



Precision planting of cereal rye cover crop improves sweet corn yield and farm benefits

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Abstract

Including cereal rye (*Secale cereale* L.) in sweet corn (*Zea mays* L.) production systems provides environmental and soil benefits. However, cereal rye often decreases sweet corn yield and thus farm profit. A novel approach to reduce this negative effect is precision planting of cereal rye, which skips the sweet corn row to minimize crop interactions, potentially increasing nitrogen (N) availability, and reducing negative effects of cereal rye on sweet corn. A four-site-yr trial was conducted during the 2022–2024 growing seasons, the first known evaluation of precision-planted cereal rye compared to a no-cover crop control and solid-planted cereal rye. The study evaluated (i) cereal rye morphology, biomass production and its quality, (ii) sweet corn plant population, morphology, and marketable yield, (iii) sweet corn quality traits, and (iv) soil nitrate-N ($\text{NO}_3\text{-N}$) dynamics and leaching potential. Our results indicated that precision planting had similar morphology, biomass yield (2735 kg ha^{-1} for precision planting vs. 3011 kg ha^{-1} for solid planting), and C:N ratio (48.2 for precision planting vs. 53.4 for solid planting) to the solid planting of cereal rye. Sweet corn plant population was similar among all treatments. Sweet corn marketable yield was significantly higher in precision planting (16841 kg ha^{-1}) compared to no-cover crop control (13914 kg ha^{-1}), while solid planting (14721 kg ha^{-1}) showed no significant difference from either of the two other treatments. Higher marketable yield was mainly due to moisture conservation by precision planting with limited impact on N immobilization during sweet corn growth. There were no differences among treatments for Brix %. Including both cereal rye treatments reduced N availability during and especially at the end of the season, minimizing $\text{NO}_3\text{-N}$ loss potential. We recommend growers utilize precision planting as a novel alternative to solid planting to ensure sweet corn production while minimizing the $\text{NO}_3\text{-N}$ loss potential.

Keywords Brix · Farm profit · Grasses · Planting methods · Sustainable · Soil nitrate-N

1 Introduction

Cover crops, particularly winter cereal cover crops (WCCC), are increasingly recognized as an in-field management strategy for improving soil physical and biological properties over time (Bagnall et al. 2022; Liptzin et al. 2022, 2023; Rieke et al. 2022), while effectively suppressing weeds (Tadiello et al. 2022). After the fall cash crop harvest and

into the following spring, WCCC, especially when planted early, are useful for keeping the soil covered and scavenging leftover N (Hashemi et al. 2013; Vaughn et al. 2022; Vyn et al. 2000; Wagger et al. 1998). This reduces nutrient losses and enhances water quality (Adeyemi et al. 2020; Blanco-Canqui 2018; Gentry et al. 2024). In Illinois and other regions of the U.S. Midwest, adoption of cover crops has been motivated by their potential to reduce soil erosion and nitrate-N ($\text{NO}_3\text{-N}$) leaching (Marks and Boerngen 2019). Beyond local contexts, cover crops have gained global attention for their role in enhancing ecosystem services and mitigating environmental impacts. For example, meta-analyses and modeling studies across North America and Europe show that cover crops can increase soil carbon (C) sequestration and contribute to greenhouse gas mitigation, though results are highly context-specific depending on soil, climate, and management (Kaye and Quemada 2017).

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International field studies highlight the variability of cover crop outcomes under contrasting conditions. In Mediterranean environments, legume and non-legume cover crops influence soil organic C dynamics and N availability differently, often constrained by water limitations (Gabriel et al. 2013; Quemada et al. 2013). In northern and western Europe, long-term trials have demonstrated that cover crops significantly reduce soil mineral N during the fall and winter, lowering the risk of $\text{NO}_3\text{-N}$ leaching by up to 50% compared with bare fallow (Constantin et al. 2012). Similarly, in humid subtropical systems of Italy, recent work combining field experiments with satellite monitoring and modeling has shown that cereal rye (CR) among other cover crops differs markedly in biomass production, N release, and soil water interactions, with important implications for optimizing cover crop integration into corn (*Zea mays* L.)-soybean (*Glycine max* L.) rotations (Raimondi et al. 2023). Collectively, these studies underscore that while cover crop benefits are consistent in reducing N losses and improving soil health, their performance varies across agroecosystems depending on species selection, climatic conditions, and management strategies.

Sweet corn is one of the main specialty crops in Illinois and the upper Midwest, USA (Kistner et al. 2018) and more broadly across North America (Revilla et al. 2021). Sweet corn production is also common in China, Brazil, and Argentina, among other parts of the world (Ahmad et al. 2024). Therefore, there is growing interest in increasing sweet corn production while improving soil health and reducing environmental impacts. Integrating WCCC including CR, into cash crop rotations like sweet corn, could offer significant nutrient cycling, weed suppression, environmental, and soil health benefits (Gaimaro et al. 2022; Reicks et al. 2021; Ryan et al. 2011; Sadeghpour et al. 2014). However, growers are less inclined to include CR prior to sweet corn due to allelopathic effects, diseases and pests, and N immobilization during sweet corn production (Cline and Silvernail 2002; Lacey et al. 2020; Singh et al. 2020). Cereal

rye is conventionally planted in 19 cm rows which intersect sweet corn rows, often leading to reductions in sweet corn stands and thus a sweet corn yield penalty (Fig. 1A). Also, when a row of CR and a sweet corn row coincide, pests and diseases are frequently transferred from CR to sweet corn, further reducing the sweet corn output (Bakker et al. 2016). A novel approach to CR planting is precision planting (PP), which eliminates CR rows from the cash crop row (STCR) (Fig. 1B). This could provide nutrient uptake benefits (Baker et al. 2024; Sadeghpour et al. 2021), alleviate the negative effects of normally planted CR (NP), and provide conditions that could help sweet corn generate similar or higher yields than in fallow [no-cover crop (NOCC)] scenarios while providing the nutrient scavenging and erosion-control benefits of a CR cover crop. To the best of our knowledge, this is the first study to evaluate the effects of CR at late termination with the precision planting method (PPCR) on sweet corn performance in two locations with different soil types and precipitation patterns.

We hypothesized that (i) using solid planted CR could decrease sweet corn marketable yield, but this effect could be alleviated by PP; (ii) CR, regardless of planting method, could decrease soil N during the fall period and at sweet corn harvest; and (iii) PP is more economical than NP and is comparable with NOCC. Our objective was to compare the effect of the method of CR planting and an NOCC system on (i) CR morphology, biomass production, N uptake, C accumulation, and quality, (ii) sweet corn plant population, morphology, marketable yield, and quality, and (iii) soil N dynamics and leaching potential.

2 Materials and methods

2.1 Experimental site

A trial was conducted at two different locations, (i) the Agronomy Research Center (ARC) in Carbondale, IL

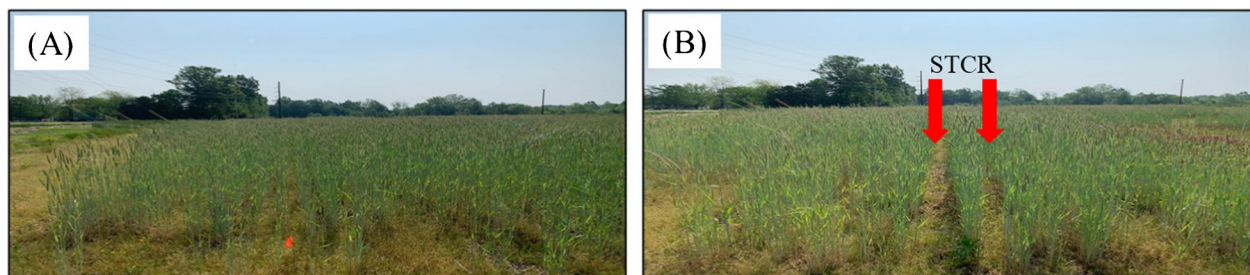


Fig. 1 Cereal rye planting configurations in sweet corn systems: **(A)** solid planting (CR), where cereal rye is sown uniformly across all rows, including the two rows that overlap with sweet corn planting positions; **(B)** precision planting (PPCR), where cereal rye is sown to

skip the two rows designated for sweet corn (STCR), increasing ease of planting and reducing competition and pest transfer. By excluding these rows, PPCR also allows for a reduced cereal rye seeding rate compared to solid planting. Photo credit: Amir Sadeghpour.

(37°41'49.2"N 89°14'22.2"W) and (ii) the Belleville Research Center (BRC) in Belleville, IL (38°31'24.9"N 89°50'29.1"W) during the 2021–2022 and 2022–2023 growing seasons (total of four site-yrs). To facilitate the presentation of each year, the 2021–2022 growing season is presented as 2022, and the 2022–2023 growing season is presented as 2023. Therefore, we had four sites: ARC22 (ARC site in 2022), ARC23 (ARC site in 2023), BRC22 (BRC site in 2022), and BRC23 (BRC site in 2023). At ARC, the dominant soil was classified as Stoy silt loam (fine-silty, mixed, superactive, mesic Fragiatic Hapludalfs) with 2–5% slopes. This corresponds to a Luvic Stagnosol (Siltic) in the World Reference Base for Soil Resources (WRB) (IUSS Working Group WRB 2015). Soil samples from a depth of 0–15 cm had a pH of 6.08 (1:1 w/v), soil organic matter (SOM) content of 23.6 g kg⁻¹, Bray-1 extractable phosphorus (P) content of 30.42 mg kg⁻¹, and Mehlich-3 extractable potassium (K) content of 135.72 mg kg⁻¹. At BRC, the dominant soil in 2022 was classified as Rushville (fine, smectitic, mesic Typic Albic) corresponding to Planosols (Albic) in the WRB (IUSS Working Group WRB 2015), with 0–2% slopes. In 2023, the dominant soil at the BRC site was Ebbert silt loam (fine-silty, mixed, superactive, mesic Argiatic Argialbolls) with 0–2% slopes. This corresponds to a Luvic Albelvisol (Siltic) in the WRB (IUSS Working Group WRB 2015). Soil samples from a depth of 0–15 cm had a pH of 6.8 (1:1 w/v), soil organic matter (SOM) content of 20.1 g kg⁻¹, Bray-1 extractable P content of 26.33 mg kg⁻¹, and Mehlich-3 extractable K content of 177.75 mg kg⁻¹. For both cereal rye and sweet corn phases, growing degree days (GDD) were calculated using modified GDD as suggested in McMaster and Wilhelm (1997). We used daily maximum and minimum air temperatures to calculate modified GDD using 10 °C as Tbase for sweet corn, 4.4 °C as Tbase for cereal rye, and 30 °C as Tmax for sweet corn (McMaster and Wilhelm 1997). During the cover crop phase, in Carbondale, IL, the average air temperature, total precipitation, and GDD were recorded as 9.5 °C, 866.0 mm, and 1247.3 for 2022 and 9.7 °C, 863.0 mm, and 1268.3 for 2023, respectively. In Belleville, the average air temperature, total precipitation, and GDD were 9.5 °C, 789.0 mm, and 1041.5 for 2022 and 8.5 °C, 640.0 mm, 1300.5 for 2023, respectively. During the sweet corn growing season, the average air temperature, total precipitation, and GDD for Carbondale, IL were 23.7 °C, 321.0 mm, and 1111.6 for 2022 and 23.0 °C, 411.0 mm, and 1032.3 for 2023, respectively. In Belleville, the average air temperature, total precipitation, and GDD of 23.5 °C, 545.0 mm, and 1110.1 were recorded in 2022, respectively. For the following year, 2023, these figures were 23.5 °C, 322.0 mm, and 1107.3 for average air temperature, total precipitation, and GDD, respectively Table 1.

2.2 Experimental design and treatments

The experiment was conducted in a randomized complete block design with four replicates per treatment. Treatments were (i) a no-cover crop control (NOCC); (ii) CR (CR solid planted; CR rows intersect with sweet corn rows) (Fig. 1A); and (iii) PPCR (CR precision planted in which sweet corn rows were skipped) as shown in Fig. 1B.

2.3 Cultural management practices

2.3.1 Cover crop planting and management

ARC site A small grain drill (InterSeeder Technologies LLC, Woodward, PA) was used to plant CR. The drill has no-till coulters, adjustable double disk openers for planting depth control, and single packing (closing) wheels. It is raised and lowered using hydraulics. Cereal rye seeding rate was 67.0 kg ha⁻¹ for CR and 50.0 kg ha⁻¹ for PP (PPCR) in each year. This seeding rate is high enough to allow for successful weed suppression while contributing to nutrient cycling and has been recently further promoted over higher seeding rates to reduce cover crop planting costs (data not shown). Cereal rye row spacing, as shown in Fig. 1, was 19 cm. Cereal rye was no-till planted on October 18, 2021 and terminated on May 16, 2022. In the second year, CR was no-till planted on October 18, 2022 and was terminated on May 18, 2023. Cereal rye was terminated using glyphosate at 0.87 a.e. ha⁻¹ rate right after cover crop biomass sampling occurred.

BRC site A small grain drill (Great Plains Manufacturing, Salina, KS) was used to plant CR. Cereal rye seeding rate was 67.0 kg ha⁻¹ for CR and 50.0 kg ha⁻¹ for PPCR in each year. The seeding in the small grain drilled is gate-controlled with coulters in front and opening disks and closing wheels. The whole unit is controlled by hydraulics, but the closing wheels are spring controlled. Cereal rye was no-till planted on November 1, 2021, with a row spacing of 19 cm. Cereal rye termination date was May 16, 2022. Cereal rye was no-till planted again on October 14, 2022, and terminated on May 24, 2023. Similar termination methods were used for the CR at both the BRC and ARC sites.

2.3.2 Sweet corn planting and management

A four row Kinze 3000 (Kinze Manufacturing, Williamsburg, IA) planter was used for no-till planting of sweet corn at 70,000 seeds ha⁻¹ with row spacing of 76 cm on June 1, 2022, and May 22, 2023, at ARC, and June 8, 2022, and May 22, 2023, at BRC. The Kinze 3000 has no-till coulters, adjustable row unit gauge wheels for planting depth control, and "V" closing wheels. It is raised and lowered using

Table 1 Average monthly temperature, cumulative monthly precipitation, and growing degree days (GDD) for cereal rye (T_{base} 4.4°C) and sweet corn (T_{base} 10°C) in two years of study in Carbondale (ARC) and Belleville (BRC) locations.

Crop	Location	Month	Mean temperature (°C)		Precipitation (mm)		Growing degree days	
			2021-22	2022-23	2021-22	2022-23	2021-22	2022-23
Rye	ARC	Oct.	17	13	133	32	118.6	135.5
		Nov.	7	7	47	58	142.4	152.3
		Dec.	9	2	138	104	186.5	71.5
		Jan.	−1	5	85	144	36.2	98.0
		Feb.	2	7	152	109	82.7	131.2
		March	9	8	132	220	180.2	148.0
		April	13	17	83	107	269.7	279.8
		May	20	19	96	89	230.8	251.8
	BRC	Oct.	16	13	131	77	-	153.8
		Nov.	16	7	21	68	137.3	148.2
		Dec.	7	1	80	67	150.9	55.1
		Jan.	−3	3	37	105	30.1	78.4
		Feb.	0	5	124	55	62.1	109.6
		March	8	7	165	154	170.8	130.1
		April	12	13	98	53	259.2	279.4
		May	20	19	133	61	231.1	345.9
Sweet corn	ARC	May	20	19	96	89	-	99.5
		June	24	23	41	45	395.3	364.5
		July	26	25	114	164	470.6	454.3
		August	25	25	70	113	245.8	114.0
	BRC	May	20	19	133	61	-	97.86
		June	24	23	57	28	313.8	363.8
		July	26	25	324	88	457.9	440.2
		August	24	24	31	145	338.4	205.4

hydraulics. The seeding rate of sweet corn was based on suggestions from two sweet corn growers in Illinois (Dane Hunter and Chris Vick, personal communication) and is in line with recommendations from studies in the area (Gentry et al. 2024). The variety of sweet corn was Revision F1. Each plot was 3.3 m wide and 10 m long with sweet corn row spacing of 0.76 m. Sweet corn received 45.0 kg N ha^{−1} (urea ammonium nitrate; UAN) as a starter fertilizer, which was applied 2×2×2 at the ARC location. Due to lack of equipment availability, the BRC location received the starter fertilizer as top-dress. At sidedress timing (V6 growth stage), sweet corn was supplemented with 134.5 kg N ha^{−1} (UAN plus urease inhibitor; 28%) in each location in each year (179 kg N ha^{−1} in total). Sweet corn was harvested on August 17, 2022, and August 8, 2023, at the ARC site and on August 25, 2022, and August 15, 2023, at the BRC site.

A John Deere tractor with factory auto-steer was used to ensure straight, even rows for both cover crops and sweet corn. The seeder has individual meters for each row that had to be manually blocked or emptied to turn them off and on, depending on the cover crop treatment. The seeder was set up to plant one treatment, that treatment was planted throughout the study, then it was set up to plant the next

treatment, and so on until all treatments were planted. All tillage management in the study was no-till.

2.4 Data collection

2.4.1 Cover crop biomass sampling and measurements

Cereal rye biomass was collected randomly from the middle of each plot using 3 frames for a total area of 0.675 m² around Feekes 10–1.5 stages (Large 1954). Grass shears (GS model 700; Black and Decker Inc., Towson, MD) were used to harvest the CR at all sites and years. The sampling dates for the ARC and BRC sites were May 12 and May 17 in 2022 and May 16 and May 22 in 2023, respectively. The wet weights of the biomass samples were recorded, and the samples were oven-dried at 60 °C for 72 h to get dry weight. Dry samples were used to determine dry matter weight (DM). The dried samples were ground and sieved using a 0.6 mm sieve for cover crop C and N concentration and to calculate the C:N ratio as explained in Weidhuner et al. (2019). The leaf area index (LAI) (5 readings) was recorded using an LP-80 ceptometer (METER Group, Pullman, WA, USA) and the normalized difference vegetation index (NDVI) (2

readings in the middle of the plot) was recorded using a GreenSeeker® (Trimble AG LLC., Pender, NE, USA) on the biomass sampling date. Cereal rye height (6 plants per plot) was measured by a ruler.

2.4.2 Sweet corn morphological measurements, marketable yield, and quality

Leaf area index (5 times), NDVI (3 times), and sweet corn plant height (5 times) were recorded during the sweet corn growing season with the same devices used during the cover crop phase. Sweet corn plant population (plant density) was recorded at the time of harvest from the two middle rows. Sweet corn was harvested by hand from a 3 m section in each of the two middle rows, totaling 6 m, within a 9 m long study area. Harvesting took place on August 17, 2022, at the ARC site and on August 25, 2022, at the BRC site. The harvest dates for ARC and BRC were August 8 and 18 during the 2023 growing season. The harvested sweet corn ears were counted, and their weights were recorded. The sweet corn was separated into two categories, marketable and unmarketable, and weighed again. The marketable sweet corn ears were peeled, and their unhusked weights were recorded. Ten of them were randomly selected, and their lengths, widths, and number of grains were measured. A ruler and caliper were used to measure sweet corn length and width, and the grain numbers were counted by hand. The sweetness of the sweet corn is often measured by assessing its Brix content. A digital refractometer from the marketable sweet corn samples was used to assess the Brix content.

2.4.3 Soil nitrate-N, volumetric water content, and temperature

Soil samples (5 cores per plot) were collected at cover crop planting, termination, before sidedress timing, at the VT (tasseling) stage, and at sweet corn harvesting to assess soil properties throughout the growing season (five times during each cover crop-sweet corn rotation).

Deep core samples were taken as 3 cores per plot from 0–15 cm, 15–30 cm, 30–60 cm and 60–90 cm depths at the cover crop planting time. The collected soil samples were air-dried, ground, and sent to Brookside Laboratory (New Bremen, OH, USA) for analysis. The measured chemical properties are reported in section 2.1. included soil pH, SOM, Bray 1 P, and Mehlich3 K.

At cover crop termination, soil samples were taken from 0–15 cm and 15–30 cm (5 cores per plot) for both sites. Also, deep core samples were taken from 0–15 cm, 15–30 cm, 30–60 cm, and 60–90 cm depth after cover crop biomass sampling and before the sweet corn planting date. Samples were air-dried, ground, and sent to Brookside Laboratory (New Bremen, OH, USA) for analysis. Additionally, at the

time of cover crop termination, soil VWC was measured using a TDR 350 soil moisture meter (Spectrum Technologies, Inc., Aurora, IL, USA), and soil temperature was measured using a Roadpro digital thermometer (Das Companies, Inc, Palmyra, PA, USA). Thus, Soil VWC (3 readings per plot) and temperature (3 readings per plot) were also evaluated only one time at cover crop termination.

During the sweet corn growing season, soil samples were taken from the two middle rows before side dress and at VT (tasseling) stage from 0–15 cm and 15–30 cm (5 cores per plot) and from 0–2 cm for on row (where the sweet corn grew) and off row (between the sweet corn rows) locations (5 cores per plot). Samples were air-dried, ground, and sent to Brookside Laboratory (New Bremen, OH, USA) for analysis. At sweet corn harvesting time, soil samples were taken from two middle rows from 0–15 cm, 15–30 cm (5 cores per plot), and 0–2 cm for on row and off row (8 cores per plot). Samples were air-dried, ground, and sent to Brookside Laboratory (New Bremen, OH, USA) for analysis. Deep core samples (3 cores per plot) were also collected on the sweet corn harvesting date in the 2023 growing season. During the sweet corn growing season, soil VWC at 0–12 cm depth and temperature (from 0–10 cm depth) were monitored using a field scout TDR soil moisture meter and a soil digital thermometer. In the sweet corn growing season, soil VWC (3 readings per plot) and temperature (3 readings per plot) were measured at 3 dates.

2.5 Statistical analysis

We used SAS software to analyze our data (SAS Institute Inc., Cary, NC, 2017). Prior to analysis, each dependent variable in ANOVA was checked for normality and homogeneity of variance to meet ANOVA assumptions using PROC Gplot and PROC Univariate. We used the Shapiro-Wilk test to assess whether the data required transformation prior to analysis. Among the evaluated data, sweet corn marketable yield, NDVI, and brix (%) were log-10-transformed. Cover crop data, including CR biomass, LAI, NDVI, plant height, N and C concentrations, C:N ratio, N uptake, and C accumulation, were analyzed via mixed models (SAS Institute Inc., Cary, NC, 2017). Mixed models, also known as linear mixed-effects models, are statistical techniques used to analyze data with both fixed effects (e.g., treatment effects that are of primary interest) and random effects (e.g., variability from grouping factors like subjects or locations). Site-yr, treatment, and their interactions were considered as fixed effects, while block was assigned as a random effect. Data for sweet corn marketable yield, ear length, ear width, and kernel number, along with brix (%), were also analyzed using mixed models in SAS. Site-yr, treatment, and their interactions were considered as fixed effects, while block was assigned as a random effect.

Data for sweet corn LAI, plant height, soil VWC, temperature, and $\text{NO}_3\text{-N}$ trends were analyzed via mixed models in SAS. In instances where measurements were relatively at the similar time, analyses were conducted by site-yr as a fixed effect. If the number of samplings or dates of sampling were different, then analyses were run by each site-yr. When run by site-yr, block, and treatments nested within block (indicating plots) were assigned as random effects, as shown in Weidhuner et al. (2022). In addition, an autoregressive covariance structure was specified for the plots being repeatedly measured over each sampling date. The fixed effects in the model were site-yr, treatment, and interactions. When treatment effects were significant, predicted means for each treatment were obtained, and a post hoc comparison was done. Least square means were separated using the PDIF option of LSMEANS in SAS PROC Mixed; LSD values are reported at $P \leq 0.05$. A similar approach was used for soil $\text{NO}_3\text{-N}$ data over different soil depths. In this measurement, soil depth was the repeated statement as previously shown in Sadeghpour et al. (2017).

Soil $\text{NO}_3\text{-N}$ on and off the sweet corn row was analyzed via mixed models in SAS by year. Block and combination of treatments and sampling position (on and off row) nested within block (indicating plots) were assigned as random effects, as shown in Weidhuner et al. (2022). In addition, an autoregressive covariance structure was specified for the plots being repeatedly measured over each sampling date. The fixed effects in the model were site-yr, treatment, sampling position, and their interactions. When treatment effects were significant, predicted means for each treatment were obtained, and a post hoc comparison was done. Least square means were separated using the PDIF option of LSMEANS in SAS PROC Mixed; LSD values are reported at $P \leq 0.05$.

Associations of cover crop biomass with its morphology, N and C concentration, C:N ratio, N uptake, and C accumulation were evaluated using PROC Factor and PROC Princomp in SAS and visualized using a principal component analysis in JMP 16.0.0. The principal component analysis biplot was analyzed on correlations, and two principal components were chosen based on eigenvalues and scree plot

outputs. Associations of sweet corn marketable yield with its morphology (LAI, NDVI, plant height, SPAD reading), quality (Brix %, ear width and length), total kernel number (TKN) and total kernel weight (TKN), soil moisture, VWC, and cover crop traits (biomass, C:N ratio, N uptake, and C accumulation) were evaluated using PROC Factor and PROC Princomp in SAS and also visualized using a principal component analysis in JMP 16.0.0. Principal component analysis biplot was analyzed on correlations, and two principal components were chosen based on eigenvalues and scree plot outputs.

3 Results and discussion

3.1 Cereal rye morphology, biomass, nitrogen uptake, C:N ratio, and their relation

Cover crop biomass was not affected by site-yr ($P \leq 0.06$), cover crop treatment ($P \leq 0.37$), or the interaction of the two ($P \leq 0.99$) (Table 2). This lack of difference in site-yrs was mainly due to similar planting date and biomass sampling date among the four site-yrs. Similar biomass between the two planting methods was due to the fact that CR has the ability to compensate for a lower seeding rate through tillering when the seeding rate is decreased (PPCR). These results are in line with those of Sadeghpour et al. (2021) and Baker et al. (2024), both suggesting that PPCR can produce similar biomass as CR and suggesting there is a potential for saving on seed costs by implementing this practice. Our results address a general question raised by Sadeghpour et al. (2021) regarding whether reducing the CR seeding rate from 100.0 kg ha^{-1} , as used in their study, to 67.0 kg ha^{-1} , as implemented in this study, would affect PPCR performance. Our results confirm that PPCR still performs similarly to CR at a lower seeding rate, suggesting that future studies should look at comparing these two planting methods at lower seeding rates. The results for CR biomass were confirmed by similar LAI data in which site-yr ($P \leq 0.09$), cover crop treatment ($P \leq 0.85$), and site-yr $\times$ cover crop treatment interaction (P

Table 2 Effect of planting method on cereal rye (CR) biomass, leaf area index (LAI), normalized difference vegetative index (NDVI), plant height, N uptake, and C:N ratio (averaged over four site-yrs). Similar letters indicate no statistical difference ($P > 0.05$).

Site-yr & Treatment effects	CR biomass (kg ha^{-1})	LAI	NDVI	Plant height (cm)	N uptake (kg ha^{-1})	C:N ratio
ARC-2022	2362 a	1.22 a	0.6 a	121 b	21.8 b	50.0
BRC-2022	2506 a	1.63 a	0.55 ab	129 b	22.2 b	48.9
ARC-2023	3139 a	1.75 a	0.5 b	155 a	26.8 ab	54.0
BRC-2023	3359 a	1.51 a	0.45 b	133 ab	31.4 a	49.9
Significance	0.06	0.09	<0.0001	0.001	0.02	0.47
Precision planting	2735 a	1.53 a	0.52 a	135 a	25.6 a	48.2 a
Solid planting	3011 a	1.50 a	0.52 a	136 a	26.0 a	53.4 a
Significance	0.37	0.85	0.56	0.92	0.87	0.052

≤ 0.98) were not significant. However, NDVI was different from site to site ($P \leq 0.001$), mainly reflecting the CR stage at which the NDVI was measured. In general, the effects of available N in the soil and its distribution in CR among more stems can influence N and chlorophyll metabolism, as stem density and plant development stages impact resource allocation and photosynthetic capacity. Our data indicated that N uptake varied significantly by site-yr ($P \leq 0.028$), with BRC23 showing higher N uptake compared to ARC22, likely due to differences in CR development stages. In 2023, fully headed CR exhibited lower NDVI readings, suggesting reduced chlorophyll content or photosynthetic activity compared to 2022, when less developed plants had higher NDVI values. The N uptake values in our study, where no N fertilizer or ammonium-based P fertilizer was applied during the fall, align with the range commonly reported in Illinois (Baker et al. 2024; Sadeghpour et al. 2021, 2022; Vaughn et al. 2024). Cereal rye C:N ratio was not affected by site-yr ($P \leq 0.47$), cover crop treatment ($P \leq 0.052$), or their interaction ($P \leq 0.95$). Sadeghpour et al. (2021) also reported similar C:N ratios between the two planting methods, with a higher C:N ratio when biomass sampling was delayed.

Principal component analysis was limited to two axes due to eigenvalue analysis (Fig. 2). Eigenvalues greater than 1 were considered significant as they account for more variance than a single original variable, thus resulting in two components that are reported in Fig. 2.

Principal component (PC) 1 (59.6%) was mainly driven by CR biomass, LAI, plant height, C:N ratio, N uptake, and C accumulation. Principal component 2 (PC2; 18.0%) was driven by NDVI and CR C concentration along with C:N ratio (Fig. 2). There was a positive correlation between CR

biomass yield with LAI ($r = 0.77$), plant height ($r = 0.75$), and C:N ratio ($r = 0.64$). Both CR N uptake ($r = 0.94$) and C accumulation ($r = 0.99$) were highly positively correlated with the CR biomass yield. Cereal rye C:N ratio was negatively correlated with CR biomass yield ($r = 0.73$) (Fig. 2; Supplemental Table 2). These results indicate that (i) NDVI, LAI, or a combination of both can predict CR biomass yield (requires future model generation and validation); (ii) CR biomass data can be used to estimate CR N uptake and C input (accumulation); and (iii) increase in CR biomass could result in decrease in N concentration leading to increased C:N ratio (Weidhuner et al. 2019). According to our data, every cm increase in CR height increased CR biomass by 34.8 kg ha^{-1} ($R^2 = 0.57$) (Supplemental Fig. 1A). Our data underestimated CR biomass yield as compared to Brennan and Smith (2023), who indicated that every cm increase in plant height increased the CR biomass by 87 kg ha^{-1} . This suggests that such approaches should be used for each environment and assessed for different varieties to ensure the predictions are accurate for growers' use. Dobbs et al. (2023) also reported a strong relationship between plant height and CR biomass ($R^2 = 0.61$). Every unit increase in LAI indicated an increase in CR biomass of $1674.8 \text{ kg ha}^{-1}$ ($R^2 = 0.60$) (Supplemental Fig. 1B). Dobbs et al. (2023) reported a strong positive correlation between CR LAI; however, due to the fact that they regressed CR biomass on the X axis, it was not possible to compare our results with theirs. Every kg increase in CR biomass ha^{-1} decreased CR N concentration by 0.001 g kg^{-1} ($R^2 = 0.52$) (Supplemental Fig. 1C). Similar to our results, every kg increase in CR biomass ha^{-1} increased CR C:N ratio by 0.005 unit ($R^2 = 0.41$) (Supplemental Fig. 1D). Every kg increase in CR biomass ha^{-1} increased CR N uptake by 0.007 kg ha^{-1} ($R^2 = 0.88$) and C accumulation by 0.46 kg ha^{-1} ($R^2 = 0.99$) (Supplemental Fig. 1E-F). The potential of CR to provide C input in cropping systems is an important ecosystem service of this cover crop to mitigate climate change and tackle the issue of extreme weather through increasing soil C (Kaye and Quemada 2017). Our results confirm some previous studies, including Jahanzad et al. (2017), Vaughn et al. (2022), Sadeghpour et al. (2022), Balkcom et al. (2023), and Baker et al. (2024), all indicating a positive relation between CR biomass with N uptake, and C accumulation. These findings raise the question of whether precision planting could be used with different species. According to Raimondi et al. (2023), variation in species should be considered, as they found huge differences in biomass and N release of different cover crops, highlighting the importance of species choice and site-specific management.

In our study, seeding rate at solid planting of CR was 67 kg ha^{-1} . Seeding rate of CR in PPCR was around 50 kg ha^{-1} . By implementing PPCR, we saved 17 kg ha^{-1} of seeds. If we assume that CR costs $\$0.72 \text{ kg}^{-1}$, this reduction in use of

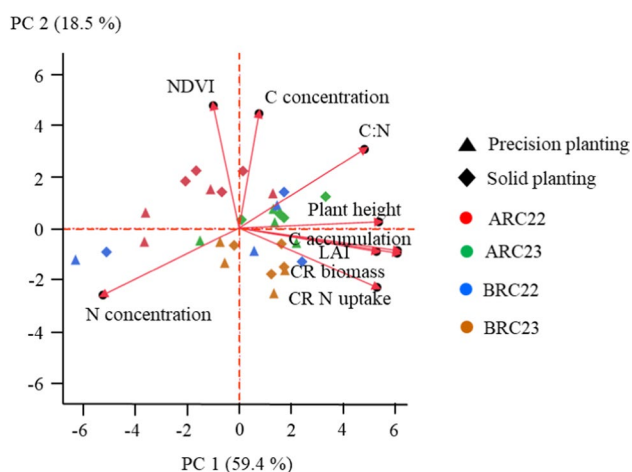


Fig. 2 Principal component analysis on CR traits, including CR biomass, LAI, plant height, NDVI, C and N concentrations, C accumulation and N uptake, and C:N ratio. Triangles indicate PPCR, while diamonds indicate CR treatments. Red, green, blue, and brown colors represent ARC22, ARC23, BRC22, and BRC23, respectively.

seeding rate equates to a savings of \$12.20 ha⁻¹ for growers. This indicates if growers utilize CR on their farm, for a 190 ha farm (average farm size in Illinois; US Department of Agriculture-National Agricultural Statistical Services, 2022) they would save about \$2,318 on seed costs alone, indicating that PPCR provides some economic benefits to growers.

3.2 Sweet corn plant population, marketable yield, morphology, yield components, quality, and their relation

Sweet corn plant population was not affected by site-yr ($P \leq 0.63$), cover crop treatments ($P \leq 0.21$), or their interaction ($P \leq 0.75$). The average sweet corn plant population was 64960 plants ha⁻¹ (data not shown). Sweet corn marketable yield was only influenced by the treatment ($P \leq 0.043$) in which PPCR (16841.0 kg ha⁻¹) had higher marketable yield than the NOCC (13914.0 kg ha⁻¹) with CR's marketable yield in between and not different from PPCR and NOCC (Fig. 3). We had hypothesized that PPCR could help close the yield gap between CR and NOCC; however, our results suggest that integrating CR through precision planting into the sweet corn cropping system could benefit sweet corn production (Fig. 3). A possible reason for such benefit is higher soil moisture conservation during July through CR residue covering the soil. Our soil VWC data indicate that around sweet corn tasseling and silking, VWC was higher in CR and PPCR treatments than the fallow treatment, perhaps explaining the higher sweet corn yield in PPCR (Supplemental Fig. 2A-B). While it is expected that cover crops reduce VWC early in the season (Reed and Karsten 2022; Wagner-Riddle et al. 2011), lack of effect on soil VWC (Raimondi et al. 2023) or increased VWC during the cash crop have also been reported (Basche et al. 2016). Raimondi et al. (2023)

emphasized the impact of VWC on the decomposition of cover crops and the release of N, which could contribute to the improvement of the following cash crop. Teasdale et al. (2008) reported that marketable yield of sweet corn was reduced by a reduction in plant population due to high biomass of cover crops [CR + hairy vetch (*Vicia villosa* Roth)], but in our study, this was never the case. Antosh et al. (2020) reported sweet corn yield reduction only in one site-yr due to winter rye and no effect on others. A key difference between our study and Antosh et al. (2020) is the seeding rate of CR. In ours, we used 67 kg ha⁻¹, which was lower than theirs (100 kg ha⁻¹). It seems a lower seeding rate may reduce the negative effects of CR on the establishment and plant population of the following sweet corn crop. Van Eerd (2018) also reported similar sweet corn yields among several cover crops, including cereal rye and a NOCC control, even though it suggested that legumes such as hairy vetch could potentially increase marketable yield.

Cereal rye is generally understood to negatively affect the following crop through allelopathic effects. However, in our study, we did not observe such effects, as plant population remained stable and sweet corn plants did not appear stunted. The later termination date used in this study may have reduced allelopathic compound levels, thereby minimizing impacts on sweet corn germination and growth. The notion that CR biomass increases while its allelopathic compounds decrease has previously been reported by Reberg-Horton et al. (2005). Sweet corn total kernel number per ear (TKN ear⁻¹) was influenced by cover crop treatments only ($P \leq 0.0282$), where PPCR had higher TKN ear⁻¹ (622 TKN ear⁻¹) than NOCC (576 TKN ear⁻¹) and CR (586 TKN ear⁻¹). In general, if TKN increases and each kernel has an adequate weight, an increase in total marketable yield is expected. Our TKN ear⁻¹ results followed a similar trend to the marketable yield, in which sweet corn marketable yield was significantly higher in PPCR compared to NOCC, while CR showed no significant difference from either PPCR or NOCC. Results of PCA also indicated that TKN was highly correlated with marketable yield ($r = 0.88$) and ear length ($r = 0.80$).

Sweet corn LAI was analyzed together for ARC23 and BRC23, but separately for ARC22 due to differences in the number of measurements. Sweet corn LAI was affected by site-yr ($P \leq 0.001$), measuring date ($P \leq 0.001$), and site-yr by measuring date ($P \leq 0.001$) for the ARC23 and BRC23 sites. Sweet corn LAI was affected by measuring date ($P \leq 0.001$) and cover crop treatments ($P \leq 0.0098$) but not their interaction for ARC22 ($P \leq 0.3904$). Sweet corn LAI was higher in ARC23 for all measuring dates except the last measuring date (August 16 for ARC23 and August 18 for BRC23). Quicker growth of sweet corn in ARC23 (slope = 0.06 LAI d⁻¹) than BRC23 (slope = 0.03 LAI d⁻¹) explains the higher yields in ARC23 as compared to BRC23.

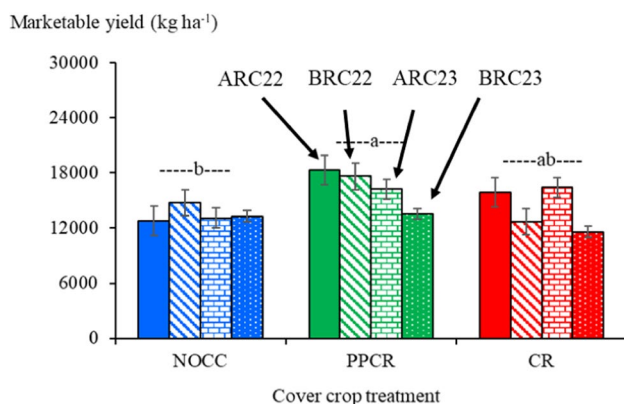


Fig. 3 Effect of cover crops on sweet corn marketable yield. NOCC: no-cover crop control; PPCR: precision planted cereal rye; CR: cereal rye planted in all rows. Bars are error bars. Letters that are different from each other are significantly different at $P \leq 0.05$.

Maximum LAI was achieved on July 16 at ARC23 vs. July 26 at BRC23. LAI at ARC23 (2.95) was still higher than at BRC23 (2.68). At ARC22, LAI increased approximately three-fold from June 27 (1.32) to July 22 (3.48). Both CR and PPCR treatments (2.59, averaged over the two treatments) had higher LAI than the NOCC (2.02) treatment, which was in agreement with sweet corn yield trends (PPCR > CR > NOCC) in that site-yr, although not statistically different. Lykhovyd (2020) reported that LAI at flowering could predict sweet corn yield accurately ($R^2 = 0.94$). Our results showed a weaker relationship between LAI and the marketable yield of sweet corn with an R^2 of 0.52 (data not shown) across the three site-yrs. In our model, for every unit increase in LAI, sweet corn marketable yield increased by 3253 kg ha⁻¹. Similarly, the results of PCA suggested that the maximum LAI was correlated with sweet corn marketable yield ($r = 0.60$).

Sweet corn NDVI was only influenced by site-yr ($P \leq 0.001$). Cover crop treatments ($P \leq 0.9803$) and site-yr by treatment interaction ($P \leq 0.9518$) had no effect on sweet corn NDVI readings. Among the site-yrs, NDVI was lowest at the BRC23 (0.59) site, with no differences between ARC22 and ARC23 detected (0.72; averaged over the two site-yrs). These results match the yield data in which sweet corn marketable yields were lower at the BRC23 site as compared to ARC22 and ARC23. Ma et al. (2007) reported that NDVI readings were strongly correlated with the number of marketable ears. We found a weaker relation between NDVI readings and sweet corn marketable yield ($R^2 = 0.30$; data not shown), which is in line with Lykhovyd (2020), suggesting that utilizing LAI to predict marketable yield provides more reliable predictions.

Sweet corn plant height was run separately for each site-yr due to differences in the number of measurements in each site-yr. Only measuring date affected the sweet corn plant height at ARC22 ($P \leq 0.001$). Plant height was similar among the three cover crop treatments ($P \leq 0.7695$), ranging from 162 cm in the NOCC treatment to 172 cm in the CR treatment. At the ARC23, date of measurement ($P \leq 0.001$) and treatment ($P \leq 0.0235$) both influenced plant height, but their interaction ($P \leq 0.0560$) did not affect plant height. Plant height was maximized on the latest measuring date (August 7th) when sweet corn height was 180.9 cm. Among the cover crop treatments, PPCR (123.3 cm; averaged over the measuring dates) resulted in taller sweet corn plants than the NOCC (117.6 cm; averaged over the measuring dates) treatment. Sweet corn plant height at the BRC22 was only affected by the date of measurement ($P \leq 0.001$). Sweet corn plant height was greatest on August 3rd (213.9 cm), which was similar to plant height measurements on August 23rd (214.7 cm). At the BRC23, date of measurement ($P \leq 0.001$), cover crop treatments ($P \leq 0.001$), and their interaction ($P \leq 0.0098$) influenced sweet corn plant height. Sweet

corn plant height was similar among all the cover crop treatments at the first measuring date on June 22nd (33.3 cm; averaged over the cover crop treatments). Starting with the second measuring date (June 30th), NOCC always resulted in taller sweet corn plants than the CR and PPCR treatments. Sweet corn plant height was greatest on July 26th when the plant height in the NOCC treatment was 185.7 cm, as compared to 175.0 and 168.9 cm in PPCR and CR, respectively.

Sweet corn quality measures included ear diameter, ear length, and Brix content. Ear diameter was not affected by site-yr ($P \leq 0.4969$), cover crop treatments ($P \leq 0.7267$), or their interaction ($P \leq 0.9088$). Sweet corn diameter ranged from 4.58 cm (BRC23) to 4.71 cm (BRC22). Averaged over the three cover crop treatments, sweet corn diameter was 4.65 cm. Lack of sweet corn diameter differences among site-yrs and cover crop treatments indicate that sweet corn diameter is less influential in predicting marketable yield and that this quality measurement is not affected by the integration of CR into sweet corn production systems. Unlike ear diameter, ear length was affected by site-yr ($P \leq 0.0028$), cover crop treatments ($P \leq 0.0031$), and their interaction ($P \leq 0.0194$). At the ARC22 site-yr, PPCR had the longest ears (22.1 cm), which was higher than both CR (20.1 cm) and NOCC (19.7 cm). At the ARC23, all cover crop treatments had similar ear lengths (19.6 cm, averaged over the cover crop treatments). At the BRC22, PPCR (21.5 cm) and NOCC (21.3 cm) had longer ears than the CR (19.3 cm) treatment.

Generally, ear length is positively associated with TKN and sweet corn marketable yield (Ghimire et al. 2020). Results of PCA showed that ear length was highly positively correlated with sweet corn marketable yield ($r = 0.80$), TKN ear⁻¹ ($r = 0.67$) (Fig. 4A). Results of PCA for the ARC sites indicate that in addition to marketable yield ($r = 0.72$) and TKN ear⁻¹ ($r = 0.60$), ear length is also highly positively correlated with max LAI ($r = 0.60$) and plant height ($r = 0.66$) (Fig. 4B). In our study, PPCR consistently had longer ears reflecting greater yields in PPCR than the two other treatments. In this study, the Brix values were similar among the cover crop treatments, and thus, CR integration into the sweet corn cropping system did not influence the sweetness of the sweet corn. The effect of CR on the Brix content of sweet corn has not been frequently evaluated or reported, but Brainard et al. (2012) found no effect of CR on Brix percent of sweet corn. The results of the PCA indicated that marketable yield was negatively correlated with Brix values ($r = -0.17$ & -0.06) and factors associated with marketable yield (Fig. 4A-B).

3.3 Soil NO₃-N dynamics and end of season NO₃-N

Soil NO₃-N trends (collected over 11 dates from 0–15 and 15–30 cm depths) were affected by date of sampling ($P \leq$

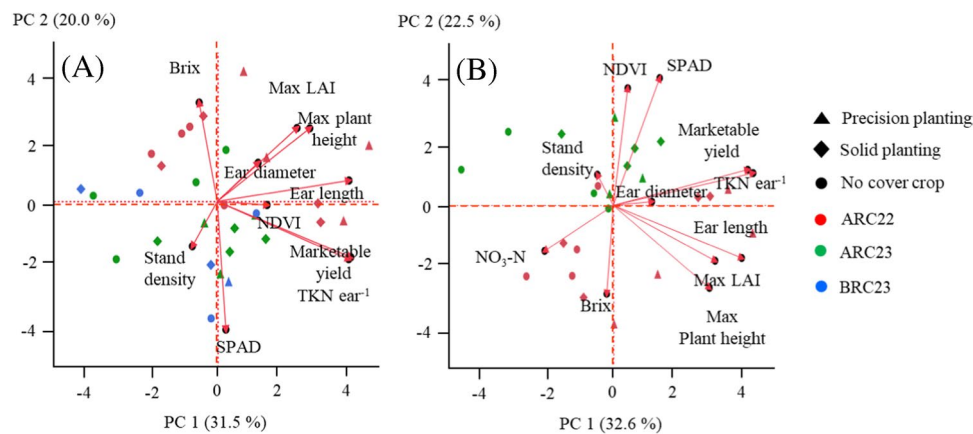
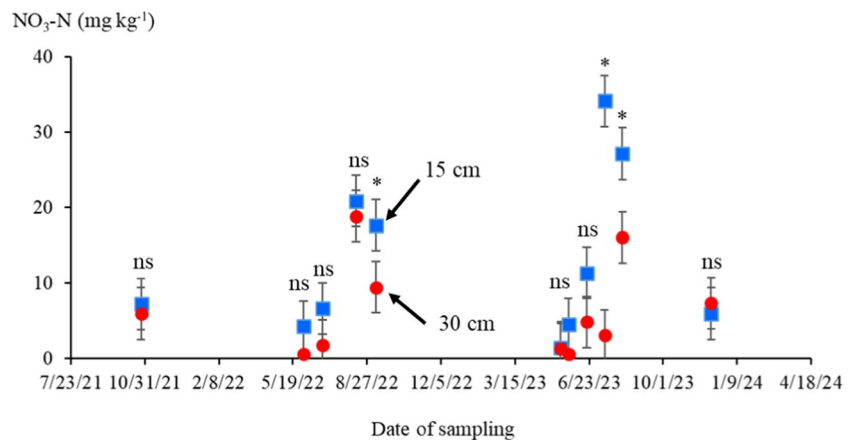


Fig. 4 Principal component analysis on sweet corn marketable yield, NDVI, and stand density, maximum LAI and plant height, ear length, ear diameter, total kernel number ear⁻¹ and brix for three site-yrs (A) and all those traits plus SPAD reading and end of season NO₃-N at

the ARC sites (B). Triangles indicate PPCR, diamonds indicate CR, and circles indicate the no-cover crop control treatments. Red, green, and blue colors represent ARC22, ARC23, BRC22, and BRC23, respectively.

Fig. 5 Soil NO₃-N trends at 0–15 and 15–30 cm depths from fall 2021 to fall 2023. Error bars are the standard error. Significant differences at $P \leq 0.05$ are shown as *. ns: no statistical differences.



0.0001), depth of sampling ($P \leq 0.0001$), cover crop treatment ($P \leq 0.0227$), and date of sampling by depth of sampling ($P \leq 0.0001$). In both years, soil NO₃-N was similar among all cover crop treatments on the spring sampling dates (Fig. 5). Similar to the results of this study, Belfry et al. (2017) and Van Eerd (2018) reported no significant differences between cover crop treatments when including CR with an NOCC treatment. In 2022, soil NO₃-N was highest at the 0–15 cm depth on August 12 (20.9 mg kg⁻¹) and September 8 (17.6 mg kg⁻¹). In 2023, soil NO₃-N was highest at the 0–15 cm depth on July 14 (34.2 mg kg⁻¹) and August 7 (27.1 mg kg⁻¹) (Fig. 5). Among the three cover crop treatments (averaged over sampling dates and depths), NOCC had higher soil NO₃-N (13.1 mg kg⁻¹) than PPCR (8.5 mg kg⁻¹) and CR (7.4 mg kg⁻¹) (data not shown).

End of season NO₃-N was influenced by site-yr ($P \leq 0.0025$), depth of sampling ($P \leq 0.0001$), site-yr $\times$ depth of sampling ($P \leq 0.0312$), and depth of sampling $\times$ cover crop treatment ($P \leq 0.0433$). End of season soil NO₃-N was

higher at the 0–15 and 15–30 cm depths in 2022 than in 2023, with no differences between 30–60 and 60–90 cm depths between the two years (data not shown). Van Eerd (2018) similarly found higher soil NO₃-N in the upper part of the soil profile. End of season NO₃-N was higher in the NOCC treatment at the 0–15 and 15–30 cm depths (18.1 and 16.4 mg kg⁻¹, respectively) than in PPCR (7.8 and 6.9 mg kg⁻¹, respectively) and CR (7.1 and 5.2 mg kg⁻¹, respectively) (Fig. 6A). These results suggest that the presence of a cover crop might reduce the end of season NO₃-N, leading to less potential for N loss at the end of the season. Similar to our results, Crandall et al. (2005) reported higher end of season soil N₃O-N with the NOCC treatment than in those that included cereal rye, especially when the termination date was delayed (late kill). Reduction in soil NO₃-N at the end of the season suggests a potential reduction in NO₃-N leaching (Sedghi and Weil 2022). These findings are consistent with European long-term trials where catch crops reduced nitrate leaching by up to 62% (Constantin et al. 2012).

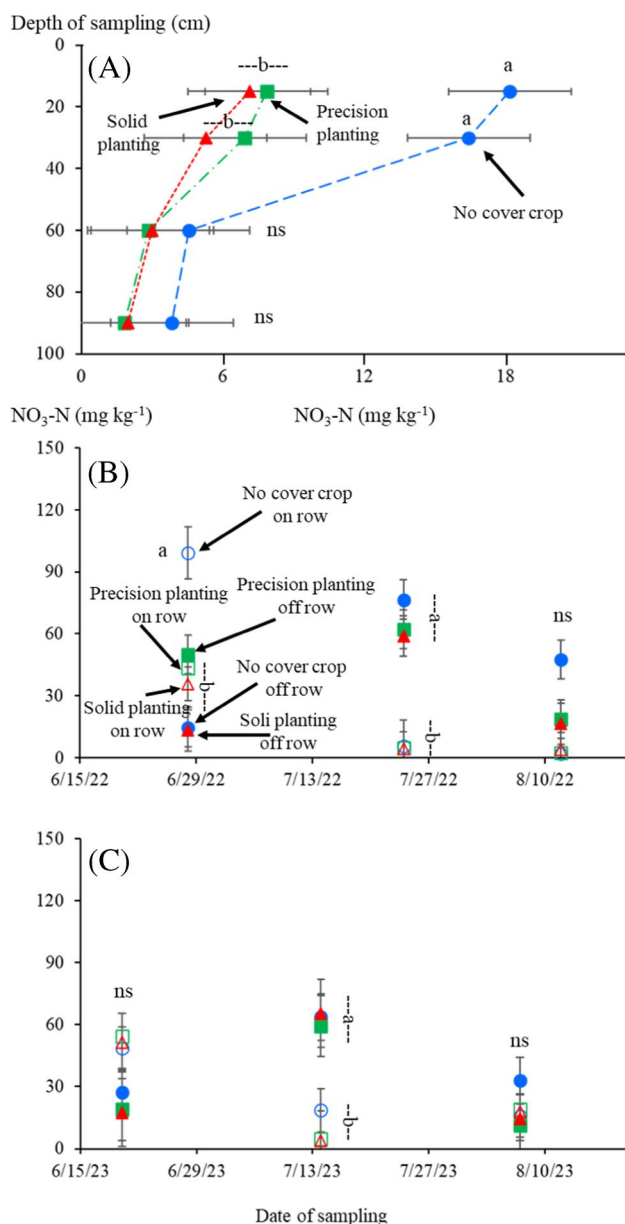


Fig. 6 Soil $\text{NO}_3\text{-N}$ trends by depth as affected by cover crops (A), by sampling dates as affected by cover crops and location of sampling in 2022 and 2023 (B–C). Error bars are the standard error. Different letters indicate significant differences at $P \leq 0.05$. ns: no statistical differences.

Soil $\text{NO}_3\text{-N}$ was affected by date of sampling ($P \leq 0.0001$), sampling location (on vs. off the sweet corn row) ($P \leq 0.0047$), cover crop treatment ($P \leq 0.015$), and their three-way interactions ($P \leq 0.015$). Therefore, a three-way interaction is presented and discussed (Fig. 6B). Soil $\text{NO}_3\text{-N}$ in the sweet corn row was higher on June 29, 2022, in the NOCC treatment than in the CR and PPCR treatments, indicating higher initial $\text{NO}_3\text{-N}$ availability early in the season (Crandall et al. 2005). The higher $\text{NO}_3\text{-N}$ in the sweet corn

row reflects application of $\text{NO}_3\text{-N}$ using $2 \times 2 \times 2$ technology as a starter. Interestingly, there was no difference between CR and PPCR, although the sweet corn row was skipped by PPCR technology (Fig. 6B). On July 27, 2022, all off row locations, regardless of the cover crop treatment, had higher soil $\text{NO}_3\text{-N}$ than the on row locations, reflecting sidedressing N. Later in the season and close to sweet corn harvest, soil $\text{NO}_3\text{-N}$ was similar among all treatments in 2022. Unlike 2022, in 2023, no differences were found among cover crop treatments at on and off the sweet corn row locations on June 20 (Fig. 6C). On July 14, 2023, off row locations had higher $\text{NO}_3\text{-N}$ than the on row locations regardless of the cover crop treatments, due to the sidedressing N. This suggests that enough N was being delivered to the sweet corn in CR and PPCR during the V6 and beyond growth stages (Van Eerd et al. 2018).

Results of our PCA analysis for ARC22 and ARC23 (Fig. 4B) indicated that higher marketable yields were negatively correlated with end of season soil $\text{NO}_3\text{-N}$ ($r = -0.40$). This could be due to better utilization of soil N in PPCR, suggesting a lower end-of-season N balance (N applied – N removed), resulting in less $\text{NO}_3\text{-N}$ availability, which was mainly observed in PPCR (high yield and minimized excess N availability during the season). Our results indicate that utilizing novel strategies such as precision planting could deliver multiple ecosystem services, including production and environmental benefits.

4 Conclusions

This study demonstrated that precision planting of cereal rye (PPCR) is a viable alternative to solid planting of cereal rye (CR) and no-cover crop control (NOCC), meeting objectives related to cover crop performance, sweet corn yield and quality, soil N dynamics, and cereal rye C inputs. Our data indicated that precision planting maintained cereal rye biomass and nutrient contributions comparable to solid planting of cereal rye, while avoiding apparent allelopathic effects on sweet corn and supporting higher marketable yields than no-cover crop control. This was likely related to improved soil moisture conservation and reduced N immobilization by precision planting as compared to solid planting of cereal rye. Both cereal rye planting strategies sustained sweet corn quality, reduced end-of-season soil $\text{NO}_3\text{-N}$ to limit loss potential, and added a similar amount of biomass as C inputs into the soil. With lower seeding costs, precision planting represents a practical “win–win” strategy for sweet corn growers, though further work is needed to directly quantify N losses and long-term environmental outcomes.

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Authors' contributions Gulcin Sener Guzel: Writing – review & editing, Writing – original draft, Validation, Formal analysis, Data curation; Osman Guzel: Writing – review & editing, Data curation; Mustafa Guzel: Writing – review & editing, Data curation; Oluwaseun Ola: Writing – review & editing, Data curation; Eric C. Brevik: Writing – review & editing, Validation, Supervision, Project administration; Amir Sadeghpour: Writing – review & editing, Writing – original draft, Supervision, Methodology, Formal analysis, Data curation, Conceptualization.

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Data availability The datasets generated and analyzed during the current study are available from the corresponding author on reasonable request.

Code availability The code for data cleaning and analysis associated with the current study is available from the corresponding author on reasonable request.

Declarations

Competing interests The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethics approval (include appropriate approvals or waivers) There were no human/animal subject related to this study that requires ethics approval.

Consent to participate/for publication All authors have read and approved the manuscript for publication.

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References

- Adeyemi O, Keshavarz-Afshar R, Jahanzad E et al (2020) Effect of wheat cover crop and split nitrogen application on corn yield and nitrogen use efficiency. *Agronomy* 10:1081. <https://doi.org/10.3390/AGRONOMY10081081>
- Ahmed M, Ahmad S, Abbas G et al (2024) Sweet Corn-Bell Pepper System. In: *Cropping Systems Modeling Under Changing Climate*. Springer, Singapore. https://doi.org/10.1007/978-981-97-0331-9_11
- Antosh E, Idowu J, Schutte B, Lehnhoff E (2020) Winter cover crops effects on soil properties and sweet corn yield in semi-arid irrigated systems. *Agron J* 112:92–106. <https://doi.org/10.1002/AGJ2.20055>
- Bagnall DK, Morgan CLS, Bean GM et al (2022) Selecting soil hydraulic properties as indicators of soil health: measurement response to management and site characteristics. *Soil Sci Soc Am J* 86:1206–1226. <https://doi.org/10.1002/saj2.20428>
- Baker K, Koduru S, Babaei S et al (2024) Precision planting effect on winter rye yield and quality for biofuel and forage production. *Biomass Bioenerg* 184:107219. <https://doi.org/10.1016/J.BIOMBIOE.2024.107219>
- Bakker MG, Acharya J, Moorman TB et al (2016) The potential for cereal rye cover crops to host corn seedling pathogens. *Phytopathology* 106:591–601. <https://doi.org/10.1094/PHYTO-09-15-0214-R>
- Balkcom KS, Read QD, Gamble AV (2023) Rye planting date impacts biomass production more than seeding rate and nitrogen fertilizer. *Agron J* 115:2351–2368. <https://doi.org/10.1002/AGJ2.21418>
- Basche AD, Kaspar TC, Archontoulis SV et al (2016) Soil water improvements with the long-term use of a winter rye cover crop. *Agric Water Manage* 172:40–50. <https://doi.org/10.1016/J.AGWAT.2016.04.006>
- Belfry KD, Trueman C, Vyn RJ et al (2017) Winter cover crops on processing tomato yield, quality, pest pressure, nitrogen availability, and profit margins. *PLoS One* 12:e0180500. <https://doi.org/10.1371/JOURNAL.PONE.0180500>
- Blanco-Canqui H (2018) Cover crops and water quality. *Agron J* 110:1633–1647. <https://doi.org/10.2134/agronj2018.02.0077>
- Brainard D, Henshaw B, Snapp S (2012) Hairy vetch varieties and bi-cultures influence cover crop services in strip-tilled sweet corn. *Agron J* 104:629–638. <https://doi.org/10.2134/agronj2011.0360>
- Brennan EB, Smith RF (2023) Predicting cereal cover crop biomass using shoot length in California vegetable systems. *Agric Environ Lett*. <https://doi.org/10.1002/ael2.20099>
- Cline GR, Silvernail AF (2002) Effects of cover crops, nitrogen, and tillage on sweet corn. *HortTechnology* 12:118–125
- Constantin J, Beaudoin N, Launay M et al (2012) Long-term nitrogen dynamics in various catch crop scenarios: test and simulations with STICS model in a temperate climate. *Agric Ecosyst Environ* 147:36–46. <https://doi.org/10.1016/J.AGEE.2011.06.006>
- Crandall SM, Ruffo ML, Bollero GA (2005) Cropping system and nitrogen dynamics under a cereal winter cover crop preceding corn. *Plant Soil* 268(1):209–219. <https://doi.org/10.1007/s11104-004-0272-x>
- Dhaliwal DS, Williams MM (2019) Optimum plant density for crowding stress tolerant processing sweet corn. *PLoS One* 14(9):e0223107. <https://doi.org/10.1371/journal.pone.0223107>
- Dobbs AM, Ginn D, Skovsen SK et al (2023) Using structure-from-motion to estimate cover crop biomass and characterize canopy structure. *Field Crops Res* 302:109099. <https://doi.org/10.1016/j.fcr.2023.109099>
- Gabriel JL, Garrido A, Quemada M (2013) Cover crops effect on farm benefits and nitrate leaching: linking economic and environmental analysis. *Agr Syst* 121:23–32. <https://doi.org/10.1016/J.AGSY.2013.06.004>
- Gaimaro J, Timlin D, Tully K (2022) Comparison of cover crop monocultures and mixtures for suppressing nitrogen leaching losses. *Agr Water Manage* 261:107348. <https://doi.org/10.1016/j.agwat.2021.107348>
- Gentry LE, Green JM, Mitchell CA et al (2024) Split fertilizer nitrogen application with a cereal rye cover crop reduces tile nitrate loads in a corn–soybean rotation. *J Environ Qual* 53:90–100. <https://doi.org/10.1002/jeq2.20530>
- Ghimire S, Scheenstra E, Miles CA (2020) Soil-biodegradable mulches for growth, yield, and quality of sweet corn in a mediterranean-type climate. *HortScience* 55:317–325. <https://doi.org/10.21273/HORTSCI14667-19>
- Hashemi M, Farsad A, Sadeghpour A et al (2013) Cover-crop seedling-date influence on fall nitrogen recovery. *J Plant Nutr Soil Sci* 176:69–75. <https://doi.org/10.1002/jpln.201200062>
- IUSS Working Group WRB (2015) World reference base for soil resources 2014, update 2015. International soil classification

- system for naming soil and creating legends for soil maps. Food and Agriculture Organization of the United Nations, Rome
- Jahanzad E, Barker AV, Hashemi M et al (2017) Improving yield and mineral nutrient concentration of potato tubers through cover cropping. *Field Crop Res* 212:45–51. <https://doi.org/10.1016/J.FCR.2017.06.023>
- Kaye JP, Quemada M (2017) Using cover crops to mitigate and adapt to climate change. A review. *Agron Sustain Dev* 37:1–17. <https://doi.org/10.1007/S13593-016-0410-X>
- Kistner E, Kellner O, Andresen J et al (2018) Vulnerability of specialty crops to short-term climatic variability and adaptation strategies in the Midwestern USA. *Clim Change* 146:145–158. <https://doi.org/10.1007/s10584-017-2066-1>
- Lacey C, Nevins C, Camberato J et al (2020) Carbon and nitrogen release from cover crop residues and implications for cropping systems management. *J Soil Water Conserv* 75:505–514. <https://doi.org/10.2489/jswc.2020.00102>
- Large EC (1954) Growth stages in cereals illustration of the Feekes scale. *Plant Pathol* 3:128–129. <https://doi.org/10.1111/j.1365-3059.1954.tb00716.x>
- Liptzin D, Norris CE, Cappellazzi SB et al (2022) An evaluation of carbon indicators of soil health in long-term agricultural experiments. *Soil Biol Biochem* 172:108708. <https://doi.org/10.1016/J.SOILBIO.2022.108708>
- Liptzin D, Rieke EL, Cappellazzi SB et al (2023) An evaluation of nitrogen indicators for soil health in long-term agricultural experiments. *Soil Sci Soc Am J* 87:868–884. <https://doi.org/10.1002/SAJ2.20558>
- Lykhovyd P (2020) Sweet corn yield simulation using normalized difference vegetation index and leaf area index. *J Ecol Eng* 21:228–236. <https://doi.org/10.12911/22998993/118274>
- Ma BL, Subedi KD, Zhang TQ (2007) Pre-sidedress nitrate test and other crop-based indicators for fresh market and processing sweet corn. *Agron J* 99:174–183. <https://doi.org/10.2134/agronj2006.0028>
- Marks B, Boerngen Ma (2019) A farming community's perspective on nutrient loss reduction. *Agricultural & Environmental Letters* 4:190004. <https://doi.org/10.2134/AEL2019.02.0004>
- McMaster GS, Wilhelm WW (1997) Growing degree-days: one equation, two interpretations. *Agr Forest Meteorol* 87:291–300. [https://doi.org/10.1016/S0168-1923\(97\)00027-0](https://doi.org/10.1016/S0168-1923(97)00027-0)
- Quemada M, Baranski M, de Nobel- Lange MNJ et al (2013) Meta-analysis of strategies to control nitrate leaching in irrigated agricultural systems and their effects on crop yield. *Agric Ecosyst Environ* 174:1–10. <https://doi.org/10.1016/J.AGEE.2013.04.018>
- Raimondi G, Maucieri C, Borin M et al (2023) Satellite imagery and modeling contribute understanding cover crop effect on nitrogen dynamics and water availability. *Agron Sustain Dev* 43:1–19. <https://doi.org/10.1007/S13593-023-00922-8>
- Reberg-Horton SC, Burton JD, Daneshmand DA et al (2005) Changes over time in the allelochemical content of ten cultivars of rye (*Secale cereale* L.). *J Chem Ecol* 31:179–193. <https://doi.org/10.1007/S10886-005-0983-3>
- Reed HK, Karsten HD (2022) Does winter cereal rye seeding rate, termination time, and N rate impact no-till soybean? *Agron J* 114:1311–1323. <https://doi.org/10.1002/AGJ2.21030>
- Reicks GW, Clay DE, Clay SA et al (2021) Winter cereal rye cover crop decreased nitrous oxide emissions during early spring. *Agron J* 113:3900–3909. <https://doi.org/10.1002/agj2.20658>
- Revilla P, Anibas CM, Tracy WF (2021) Sweet corn research around the world 2015–2020. *Agron* 11:534. <https://doi.org/10.3390/AGRON11030534>
- Rieke EL, Bagnall DK, Morgan CLS et al (2022) Evaluation of aggregate stability methods for soil health. *Geoderma* 428:116156. <https://doi.org/10.1016/J.GEODERMA.2022.116156>
- Ryan MR, Curran WS, Grantham AM et al (2011) Effects of seeding rate and poultry litter on weed suppression from a rolled cereal rye cover crop. *Weed Sci* 59:438–444. <https://doi.org/10.1614/ws-d-10-00180.1>
- Sadeghpour A, Adeyemi O, Hunter D et al (2021) Precision planting impacts on winter cereal rye growth, nutrient uptake, spring soil temperature and adoption cost. *Renew Agr Food Syst* 36:328–333. <https://doi.org/10.1017/S1742170520000411>
- Sadeghpour A, Adeyemi O, Reed B et al (2022) Profitability of dual-purpose rye cover crop as influenced by harvesting date. *Agron J* 114:627–640. <https://doi.org/10.1002/AGJ2.20890>
- Sadeghpour A, Hashemi M, DaCosta M et al (2014) Assessing winter cereals as cover crops for weed control in reduced-tillage switchgrass establishment. *Ind Crop Prod* 62:522–525. <https://doi.org/10.1016/j.indcrop.2014.09.027>
- Sadeghpour A, Ketterings QM, Godwin GS, Czymmek KJ (2017) Under-over-application of nitrogen impact corn yield, quality, soil, and environment. *Agron J* 109:343–353. <https://doi.org/10.2134/AGRONJ2016.06.0355>
- Sedghi N, Weil R (2022) Fall cover crop nitrogen uptake drives reductions in winter-spring leaching. *J Environ Qual* 51:337–351. <https://doi.org/10.1002/JEQ2.20342>
- Singh G, Dhakal M, Yang L et al (2020) Decomposition and nitrogen release of cover crops in reduced- and no-tillage systems. *Agron J* 112:3605–3618. <https://doi.org/10.1002/agj2.20268>
- Tadiello T, Potenza E, Marino P et al (2022) Growth, weed control, and nitrogen uptake of winter-killed cover crops, and their effects on maize in conservation agriculture. *Agron Sustain Dev* 42:1–15. <https://doi.org/10.1007/S13593-021-00747-3>
- Teasdale JR, Abdul-Baki AA, Park YB (2008) Sweet corn production and efficiency of nitrogen use in high cover crop residue. *Agron Sustain Dev* 28:559–565. <https://doi.org/10.1051/AGRO:2008029>
- US Department of Agriculture- National Agricultural Statistical Services (2022) https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=ILLINOIS (Accessed May 11, 2025).
- Van Eerd LL (2018) Nitrogen dynamics and yields of fresh bean and sweet corn with different cover crops and planting dates. *Nutr Cycl Agroecosyst* 111:33–46. <https://doi.org/10.1007/s10705-018-9914-x>
- Vaughn K, Adeyemi O, Zandvakili O et al (2022) Winter rye cover crop biomass, nutrient uptake, and quality in response to fall and spring N fertilization. *Cogent Food & Agriculture* 8:1. <https://doi.org/10.1080/23311932.2022.2132843>
- Vaughn K, Adeyemi O, Zandvakili OR et al (2024) Nitrogen rate and harvesting time based on growing degree days influenced winter cereal rye morphological traits, forage yield, quality, and farm profit in poorly drained Alfisols. *Grass Forage Sci* 79:239–253. <https://doi.org/10.1111/GFS.12645>
- Vyn TJ, Faber JG, Janovicek KJ, Beauchamp EG (2000) Cover crop effects on nitrogen availability to corn following wheat. *Agron J* 92:915–924. <https://doi.org/10.2134/AGRONJ2000.925915X>
- Waggoner MG, Cabrera ML, Ranells NN (1998) Nitrogen and carbon cycling in relation to cover crop residue quality. *J Soil Water Conserv* 53:214–218. <https://doi.org/10.1080/00224561.1998.12457221>
- Wagner-Riddle C, Gillespie TJ, Swanton CJ (2011) Rye cover crop management impact on soil water content, soil temperature and soybean growth. *Can J Plant Sci* 74:485–495
- Weidhuner A, Afshar RK, Luo Y et al (2019) Particle size affects nitrogen and carbon estimate of a wheat cover crop. *Agron J* 111:3398–3402. <https://doi.org/10.2134/AGRONJ2019.03.0164>
- Weidhuner A, Zandvakili OR, Krausz R et al (2022) Continuous no-till decreased soil nitrous oxide emissions during corn years after 48 and 50 years in a poorly-drained Alfisol. *Sci Total Environ* 838:156296. <https://doi.org/10.1016/j.scitotenv.2022.156296>