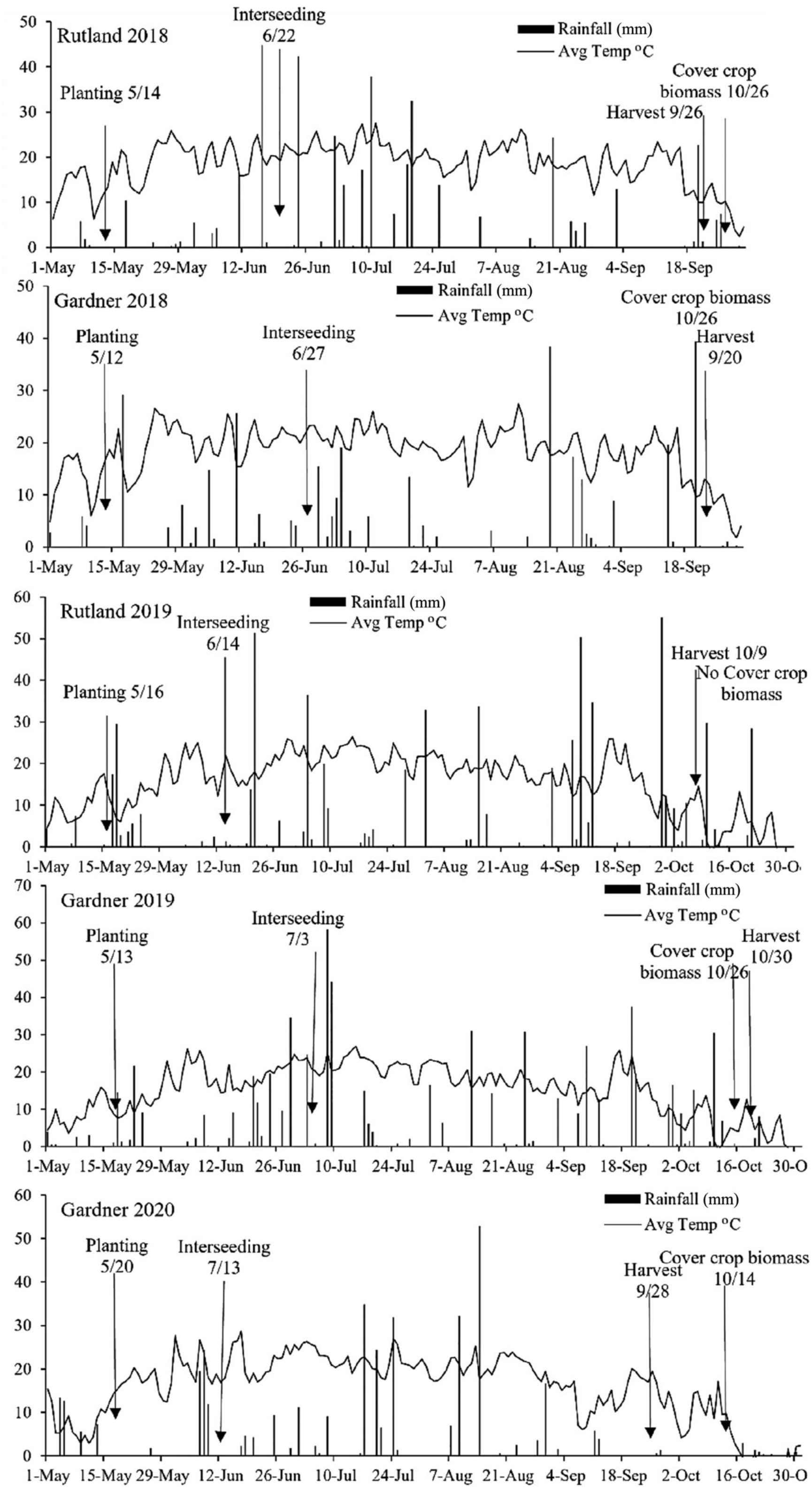

FIGURE 1 Daily average air temperature (˚C), rainfall (mm) data and dates of field operations for five site-year field experiments in eastern North Dakota during 2018–2020 growing seasons.

3.2 | Cover crop biomass

Cover crop biomass varied with site and year. Across five site-years, measurable cereal rye biomass was found. At Rutland in 2018, rye biomass produced was 17.4 kg ha^{-1}, but cereal rye did not germinate in 2019 due to extreme dry conditions. At the Gardner site, cereal rye biomass measured was 98.8, 352, and 70.3 kg ha^{-1} during 2018–2020. Amount of cover crop biomass produced was extremely variable due to annual variation in rainfall distribution during late growing

TABLE 2 Type III test for fixed effects (Pr > *F*) of cover crop, fertilizer-nitrogen rate, and their interactions on corn grain yield (Mg ha^{-1}) for five site-years in eastern North Dakota.

	Site-year				
	2018		2019		2020
Factors	Rutland	Gardner	Rutland	Gardner	Gardner
Cover crop	0.75	0.35	0.32	0.90	0.98
Fertilizer-N	0.03*	<0.01*	0.01*	0.01*	<0.01*
Cover crop × fertilizer N	0.47	0.54	0.42	0.75	0.28

*Significant differences in means at 95% significance level.

FIGURE 2 Accumulation of dew on oat (*Avena sativa*) canopy, no dew accumulation on residues, observed on August 30, 2020, at the Gardner site.

season (July–August), and insufficient sunlight due to canopy closure. Schmitt et al. (2021) found that fall rye cover crop biomass for interseeding at corn V7 stage was less than 100 kg ha^{-1} and attributed to large decline in the amount of photosynthetic radiation reaching the third week of cover crop planting. Fall cover crop biomass production also depends on weather conditions. Sigdel et al. (2021) reported interseeded cereal rye biomass production of 141 kg ha^{-1} in 2018, 1685 kg ha^{-1} in 2019, and 692 kg ha^{-1} in 2020 under sugarbeet production in the Red River Valley of Minnesota.

3.3 | Corn grain yield

Cover crop and its interaction with fertilizer-N application rate had no effect on grain yield; but fertilizer-N rate had a significant effect for all five site-years (Table 2). At the Rutland site, without and with cover crop treatments had average grain yields of 13.8 and 13.6, 11.3 and 10.7 Mg ha^{-1}, for 2018 and 2019 growing seasons, respectively (considering all N rates). At the Gardner site, without and with cover crop treatments had average grain yields of 10.9 Mg ha^{-1} and 10.1 Mg ha^{-1}, 5.50 Mg ha^{-1} and 5.58 Mg ha^{-1}, and 7.60 Mg ha^{-1} and 7.62 Mg ha^{-1}, for 2018, 2019, and 2020 growing seasons, respectively (considering all N rates). At the Rutland site, the highest grain yield was observed with fertilizer-N application at the rates of 135 kg N ha^{-1} and 180 kg N ha^{-1}, respectively, for 2018 and 2019 growing seasons, significantly higher than control for 2019 only. At the Gardner site, the highest grain yield was observed with 180 kg N ha^{-1} in 2018 and 2019 and 225 kg N ha^{-1} in 2020. The grain yield difference between cover crop and without cover crop was negative for control (0 kg N ha^{-1}) and fertilizer-N rate (at the rate of 45 kg N ha^{-1}) for all five site-years (Figure 3). At the Rutland site in 2018, cover crop increased yield over without cover crop at 180 kg N ha^{-1} (0.27 Mg ha^{-1}) and 225 kg N ha^{-1} (+2.50 Mg ha^{-1}). At Rutland in 2019, an increase in grain yield with cover crop was found at 135 kg N ha^{-1} and 225 kg N ha^{-1}. At Gardner, 2018, the positive effect of cover crop on grain yield was observed at 90 kg N ha^{-1} and 180 kg N ha^{-1}. In 2019 and 2020, fertilizer-N rates at 135 kg N ha^{-1} and 225 kg N ha^{-1} had yield gains due to cover crop interseeding.

TABLE 3 Fertilizer-nitrogen rate (kg N ha^{-1}) to optimize the corn grain yield with and without cover crop for five site-years in eastern North Dakota.

	2018		2019		2020
Treatments	Rutland	Gardner	Rutland	Gardner	Gardner
−Cover	132	262	210	227	275
+Cover	201	174	170	*	190

Note: +Cover: soil with cover crop; −Cover: soil without cover crop.
*Parameter coefficients are not significant at $p < 0.05$.

The quadratic fit between fertilizer-N rate and grain yield with and without cover crop for five site-years is presented in Figure 3. Solving the regression equation for the optimum N rate (when the change in grain yield is equal to change in fertilizer-N rate) is calculated (Table 3). Three out of five site-years showed that including cover crop interseeding has lower optimum N rate value than without cover crop.

Our five site-year study revealed that interseeding corn did not compromise corn grain yield. Other studies like Brooker et al. (2020) in Michigan, Rusch et al. (2020) in Minnesota also found neither beneficial nor detrimental effects of interseeding on corn. Brooker et al. (2020) found that

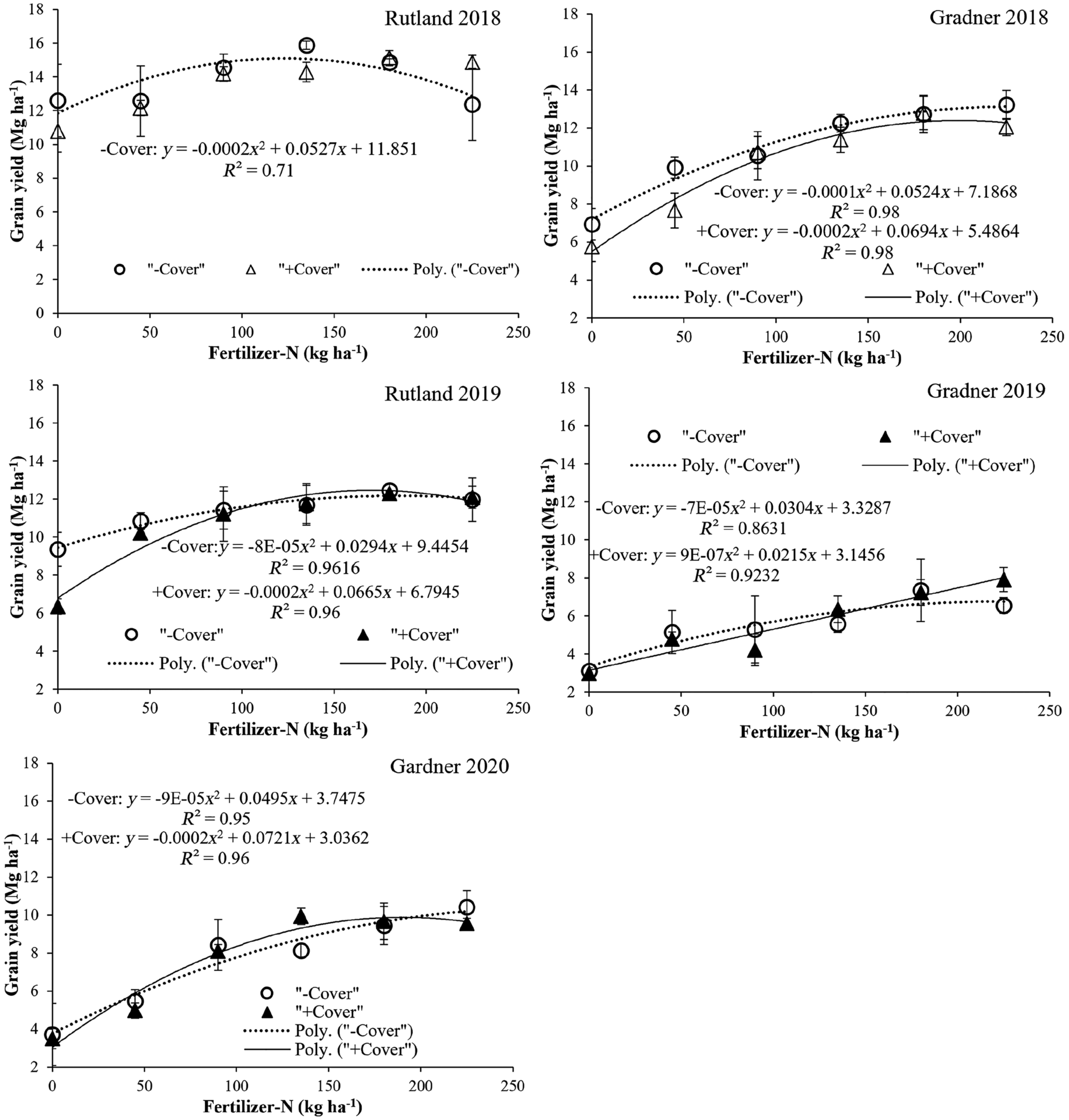

FIGURE 3 Corn grain yield (Mg ha^{-1}) in response to incremental six fertilizer-N application rates with and without cover crop interseeding at five site-years in the eastern North Dakota.

annual ryegrass (*Lolium multiflorum* L.) and oilseed radish interseeded in V2–V7 corn did not reduce yield and found maximum fall biomass occurred in the case of early interseeding. Rusch et al. (2020) attributed lack of corn yield response to limited cover crop growth with little to no competition between plant species.

Lack of interaction between cover crop and fertilizer-N rate indicates that lack of cover crop biomass might have limited effect on corn N use efficiency after V7 growth stage. However, yield reduction induced by cover crop treatment was observed at lower fertilizer N rate increments of 0 and 45 kg N ha^{-1}, which indicates cover crops take up mineralizable soil inorganic N as they grow, reducing soil inorganic N levels, which can limit the yield under drought conditions (Deines et al., 2023; Hunter et al., 2021). We also observed some negative values (yield loss with cover crop) at higher N rate. Bourgeois et al. (2022) found that cover crop benefits decreased when N fertilizer exceeded 60 kg N ha^{-1}.

Optimum N rate derived from the corn yield and fertilizer-N response curve showed that there might be some growing seasons for specific sites when the corn response to N might be improved with the introduction of cover crops over without cover crops. Previous studies like Pantoja et al. (2015) found similar economic optimum fertilizer-N rate with and without rye cover crops; whereas Johnson et al. (2021) could not find any evidence to support that corn yield could be maintained with less fertilizer-N compared with no cover crop.

The amount of cover crop biomass to have effect on corn yield and N-use efficiency depends on the rainfall during the late growing season (July–August). Lack of rainfall might lead to failure to germination or not enough cover crop biomass that might have hardly any effect on corn grain yield or ecosystem services expected from cover crop. In addition, the extent of corn canopy cover is also critical for the cover crop growth. However, under favorable growing conditions, interseeding had a better chance to produce more cover crop biomass production than post-harvest planting of cover crops.

Future studies should investigate the dew formation under different species and weather scenarios. Five site-years of data showed that interseeding did not cause a grain yield loss. These results were not consistently influenced by the amount of nitrogen fertilizer added. Our results will encourage interseeding of cover crops in eastern North Dakota at recommended rates of fertilizer-N, increasing cover crop benefits to the environment. These results are useful to farmers and researchers of cover crops and soil nutrients.

4 | CONCLUSION

Interseeding cereal rye as a cover crop did not cause a grain yield loss, and outcomes were not consistently affected by the amount of fertilizer-N added. Depending on the growing season and weather, interseeding can increase benefits like protection from soil erosion and nutrient loss through the addition of cover crop biomass over cover crop planting after harvest. Cover crops have the potential to trap dew, and dew can compensate for the soil moisture utilized for the cover crop biomass production. Dew entrapment is only feasible when the cover crop is interseeded because most of the dew events occurred during the summer months (July and August). Use of paper towels provides a quick and easy estimate of dew accumulation by cover crops. Our results will encourage interseeding of cover crops in eastern North Dakota at recommended rates of fertilizer-N, increasing cover crop benefits to the environment.

AUTHOR CONTRIBUTIONS

David Franzen: Conceptualization; data curation; funding acquisition; investigation; project administration; resources; supervision; writing—original draft. **Abbey Wick**: Conceptualization; methodology; resources. **Honggang Bu**: Formal analysis; investigation; methodology; writing—original draft. **Daryl Ritchison**: Data curation; investigation. **Barbara Mullins**: Data curation; investigation; methodology. **Amitava Chatterjee**: Formal analysis; visualization; writing—review and editing.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

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