Scientific Research Publishing

Agricultural Sciences, 2026, 17(3), 155-178
https://www.scirp.org/journal/as
ISSN Online: 2156-8561
ISSN Print: 2156-8553

Impact of Cover Crops and Fall-Applied Broiler Litter on Dryland No-Till Corn

Ardeshir Adeli*, John P. Brooks, Dana Miles, Johnie N. Jenkins

USDA-ARS, Mississippi State, MS, USA
Email: *ardeshir.adeli@usda.gov

How to cite this paper: Adeli, A., Brooks, J.P., Miles, D. and Jenkins, J.N. (2026) Impact of Cover Crops and Fall-Applied Broiler Litter on Dryland No-Till Corn. *Agricultural Sciences*, **17**, 155-178.
https://doi.org/10.4236/as.2026.173011

Received: December 17, 2025
Accepted: March 2, 2026
Published: March 5, 2026

Abstract

A four-year field study was conducted on Leeper silty clay loam at the Plant Science Center of Mississippi State University to evaluate the combined effects of cover cropping and fall-applied broiler litter (BL) (*Gallus gallus*) on no-till dryland corn (*Zea mays* L.). The experiment followed a split-plot randomized complete block design with three replications. The main plot treatments consisted of crimson clover (CC) (*Trifolium incarnatum*), cereal rye (CR) (*Secale cereale* L.), a mixture of cereal rye and crimson clover (Mix), and no winter cover crop. Each main plot was divided into sub-plots, with and without fall-applied BL. Before cover crop termination, aboveground biomass was collected, and dry matter was measured. After termination, pre-plant soil nitrate-N (NO_3-N) content was determined. Results indicated that corn grain yield was lower with CC than with CR and Mix, likely due to its rapid residue decomposition, released nitrogen (N) early in the corn growth cycle and left less residue on the soil surface. No difference in corn grain yield was observed between CR and the Mix; however, grain N content was 33% higher in the Mix compared to CR alone, particularly in the drier year. The main effect of BL increased corn grain yield and grain N content by 16% and 19%, respectively, compared to inorganic fertilizer and the unfertilized control. The Mix cover crop combined with BL, may serve as an optimal cover crop strategy for sustaining corn grain yield.

Keywords

Broiler Litter, Cereal Rye, Crimson Clover, Mix Cover Crop, Dry Land, No-Till, Corn

1. Introduction

Sustainable agricultural practices have gained increasing attention for their role in maintaining row crop productivity and preserving ecosystems. In the southeastern United States, current row crop production practices often rely on conventional farming, including intensive tillage and leaving fields fallow during winter. Additionally, they are heavily dependent on Inorganic-nitrogen (N) [1]. Leaving fields fallow during the rainy season increases vulnerability to erosion and nutrient losses through leaching and surface runoff [2].

The reliance on inorganic N fertilizers has led to price volatility, rising costs, and significant environmental consequences, such as eutrophication from nutrient runoff, leaching loss and nitrous oxide emissions [3]-[5].

Identifying viable strategies for growers to optimize resources in the southeastern United States is essential for enhancing crop production, improving soil health and increasing overall profitability. Cover crops and BL are promising resources that can be integrated into the cropping systems to address these challenges. Cover crops contribute to weed suppression, organic matter buildup, and nitrogen fixation, ultimately benefiting subsequent cash crops [6] [7]. Broiler litter, abundantly generated in the southeastern United States, is a nutrient-rich organic amendment, has been increasingly explored for its ability to enhance soil fertility while reducing reliance on synthetic fertilizers [8]. In the southeast, BL is often applied in the fall following crop harvest and incorporated into the soil to avoid the wet conditions of early spring. However, fall application of BL increases the risk of nutrient leaching due to high precipitation during winter and early spring, which can reduce its fertilizer value [9]. Beckwith *et al.* (1998) [10] reported that fall and winter applications of BL significantly increased N loss through leaching.

Management practices such as winter cover cropping can help retain post-harvest BL-derived N during the off-season, enhance N cycling, increase soil organic matter, sustain crop yields, and mitigate negative impacts on soil health [11] [12]. Cover crops may also contribute a portion of the N needed by subsequent crops, thereby reducing the need for synthetic N inputs and minimizing N losses from agroecosystems.

The benefits of covering crops depend on the species selection, biomass production and cover crop composition. For example, cereal rye—a widely used grass cover crop in the Mid-South—is known for its rapid growth, high biomass production, weed suppression, and soil conservation benefits [13]. Cereal rye effectively scavenges residual soil nitrate (NO_3-N) [14].

In contrast, legume cover crops, including peas (*Pisum sativum* L.), clover (*Trifolium repense* L.), and vetch (*Vicia villosa* Roth), improve soil N availability [15]-[17]. Research indicates that legumes can supply 17% - 37% of the N required for the subsequent corn crop [18]. However, legumes are generally less effective at weed suppression and soil conservation than grasses, primarily due to slower growth during fall establishment and rapid decomposition following termination [19] [20].

As a result, selecting an appropriate cover crop management strategy to balance these limitations while maximizing benefits remains a challenge. Planting a bicultural of legume and grass species may offer complementary advantages, providing both N enrichment and soil conservation benefits for subsequent cash crops compared to planting these species individually. However, this practice is not yet widely adopted, and its impact on row crop production in the region remains underexplored.

Several studies have evaluated the impact of cover crops on soil properties and subsequent crop productivity [21] [22], and others have assessed poultry litter as an organic amendment [23] [24]. While cover cropping and poultry litter applications are individually recognized for their agronomic and environmental benefits, their combined effects on crop yield have not been well documented in southeastern United States and remain inadequately quantified. Therefore, the objective of this study was to evaluate the integration of single and mixed cover crop species with fall-applied BL on dryland corn grain yield and soil-crop dynamics in southeastern agroecosystems.

2. Materials and Methods

2.1. Site Description and Field Operation

The study was conducted at Mississippi State Plant Science Center, on a Leeper silty clay loam (fine, smectitic, nonacid, thermic Vertic Epiaquepts) soil in the fall of 2019 and had been continually conducted on the same plots for 4 years (2019-2022). Mean monthly temperature, total monthly and 30-year normal rainfall data were obtained from a weather station at the Plant Science Center, Mississippi State University, as shown in **Table 1**. A randomized complete block split-plot design with three replicates was used in this study. The four main plots treatments included winter fallow (WF) (no cover crop), inoculated crimson clover (CC) (*Trifolium incarnatum*), Elbon cereal rye (CR) (*Secale cereale* L), and cereal rye + crimson clover (Mix). No fertilizer, inorganic fertilizer and fall-applied broiler litter (BL) were the sub-plot treatments. Each subplot was 4 rows wide by 9 m length with a row spacing of 1 m. Each year, broiler litter at the rate of 4.5 Mg/ha was applied surface broadcast after cover crop establishment and to WF using a calibrated manure spreader. There were approximately 32 g total N/kg, 18 g total P/kg, and 28 g total K/kg in BL on average. Cereal rye (CR) and CC were planted with a John Deere 1560 drill (Deere & Company, Moline, Illinois, USA) with a row spacing 20 cm parallel to crop rows. Crimson clover and CR were seeded at a rate of 35 and 120 kg ha^{-1}, respectively. The rates for CR and CC in the Mix were 60 and 18 kg/ha, respectively. The seeding rate was selected to optimize biomass production and suppress weeds. Cover crops were planted approximately mid-September through mid-October. In the spring, the cover crops were terminated by spraying 1.5 kg/ha of the active ingredient glyphosate (*N*-(*phosphonomethyl glycine*). After termination, in 2020 and 2021 corn cultivar Dekalb 63-84 and in 2022 Dekalb 66-40 was planted using precision No-Till planter (John Deere, Moline, Illinois, USA). With WF and cover crops, plots received BL, supplemented with inorganic fertilizer at the rate of 80 kg N/ha at V6 corn growth stage. With inorganic fertilizer plots, corn received 224 kg N/ha as UAN (urea ammonium nitrate, 32% N), applied as side-dress split application: 56 kg N/ha at planting and

168 kg N/ha at the V6 growth stage, as recommended by the Mississippi Soil Testing Laboratory. Fertilizer was injected 5 cm to the side and 10 cm deep using a liquid applicator.

Table 1. Total monthly and 30-year normal rainfall (mm) received and temperature (˚C) at the Plant Science Center, Mississippi State, MS from 2019 to 2022.

Month	2019	2020	2021	2022	30-year normal	2019	2020	2021	2022	30-year normal
	Rainfall					Temperature				
January	97	257	119	99	138	6.0	10.3	5.8	6.1	6.5
February	119	368	197	112	155	11.4	9.3	5.8	8.1	8.6
March	106	178	186	122	134	11.7	16.9	14.9	13.1	12.8
April	151	283	165	135	152	16.9	16.1	16.6	16.5	17.3
May	189	46	119	141	106	23.7	20.5	20.8	23.5	22.1
June	208	136	291	40	65	25.1	25.6	25.3	27.5	27.6
July	267	105	160	96	93	26.6	28.2	27.1	28.7	28.8
August	138	74	157	103	105	25.3	27.3	27.3	27.2	27.3
September	300	110	110	111	94	26.7	24.3	23.9	23.6	24.2
October	92	101	66	52	92	19.1	18.4	19.8	16.7	17.9
November	124	60	163	152	111	14.8	13.5	11.1	12.4	11.9
December	170	112	96	121	133	13.0	7.4	7.2	9.0	8.0

2.2. Sampling and Measurements

Before initiating the experiment and before planting cover crops in the fall of 2019, composite soil samples were collected using a 2.5-cm diameter probe at depths of 0 - 15 cm. Soil samples were air-dried and analyzed for soil chemical and physical properties. Soil pH was determined by using a pH meter with a 1:1 mixture of soil and 0.05 m calcium chloride solution (Fisher Scientific, Pittsburgh, PA, USA) (Reference). Total C and N content were analyzed using an elemental CN analyzer, the Vario Max Cube (manufactured by Elementar American Inc., Mt. Laurel, NJ, USA). Soil cations and anions were extracted using 1:10 ratio (2.5 g soil :25 ml M3 solution), shaken for 5 min (Mehlic 3, 1984), filtered and analyzed by inductively coupled argon plasma spectrophotometer (ICP 9000) (Thermo Jerrell Ash, Franklin, MA).

Soil bulk density was measured using a hammer-driven core sampler with an inner ring diameter of 5.7 cm at 0 - 15 cm depth. The weight of each field-moist sample was recorded. Soil was oven-dried at 105˚C for 48 hours. Soi bulk density was calculated by dividing the dry weight by the volume of the soil, as described by Blake and Hartge (1986) [25]. Soil cation exchange capacity (CEC), number of exchangeable sites within a soil for cations, was determined using ammonium acetate, buffered at pH = 7, compulsory displacement method [26]. Initial soil nutrient concentrations were, total C and total N were 11.6 g/kg and 0.83 g/kg, respectively and extractable soil phosphorus (P) and potassium (K) were 52 and 184 mg/kg, respectively. The soil bulk density was 1.27 g/cm^3 and soil CEC was 42 cmol$_c$/kg.

Broiler litter sample was taken before application by collecting multiple samples from different locations within the BL delivered. These samples were then combined and mixed to obtain a representative sample for determining nutrient content and ensuring optimal nutrient delivery to corn. Broiler litter samples were dried, ground to pass a 2 mm sieve and analyzed for total N and C content using an elemental CNS analyzer (described above) with dry combustion. Total P, K, Ca, and Mg contents of BL were assessed by dry-ashing a 1.0-g sample, following the methods outlined by Isaac and Kerber (1977) [27]. These elements were then quantified using an ICP. The chemical characteristics of BL are summarized in **Table 2**.

Table 2. Broiler litter chemical characteristics and total amounts nutrients applied with application of broiler litter at the rate of 4.5 Mg ha^{-1}y^{-1}.

Year	Moisture	Total C	Total N	Total P	Total K	Cu	Zn	B	pH
			g kg^{-1}				mg kg^{-1}		
2019-2020	240	322	31	16	29	321	228	35	7.7
2020-2021	260	312	33	18	28	360	280	46	7.6
2021-2022	220	301	32	16	26	312	233	41	7.8
					Amount applied				
					kg ha^{-1}				
2019-2020			140	72	131	1.44	1.02	0.157	
2020-2021			149	81	126	1.61	1.25	0.206	
2021-2022			144	72	117	1.44	1.04	0.184	

In April of each year, prior to termination of cover crops, four randomly selected 0.5 m square quadrat samples of cover crop aboveground biomass were harvested from each cover crop plot. Samples were cut with pruning shears approximately 1.0 cm above the soil surface, dried at 65˚C and dry weight was recorded. Dried samples were ground through a Wiley mill to pass a 1-mm screen. Ground samples were re-dried for another 24 h and sealed in vials. Samples were weighed and analyzed for total C and N analysis using an elemental CN analyzer (described above). The total N content in the cover crop aboveground biomass was calculated by multiplying the dry matter collected in the sampled squares by the corresponding N concentration. After the cover crop was fully desiccated, soil cores were collected from each plot using a 2.5-cm diameter soil probe at a depth of 0 - 15 cm just before planting corn. Soil samples were air dried, ground, and extracted with 2M KCL and analyzed for NO_3 and NH_4 using a Lachat instrument (QC 8000 flow injection analyzer; Lachat, Loveland, CO). At R1corn growth stage (silking), 3 soil samples were collected at 0 - 15 cm depth, thoroughly mixed, one composite sample was taken and analyzed for NO_3-N concentration. The field operation information is shown in Table 3.

Table 3. Field operations in a four-year corn study at Plant Science Center, Mississippi State, MS.

Cover crop		Corn			Fertilization	
Planting	Termination	Planting	Harvesting	Cultivar	Broiler litter applied	UAN, applied
October 1, 2019	March 15, 2020	April 18, 2020	September 16, 2020	Dekalb 63-84	September 22, 2019	May 13, 2020
October 3, 2020	March 12, 2021	April 13, 2021	September 17, 2021	Dekalb 63-84	October 2, 2020	May 19, 2021
October 2, 2021	March 13, 2022	April 12, 2022	September 9, 2022	Dekalb 66-40	September 18, 2021	May 23, 2022

UAN: urea ammonium nitrate.

At physiological maturity, whole corn plant was collected from 0.3 m^2 in one of the border rows in each plot, oven dried at 65˚C and dry matter was recorded. Corn grain was harvested from the center two rows the whole length of each plot using an automated plot combine. All reported grain yield was adjusted to 15.5% moisture content. At harvest, a sample of grain, approximately 400 g, was collected from each plot, dried, ground, and analyzed for grain N concentration using CN dry combustion analyzer. Grain P, K, Cu and Zn contents were determined by dry-ashing a 1.0-g sample, following the methods outlined by Isaac and Kerber (1977). These elements were then quantified using an ICP. Additionally, the total grain nutrient uptake was calculated as the product of the nutrient concentration and the total grain yields. After corn harvest, on 15 September in each plot, 3 soil samples were collected at 0 - 15, 15 - 30- and 30 - 60 cm depth, thoroughly mixed by depth, and one composite sample was taken for each depth per plot, air-dried, ground, and analyzed for residual NO_3-N.

2.3. Data Analysis

Data was analyzed using a MIXED model procedure with block and block by cover crop as random effects and cover, fertilizer, and cover by fertilizer interaction as fixed effects in Statistical Analysis System (SAS) [28]. The mixed-model procedure provides Type III F values for cover using block by cover as error and fertilizer and fertilizer by cover using as residual error. Corn grain yield, grain nutrient concentrations, pre-planting, and post-harvest soil NO_3-N were considered dependent variables, while cover cropping and fertilization were considered independent variables in the analysis. Year was treated as a fixed effect to determine interactions involving year. If cover crop by fertilizer interaction is not significant, the main effects are reported but if the interaction is significant, the simple effect of fertilizer within each cover level or *vise versa* are reported. Mean separation was evaluated through a series of pairwise contrasts among all treatments. Main effects and all interactions were considered significant when $P \leq 0.05$.

3. Results and Discussion

3.1. Weather Conditions

Rainfall quantity and distribution varied across years (**Table 1**). Cumulative rainfall during the corn growing season (April through August) was 644 mm in 2020, 892 mm in 2021, and 515 mm in 2022. Over the three-year period, rainfall fluctuated, with 2022 and 2020 receiving approximately 28% and 42% less rainfall than 2021, respectively. The total rainfall received during the critical corn growth stages (flowering to grain filling) in June and July was 241 mm in 2020, 451 mm in 2021, and 136 mm in 2022. Mean air temperatures in June, July, and August were 27.0˚C, 26.6˚C, and 27.8˚C in 2020, 2021, and 2022, respectively (**Table 1**). From June to August, the mean monthly temperatures in 2020 and 2022 were comparable to the historical average of 27.9˚C. These months were generally warmer and drier in 2020 and 2022, suggesting that plants were exposed to relatively hot and dry conditions, particularly during flowering and grain filling.

3.2. Cover Crop Dry Matter (DM) Yield, Carbon, and Nitrogen Content

Dry matter residues produced by winter cover crops play an important role in preserving soil moisture and suppressing weeds [29] during the corn growing season. Cover crop DM, C and N concentrations, and C/N ratio were significantly affected by year (**Table 4**). Cumulative rainfall throughout the cover crop growing season (October to April) was 1189 mm in 2019/2020, 775 mm in 2020/2021, and 558 mm in 2021/2022. Averaged across cover crop types and fertilization treatments, the magnitude of winter cover crop DM, was greater during the first growing season (2019/2020) (9.4 Mg/ha) than during the second (2020/2021) (6.5 Mg/ha) and third (2021/2022) (5.8 Mg/ha) growing seasons. Due to the significant interaction between winter cover crops and year (**Table 4**), treatment effects on DM, N and C contents, and the C/N ratio are presented separately by year, meaning rerun the model with year taken out to determine the means and mean separation. Averaged across fertilization, CR produced greater amounts of DM than those produced by CC and the cover crop mixture in 2020, but no differences in DM yield was obtained between CR and the mixture in 2021 and 2022 (**Table 5**). Crimson clover DM yield was smaller than those produced by CR and the mixture in 2021 and 2022 (**Table 5**). The greater biomass produced by CR is most likely related to better growth overwinters, which enables it to form a physical barrier that suppresses weeds by producing large amounts of biomass [30]. The lower DM yield in CC in 2021 and 2022 may be related to lower temperatures in December and January of 2020/2021 (7.4˚C and 5.8˚C) and 2021/2022 (7.2˚C and 6.1˚C) (**Table 1**), which likely led to stand reduction and decreased biomass production. In agreement with our results, Thurston *et al.* (2022) [31] reported that cold stress, especially when temperatures drop below 10˚C, reduces nodulation and symbiotic nitrogen fixation (SNF) in winter annual legumes. In contrast to DM yield, N content in CR was significantly less than CC (**Table 5**). This contrast between nitrogen (N) content and DM production in CR versus CC is a classic example of how plant physiological roles shape cover crop performance. For example, CR scavenges possible residual soil nitrogen left over from previous crops limits its N content to what's available in the soil [30]. In contrast, CC fixing atmospheric nitrogen allows it to accumulate higher N concentrations in its tissues. However, in 2022, N content by above ground biomass was greater with the mixed cover crop than individual CR and CC species (**Table 5**). This may have resulted from the N supplied by CC, thereby increasing N concentration in the mixture, reduced the CN ratio as compared to CR alone (from 35 to 16) (**Table 5**). In agreement with the results, Ranells and Wagger (1996) [19] reported when cereal rye was grown in bicultural with crimson clover, increased N content by the biomass and the C:N ratio reduced from 40:1 in cereal rye grown in monoculture to 28:1 when cereal rye grown with crimson clover has less likelihood of immobilizing N during decomposition. Averaged across cover crop species, the main effect of BL significantly increased aboveground biomass in 2020 and 2021 compared to the control and inorganic fertilizer (**Table 5**). Since inorganic fertilizer was not applied to established cover crops in the fall, no differences in DM yield were observed between inorganic fertilizer and the control in 2020 (**Table 5**). The means of DM yield added to the soil system across all three years was significantly greater with cereal rye (8.7 Mg/ha) than with crimson clover (6.5 Mg/ha) or combined cereal rye and crimson clover (6.6 Mg/ha). The contribution of cover crop residues can potentially enhance soil structure by creating and modifying macropores, leading to better soil aggregation [32] and microbial activity [33], thereby improving root growth and overall plant vigor, which leads to greater total biomass (**Table 5**). Averaged across fertilization treatments, the main effects of cover crops on C and N concentrations and contents were evaluated. Carbon concentration was significantly greater in CR compared to CC and mixed cover crops across all years (**Table 5**), following the order of CR > the mixture > CC. The greater C content in CR plots than in CC plots resulted from the greater biomass yield of CR, as C content is a product of cover crop biomass and C concentration. Conversely, the greater N content in CC plots compared to CR plots was primarily due to the greater N concentration in CC. In the first two years, the mixed cover crop had lower C content than CR but comparable C content to CC. However, in 2022, the cover crop mixture yielded higher dry matter, C, and N contents than either species grown alone (**Table 5**). This was due mainly to the effect of legumes on CC, which could fix biological nitrogen, improve nutrient cycling, and promote nitrogen transfer to CR [34], thereby increasing the biomass yield and N concentration of CR in the mixed cover crop, as also reported by Ranells and Wagger (1996). Although non-legume cover crops, such as CR, scavenge nitrogen (N) and reduce N leaching [35], they typically have lower N concentrations and higher C/N ratios compared with legume cover crops, thereby providing less N required for crop production [36]. The C/N ratio of CR ranged from 33 to 39 in 2020 and 2021, while the C/N ratio of CC ranged from 11 to 12 (**Table 5**). When the CC was grown with CR in the cover crop mixture, the C/N ratio dropped to a range of 13 to 14 in 2020 and 2021. As a result, the potential of CR in the mixture, compared with CR alone, to immobilize soil N was reduced, probably due to the differing proportions of CC and CR in the mixture. This likely resulted in the release of more N from the cover crop mixture residue in the soil than from CR residue alone, as evidenced by greater N content in the mixed cover crop in 2022 (**Table 5**). Therefore, a legume-cereal combination can reduce the C/N ratio of CR cover crops and increase the potential for soil N mineralization and availability for the succeeding crop. Averaged across cover crop treatments, the main effect of fertilization treatments did not have any significant effects on cover crop C concentrations in 2020 and 2021. However, in 2022, the main effect of BL significantly increased cover crop C concentration compared to the unfertilized control treatment. Nitrogen concentration showed different patterns, being greater in CC than in CR and the mixed cover crops in 2020 and 2021, and similar between the mixed and CC cover crop alone in 2022.

As a result, the C/N ratio was higher in CR and lower in CC and the mixed cover crop (**Table 5**). The effects of cover crops and BL treatments on total N content of residues were like the dry matter results, with cover crop responses varying by year. The effect of poultry litter was significant, while no interactions were observed between cover crops and fertilization treatments. Overall, CC and the mixed cover crop resulted in the greatest N contents in all three years (**Table 5**).

Averaged across cover crop species, fertilization followed a similar pattern to cover crop species, where the main effect of broiler litter had a greater impact on cover crop N concentration than the main effects of inorganic fertilizer and unfertilized control in 2020 and 2021 (**Table 5**). In 2022, no differences in cover crop N concentration were observed between the main effects of broiler litter and inorganic N fertilizer, but both resulted in greater cover crop N concentration than the unfertilized control. As with biomass yield, averaged across fertilization treatments, the C content in CR and in the mixed cover crop were similar in 2021 and 2022, however, N content in the mixed cover crop was greater and C/N ratio was lower than that in CR cover crop in 2022 (**Table 5**).

Table 4. Probability levels from analysis of variance (ANOVA) associated with the treatments' effects on cover crop dry matter yield, N and carbon concentrations and uptake and C/N ratio, Plant Science Center, Mississippi State, Ms.

	Dry matter	N concentration	C concentration	C/N ratio	N uptake	C uptake
Year	<0.0001	<0.0001	<0.0001	0.0018	<0.0001	<0.0001
Cover crop	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001
Year*cover crop	<0.0001	0.0017	<0.0001	0.0057	0.0234	<0.0001
Fertilizer	0.0049	<0.0001	0.1971	<0.0001	<0.0001	0.0060
Year*fertilizer	0.0077	0.0089	0.6104	0.0298	0.0007	0.0217
Cover crop*fertilizer	0.3553	<0.0001	0.0001	0.0018	0.0012	0.8081
Year*cover crop*fertilizer	0.9183	0.2389	0.1292	0.5181	0.4022	0.9761

Table 5. Effects of fall-applied broiler litter on cover crop dry matter production and carbon and nitrogen uptake at the Plant Science Center, Mississippi State, MS.

		Concentration		Content		
	DM Yield	N	C	C	N	CN ratio
	Mg ha^{-1}	g kg^{-1}		kg ha^{-1}		
Cover crop			**2020**			
Rye	13.2 a	13 c	447 a	5885 a	171 b	33 a
Crimson clover	6.8 b	30 a	317 c	2635 b	204 a	11 c
Mix	8.4 b	26 b	350 b	2372 b	218 a	13 b
Fertilization						
Control	6.9 b	17 c	371	2698 b	117 c	22 a
Broiler Litter	11.1 a	28 a	372	4263 a	311 a	13 b
Fertilizer	7.2 b	24 b	371	3042 b	197 b	15 b
Cover crop			**2021**			
Rye	7.2 a	11 c	444 a	3181 a	79 b	40 a
Crimson clover	6.3 b	28 a	333 c	2105 b	179 a	12 c
Mix	7.2 a	26 b	350 b	2510 b	186 a	13 b
Fertilization						
Control	6.2 b	17 c	374	2318 b	105 b	22 a
Broiler Litter	8.9 a	27 a	377	3355 a	240 a	14 c
Fertilizer	6.8 b	21 b	376	2553 b	143 b	18 b
Cover crop			**2022**			
Rye	6.6 a	10 b	348 a	2297 a	66 c	35 a
Crimson clover	4.1 b	21 a	264 b	1082 b	86 b	13 c
Mix	6.8 a	16 a	280 b	1910 a	109 a	17 b
Fertilization						
Control	3.2	11 b	290 b	928 c	35 c	26 a
Broiler Litter	5.1	18 a	303 a	1545 a	92 a	17 b
Fertilizer	4.4	14 b	291 b	1284 b	62 b	21 b

Different letters in a column indicate a significant difference between soil amendments or cover cropping system at $P \leq 0.05$ level.

3.3. Pre-Planting Soil NO_3-N Content

Nitrate-N concentrations in the soil were measured from samples collected at a depth of 0 - 15 cm throughout the experiment. The NO_3-N results are presented in two phases: Phase 1, occurring prior to corn planting or approximately 30 days after cover crop termination; and Phase 2, corresponding to the R1 growth stage, which marks the onset of silking and kernel formation (**Figure 1**).

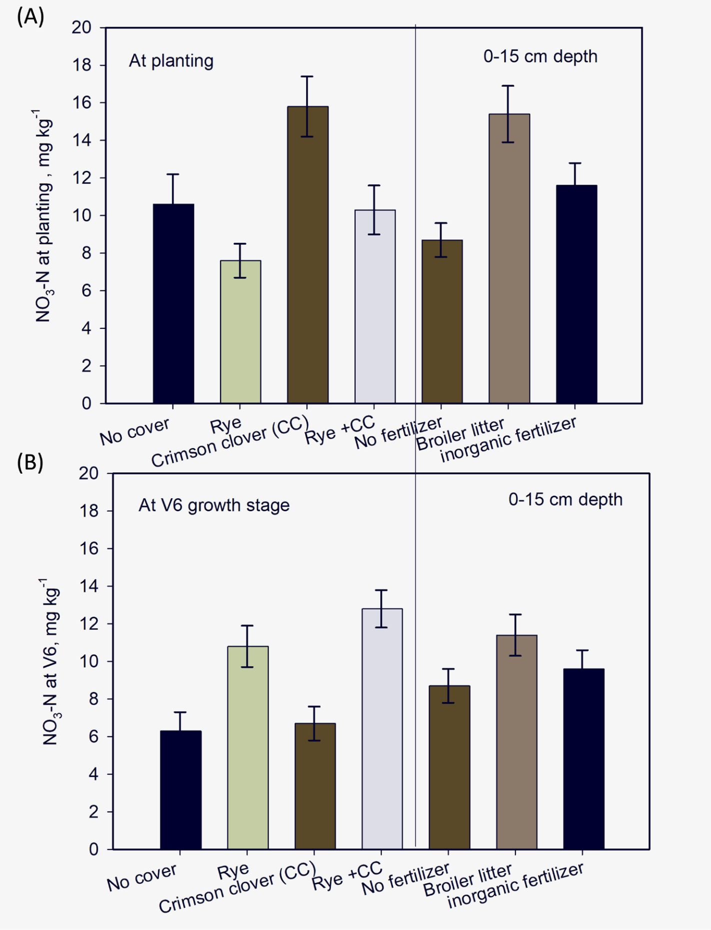

Figure 1. Soil NO_3-N in 0 - 15 cm depth at corn planting (A) and at R1 corn growth stage (B) as affected by cover crop species and fertilization treatments averaged across years (2020-2022).

Pre-plant soil NO_3-N content in the top 15 cm (phase 1) was significantly influenced by cover crop type, fertilizer source, and their interaction (**Table 6**). Because the interaction between winter cover crops × year ($P = 0.1677$) and year × fertilization ($P = 0.8567$) were not significant, soil NO_3-N data collected each year at corn planting and during the R1 growth stage were averaged across years. The resulting mean values are presented in **Figure 1**. The vertical lines between fertilizer treatments and cover crops indicate comparisons of the main effects of these treatments on soil NO_3-N concentrations.

Averaged across fertilization treatments, soil NO_3-N levels at the corn planting stage were greater in CC plots than in CR plots, likely due to differences in N cycling between the two cover crops (15.8 mg/kg vs. 7.9 mg/kg (**Figure 1**). The greater NO_3-N levels in CC plots were most likely related to the rapid decomposition of residues after termination, driven by the low carbon-to-nitrogen (C/N) ratio of 12. This accelerated breakdown released nitrogen into the soil, enhancing early-season N availability, as also reported by Büchi *et al.* (2015). In contrast, CR residues, with a high C/N ratio of 36, decomposed more slowly. This slower breakdown initially immobilized nitrogen as soil microbes processed the residues, temporarily reducing N availability at planting (**Figure 1**).

Although higher NO_3-N levels were recorded in CC and mixed cover crop treatments compared to the controls, no significant differences in NO_3-N concentrations were observed among the control, CC, and the mixed cover crop at corn planting ($P > 0.05$). In contrast, pre-planting soil NO_3-N concentrations were significantly lower in CR plots (**Figure 1**). According to Lacey *et al.* (2022) [37] and Roth *et al.* (2022) [38], only 10% of the nitrogen scavenged by CR cover crops and assimilated in the aboveground residue was subsequently recovered in the corn crop. The reduced nitrogen release from CR residues at planting is likely due to nitrogen immobilization, driven by its high carbon-to-nitrogen (C/N) ratio (**Table 5**).

The findings are consistent with those of by Ranells and Wagger (1997), who reported that cover crop residue can influence N availability to subsequent crops, with high C/N ratios posing a risk of short-term N immobilization and potential due to high C/N ratios posing a risk of short-term and potential yield reduction. Soil NO_3-N levels with CC cover crop plots were 36% and 60% greater than those observed in no cover crop and CR treatments, respectively (**Figure 1**). The lower NO_3-N levels in no winter cover crop were likely due to nitrogen losses, through leaching or denitrification in winter fallow.

At corn planting, there was no significant difference in soil NO_3-N between the cover crop mixture (13.7 mg/kg) and crimson clover (15.4 mg/kg) (**Figure 1**). Averaged across cover crop treatments, the mean pre-planting soil NO_3-N content with broiler litter application was 29% and 45% greater than with inorganic N fertilizer (15.4 vs. 11.6 mg/kg) and the unfertilized control (15.4 vs. 8.7 mg/kg), respectively (**Figure 1**). Although inorganic N fertilizer was not applied to established cover crops in the fall, the greater pre-planting soil NO_3-N in inorganic N fertilizer plots compared to unfertilized plots (11.6 vs. 8.7 mg/kg) may be attributed to residual soil N left after the previous corn harvest.

At the R1 corn growth stage, N tied up in microbial biomass as organic N appears to have started becoming available through mineralization. At R1, NO_3-N levels were significantly ($P < 0.05$) higher in all cover crop treatments compared to controls; however, the cover crop treatments were not significantly different from one another (**Figure 1**). This is likely related to supplemental inorganic N fertilizer applied to all cover crop treatments during the V6 corn growth stage, at a rate of 80 kg N/ha, to prevent potential N deficiencies.

Although the differences were not significant, soil NO_3-N levels were generally greater with CR and Mixed cover crops compared to CC cover crops (**Figure 1**). The lower NO_3-N concentrations in CC cover crops at the R1 corn growth stage were likely due to the rapid decomposition rate of residues, which released N into the soil before corn planting. In contrast, a substantial portion of CR and mixed cover crops residues remained on the soil surface throughout the corn growing season. Thus, N released from CC residues may have leached beyond the root zone, or lost through denitrification, leading to reduced NO_3-N levels relative to

CR and mixed cover crops.

These findings align with Nagumo and Nakamura (2013) [39] who observed that only 5% of hairy vetch residue remained at the end of corn season. Similarly, Lee *et al.* (2002) reported that legumes, particularly vetch, lost 72% - 81% of their initial weight within one month after termination, concluding that crimson clover could serve as a nitrogen starter fertilizer but not a sustainable N source due to its rapid decomposition. The results with CC cover crop highlight the rapid mineralization and early release of mineral N due to its C/N ratio of 12 (**Table 5**). However, CR cover crop residue decomposed more gradually, with a sustained release of mineral N due to its high C/N ratio of 36 (**Table 5**), better synchronizing with the development of corn plants.

Ruffo and Bollero (2003) found that CR cover crops were a more suitable material than vetch for N supply and soil conservation. The addition of CR cover crops resulted in more sustained release of mineral N, and with timing that better matched crop N requirements during early growth stages. The slower N release from CR cover crops make it a more effective cover crop for reducing NO_3-N leaching and mitigating water pollution [40]. Therefore, from a soil fertility perspective, CR cover crops can be considered as a better cover crop option than legumes such as CC but need to be fertilized to minimize N deficiency and prevent corn yield reduction. However, mixed cover crop did not differ significantly from CR cover crop alone.

At the R1 corn growth stage, CR cover crop and the cover crop mixture exhibited the greatest levels of soil NO_3-N (11.8 mg/kg), as compared to CC cover crops alone (**Figure 1**). These results are consistent with findings by De Notaris *et al.* (2018), who reported that mixtures of legumes and non-legumes reduced nitrate leaching by approximately 60% in loamy sand soils under temperate conditions. Averaged across cover crops, soil NO_3-N at the R1 corn growth stage was greater with the application of broiler litter (11.4 mg/kg) compared to inorganic N fertilizer (9.6 mg/kg and the unfertilized control (8.7 mg/kg) (**Figure 1**).

Table 6. Probability levels from analysis of variance (ANOVA) associated with the treatment's effects on corn grain yield, grain nutrient uptakes, Plant Science Center, Mississippi State, MS.

		grain nutrient uptake								Soil	Corn
	grain yield	N	P	K	S	Zn	Cu	Fe	B	NO_3-N	DM
Year (Yr)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.3233	<0.0001	0.3831	<0.0001	<0.0001
Cover crop (CC)	0.0267	0.0710	0.4596	0.0902	0.0015	0.2051	0.6396	0.0376	0.0059	0.0105	0.0059
Yr*CC	0.0414	0.0173	0.7831	0.0896	0.0012	0.7047	0.5925	0.1479	0.8515	0.1684	0.6440
Fertilization (Fert)	0.0005	<0.0001	0.0282	0.1099	0.1944	0.3417	0.0421	0.7918	0.0849	<0.0001	0.0027
Yr*Fert	0.0334	0.0510	0.1136	0.9400	0.7306	0.0230	0.2728	0.4739	0.6635	0.8519	0.3418
CC*Fert	0.3865	0.4882	0.7710	0.4787	0.8665	0.5594	0.8091	0.8451	0.5437	0.0163	0.6107
Yr*CC*Fert	0.7269	0.9559	0.6961	0.6466	0.9692	0.8576	0.9393	0.7197	0.9802	0.2870	0.9965

3.4. Corn Grain Yield and Grain Nutrient Utilization

In the comprehensive analysis, interaction between year × fertilization and year × cover crop was statistically significant for both grain yield and grain N uptake (**Table 6**). Therefore, the effects of treatments on corn grain yield and grain N uptake were presented and discussed separately for each year. Averaged across cover crops and fertilization treatments, corn grain yield in 2022 was 58% lower than in 2020 (3634 vs. 825 kg ha^{-1}) and 45% lower than in 2021(3634 vs. 8027 kg ha^{-1}) (**Table 7**).

This reduction in grain yield in 2022 likely reflected poor growing conditions, primarily due to water stress during June and July—critical growth stages for corn, including tasseling, silking, pollination, and kernel development. Any level of water stress during this phase can significantly reduce grain yield. Total rainfall during June and July was 136 mm in 2022, compared to 241 mm in 2020 and 451 mm in 2021 (**Table 1**). The markedly lower rainfall in 2022 contributed to poor pollination, kernel abortion, and reduced grain weight, ultimately resulting in diminished yields, as previously reported by Shaw (1988) [41].

Averaged across fertilization treatments, the main effect of cover crops did not significantly influence corn grain yield in 2020 and 2021. However, in 2022, the main effect of cover crops significantly influenced corn grain yield (**Table 7**), suggesting that corn responded to cover crop residues under drier conditions. These residues are likely to help conserve soil moisture, mitigating the impact of water stress during the growing season. The results are consistent with Alvarez *et al.* (2017) [42], who found that maize yield response was higher in areas with <500 mm annual rainfall compared to areas with rainfall ranging from 500 to 700 mm during the growing season. Thus, low soil moisture conditions can improve the growth and increase associated benefits of cover crops with poultry litter by reducing nutrient leaching, which in turn can positively affect early-season growth, development, and yield of succeeding main crops [43].These findings are consistent with those of Tewolde *et al.* (2015) [44], who observed minimal effects of cover crops on cotton lint yield during wetter years, but reported enhanced lint yield under suboptimal rainfall conditions.

In 2022, averaged across fertilization treatments, the main effects of CR cover crop and the mixed cover crop significantly increased corn grain yield as compared to CC cover crop (**Table 7**). The greater corn grain yield in CR and mixed cover crop treatments than CC or no cover crop most likely related to N uptake. Nitrogen uptake was significantly greater with mixed cover crop than in the other cover crop treatments (**Table 7**). These findings suggest that less N input may be sufficient for corn grown in legume/non-legume cover crop mixtures. The effectiveness of cover crops in reducing residual soil nitrogen accumulation depends on their ability to establish quickly in the fall, the extent of their root systems, and their biochemical composition—particularly the carbon-to-nitrogen ratio [45].

The lower grain yield associated with CC cover crops was likely due to limited nitrogen mobility, which was hindered by insufficient soil moisture during June and July (Table 1). Because approximately 90% of legume biomass decomposes within one month of termination due to rapid breakdown, the absence of CC residue on the surface during these critical months failed to conserve soil moisture through evaporation suppression. As a result, corn plants were unable to effectively utilize soil-available nutrients, leading to reduced grain N uptake and lower yields (Table 7).

These findings are consistent with previous studies reporting that cover cropping can negatively impact main crop yields by reducing the availability of inorganic nitrogen for crop uptake (Kaspar & Bakker, 2015) [46]. However, at the same Mississippi State location with similar soils, Seman-Varner *et al.* (2017) [47] reported that corn grain yield was greatest under legume cover crops, followed by legume-rye mixtures, and lowest under cereal rye, highlighting the context-dependent nature of cover crop effects on yield outcomes. This may be because, weather-driven changes in clover biomass, N release, soil moisture, and microbial activity can easily cause corn to respond positively in one year and negatively in another.

Averaged across years, the main effects of CR and the mixed cover crops increased corn grain yield by 20% as compared to crimson clover (Table 7). No significant differences in corn grain yield were observed between the main effects of CR and mixed cover crop (Table 7). In contrast to these findings, Pantoja *et al.* (2016) [48] in Iowa and Qin *et al.* (2021) [49] in Illinois reported corn grain yield reductions when corn followed CR cover crops. The contrasting results from Mississippi vs. Iowa and Illinois are actually very typical in cover-crop research due to rapid decomposition under hot and humid conditions in Mississippi vs. slow breakdown in cool and wet in Iowa and Illinois.

In 2022, low precipitation during corn critical growth period in June and July reduced N uptake (29 kg/ ha) compared to 2020 (105 kg/ha) and 2021 (101 kg/ha) (Table 7). No differences in corn grain yield were observed in 2020 and 2021 (Table 7), likely due to similar precipitation levels (Table 1) and comparable N utilizations (Table 7). These results align with findings by Spackman *et al.* (2019), who reported that the effectiveness of in-season nitrogen fertilization for corn is strongly influenced by growing season precipitation.

Despite corn receiving approximately equivalent nitrogen (N) rates from poultry litter and inorganic N fertilizer, corn grain yield in 2021—averaged across cover crop treatment was 20% higher with poultry litter compared to inorganic N fertilizer (9625 vs. 7666 kg/ha) (Table 7). This yield advantage associated with poultry litter in 2021 can be attributed to adequate precipitation (Table 1) and potentially enhanced N carryover [47] resulting from the mineralization of organic N from fall-applied poultry litter in 2019 and 2020. The positive effects of residual or carryover N on crop growth and yield have been well-documented [50]-[52]. Furthermore, soil amended with poultry litter typically supports more active microbial communities than those treated with inorganic fertilizer, thereby enhancing nutrient availability, improving soil health, and boosting crop productivity.

Table 7. Effects of cover crop treatments and fertilizer application on corn grain yield and grain N uptake, Plant Science Center, Mississippi State, MS.

	corn grain yield				grain N uptake			
Fertilization	kg ha^{-1}							
Year	2020	2021	2022	Ave	2020	2021	2022	Ave
Fertilization								
Control	8031	6792 b	3445	6325 b	99	76 c	25	66 b
Broiler litter	9216	9625 a	3902	7580 a	105	129 a	34	92 a
Inorganic Fertilizer	8629	7666 b	3555	6380 b	112	97 b	26	74 b
Cover crop								
No Cover crop	8281	7017	3086 b	6128 b	101	99	23 b	75 b
Cereal rye	9411	8603	3789 ab	7268 a	103	102	30 b	78 b
Crimson clover	7941	7391	2239 c	5859 b	98	91	19 b	71 b
Rye + Clover	8861	8089	4682 a	7206 a	119	110	43 a	90 a
Ave	8625 A	7883 A	3634 B		105 A	101 A	29 B	
ANOVA								
Cover crop	0.2393	0.3848	0.0547	------	0.3389	0.3242	0.0029	------
Fertilization	0.2111	0.0002	0.6985	------	0.4680	<0.0001	0.2002	------
Cover crop × fertilization	0.4157	0.8469	0.4522	------	0.7881	0.6206	0.8945	------

Different letters in a column indicate a significant difference between soil amendments or cover cropping system at $P \leq 0.05$ level.

In 2022, averaged across cover crop treatments, no significant differences in corn grain yield were observed among fertilization treatments—including inorganic N fertilizer, broiler litter, and the unfertilized control (Table 7). This lack of response is likely due to low precipitation and limited soil moisture, which constrained nutrient mobility and uptake by plant roots [53] [54]. These conditions likely increased plant stress, which collectively impeded the effectiveness of N fertilization, as evidenced by lower N uptake and reduced corn grain yields compared to 2020 and 2021 (Table 7).

The comparative yield response of unfertilized control plots, relative to poultry litter and inorganic nitrogen (N) fertilizer treatments, may be attributed to the presence of legume cover crops in control sections where no fertilizer was applied. Biological N fixation by legumes, along with N mineralization from decomposing cover crop residues, likely contributed to residual soil N accumulation in control plots, as indicated by elevated NO_3-N levels at planting (Figure 1).

A key contribution of cover cropping is nutrient conservation during fallow periods, with legumes introducing fixed nitrogen into the system. In the present study, although soil-available NO_3-N was significantly influenced by cover crops ($P = 0.0105$), N concentration in corn grain—which reflects soil N availability—was not significantly affected by cover crops ($P = 0.0710$). However, the interaction between year and cover crop was significant ($P = 0.0173$) (Table 6). None of the cover crop treatments, whether single species or mixtures, increased grain N content compared to the no-cover crop control in 2020 and 2021. In contrast, during the drier year of 2022, the mixed cover crop significantly increased corn grain N content relative to both single cover crops and the no-cover crop control (Table 7).

Table 8. Effects of cover crop treatments and fertilizer application on corn grain nutrient concentrations at the Plant Science Center, Mississippi State, MS (2020-2022).

Treatment	P	K	S	Zn	Mn	B	Cu	Fe	N
Fertilization					g kg^{-1}				
Control	3.36 a	6.94	2.79	0.0193	0.0175	0.0053	0.0041 b	0.109	10.1 b
Broiler litter	2.79 b	7.21	3.02	0.0193	0.0156	0.0054	0.0052 a	0.122	10.9 a
Inorg Fertilizer	2.78 b	6.87	3.16	0.0185	0.0172	0.0053	0.0042 b	0.108	11.4 a
LSD $_{(0.05)}$	0.421	NS	NS	NS	NS	NS	0.001	NS	0.79
Cover crop									
No cover crop	2.76	6.79	2.94	0.0183	0.0166	0.0055 ab	0.0044	0.132	10.7
Cereal rye	3.21	7.18	2.92	0.0192	0.0172	0.0051 b	0.0047	0.109	10.6
Crimson clover	2.99	7.04	2.85	0.0191	0.0179	0.0050 b	0.0042	0.105	10.7
Rye + Clover	2.91	7.01	3.25	0.0194	0.0156	0.0058 a	0.0048	0.107	11.2
LSD $_{(0.05)}$	NS	NS	NS	NS	NS	0.0006	NS	NS	NS

Different letters in a column indicate a significant difference between soil amendments or cover cropping system at $P \leq 0.05$ level. Fertilizer values averaged over cover crops. Cover crop values averaged over fertilizer.

Corn grain macro- and micronutrient concentrations varied significantly across years ($P < 0.0001$). Interactions between year × cover crop and year × fertilization were not significant; therefore, the effects of cover crop and fertilization treatments on grain nutrient concentrations are presented as averages across years (Table 8).

Averaged across years, corn grain macro- and micronutrient concentrations—including phosphorus (P), potassium (K), sulfur (S), manganese (Mn), zinc (Zn), iron (Fe), and copper (Cu)—were not significantly affected by the main effects of cover crops (single or mixed) or fertilization treatments, with the exception of Cu. Broiler litter fertilization significantly increased Cu concentrations compared to both inorganic fertilizer and unfertilized treatments (Table 8). Given that corn grain nutrient concentrations reflect soil nutrient availability, the lack of fertilization effects on grain P and K concentrations is likely due to the very high baseline soil test P (52 mg kg^{-1}) and high soil test K (184 mg kg^{-1}) levels at the 0 - 15 cm depth, as reported by the Mississippi State University Soil Test Laboratory. Additionally, the main effects of cover crop treatments, averaged across fertilization treatments, had no significant influence on corn grain P, K, or N concentrations (Table 8).

Although fertilization treatments did not significantly affect grain nutrient concentrations, broiler litter application significantly increased grain P, K, boron (B), and Cu contents compared to the unfertilized control (Table 9). Because grain nutrient content is calculated by multiplying harvested grain yield by the corresponding nutrient concentration, the elevated grain P, K, B, and Cu contents are likely attributable to increased corn grain yield rather than differences in nutrient concentration alone.

Table 9. Effects of cover crop treatments and fertilizer application on corn grain nutrient uptake at the Plant Science Center, Mississippi State, MS (2020-2022).

Treatment	P	K	S	Zn	Mn	B	Cu	Fe	DM
Fertilization					kg ha^{-1}				
Control	17.5 b	35.0 b	12.3	0.172	0.072	0.029 b	0.024 b	0.625	29,836 b
Broiler litter	22.8 a	41.8 a	14.8	0.199	0.083	0.036 a	0.033 a	0.704	40,738 a
Inorg Fertilizer	20.4 ab	37.8 ab	13.1	0.189	0.075	0.031 ab	0.023 b	0.694	35,840 ab
LSD $_{(0.05)}$	3.16	6.38	NS	NS	NS	0.007	0.008	NS	6011
Cover crop									
No cover crop	21.5	34.7 b	11.8 b	0.174	0.071 bc	0.029 b	0.025	0.694 ab	33,131 b
Cereal rye	23.6	38.7 ab	11.4 b	0.167	0.067 c	0.027 b	0.025	0.421 b	36,375 ab
Crimson clover	21.2	35.8 b	13.0 b	0.200	0.084 ab	0.032 b	0.026	0.753 a	29,921 b
Rye + Clover	22.5	43.5 a	17.4 a	0.204	0.085 a	0.041 a	0.031	0.827 a	42,371 a
LSD $_{(0.05)}$	NS	7.37	3.27	NS	0.016	0.008	NS	0.289	7011

Different letters in a column indicate a significant difference between soil amendments or cover cropping system at $P \leq 0.05$ level. Fertilizer values averaged over cover crops (main effect). Cover crop values averaged over fertilizer (main effect).

3.5. Post-Harvest Soil NO_3-N Content

After harvesting corn, the post-harvest residual soil NO_3-N levels were significantly affected by both cover crop type and nitrogen fertilizer source. Due to a significant interaction between these factors ($P = 0.0163$), post-harvest NO_3-N concentrations were analyzed separately for treatments with and without cover crops (Table 10). In unfertilized control treatments, no differences in post-harvest residual NO_3-N were observed among cover crop treatments (Table 10), and the concentration of residual soil NO_3-N remained consistent across soil depths (Table 10). With inorganic N fertilizer, post-harvest soil residual NO_3-N levels were greater in no-cover crop plots at both 0 - 15 cm depth (10.3 mg/kg) and 30 - 60 cm depth (13.3 mg/kg) compared to plots with cover crops (Table 10). At 15 - 30 cm depth CC cover crop had the greatest amount of NO_3-N.

Because no-cover crop plots also received broiler litter at a rate of 4.5 mg ha^{-1} in the fall, supplemented with inorganic N fertilizer at planting and at the V6 corn growth stage to prevent N deficiency, it appears most of the N applied at planting (56 kg/ha) leached beyond the root zone—likely a result of the underdeveloped root system early in the corn growing season. Averaged across depths, there were no significant differences in post-harvest NO_3-N between broiler litter and inorganic fertilizers at the same depth (7.3 vs. 7.0 mg/kg). However, both sources showed significantly greater NO_3-N levels compared to the unfertilized control (4.1 mg/kg) (Table 10).

Table 10. Cover crop and fertilizer interaction effect on post-harvest soil residual NO_3-N at 0 - 15-, 15 - 30- and 30 - 60 cm depth, Plant Science Center, Mississippi State, MS.

	Unfertilized control	Inorganic N fertilizer	Broiler litter	Mean over fertilizer
		mg kg^{-1}		
		0 - 15 cm depth		
No Cover crop	5.7	10.3 a	9.3 bc	8.8 a
Cereal Rye (CR)	4.4	5.6 b	6.6 c	5.5 b
Crimson clover (CC)	5.2	8.3 ab	13.4 a	9.0 a
CR + CC	5.4	7.3 b	10.3 b	7.7 ab
		15 - 30 cm depth		
No Cover crop	4.7	5.7 b	7.1 ab	5.8
Cereal Rye (CR)	3.2	5.3 b	6.8 b	4.8
Crimson clover (CC)	5.3	11.2 a	4.2 b	6.9
CR + CC	4.0	6.4 b	9.9 a	6.8
		30 - 60 cm depth		
No Cover crop	2.2	13.3 a	4.8	6.8
Cereal Rye (CR)	3.1	2.3 c	3.5	3.1
Crimson clover (CC)	3.6	6.8 b	3.2	4.5
CR + CC	2.8	4.8 b	4.7	4.1
Mean over CC and depths	4.1 B	7.3 A	7.0 A	6.2

Post-harvest residual NO_3-N at 15 - 30 cm depth was substantially greater with CC cover crops (11.2 mg/kg) compared to other cover crops treatments (Table 10). This outcome may be attributed to two factors. First, CC cover crop residues decompose rapidly due to their low C/N ratio (12), potentially releasing N early in the season that the plants were unable to fully utilize, resulting in N leaching beyond the root zone. Second, excess N was released in CC plots through biological nitrogen fixation, supplemental N fertilizer at the V6 growth stage (80 kg N/ha), and fall-applied broiler litter.

With broiler litter applications, post-harvest residual NO_3-N accumulation was observed only in CC plots and in plots with mixed cover crops at 0 - 15 cm depth (Table 10). Beyond 15 cm depth, no differences in post-harvest residual NO_3-N were found among cover crop treatments with broiler litter applications. This is likely due to the slow N release from residues, which may have been synchronized with corn N uptake.

Averaged across depths, post-harvest residual NO_3-N did not differ between broiler litter (7.0 mg/kg) and inorganic N fertilizer (7.3 mg/kg), though both were approximately 44% greater than the unfertilized control (4.1 mg/kg) (**Table 10**). Across years, no differences in corn grain yield were observed between the control and inorganic N fertilizer treatments (**Table 7**). Interestingly, averaged across fertilization treatments, post-harvest residual NO_3-N did not differ among cover crop treatments, except at the 0 - 15 cm depth, where CC plots had significantly greater NO_3-N than CR plots (**Table 10**).

4. Conclusion

This study investigates the effects of integrating various cover crops with fall-applied BL in dryland no-till corn systems. The study suggests that a mixture of crimson clover and cereal rye in the presence of broiler litter served as an optimal practice in the region as compared to either crop alone. These insights recommended to the growers through Mississippi State extension specialist to the farmers, agronomists, and policymakers to refine their cover crop selection and management to improve soil health, nutrient retention and availability, and crop resilience, produced the most favorable outcomes to the growers as it has been used as a common practice in the region. Although this study comprehensively evaluated the integrating cover crops with BL in dryland no-till corn systems, it did not consider regional differences such as soil type, climate, temperature and rainfall. Future research should combine different climate zones and soil types to further explore the regional adaptability of tillage, providing more precise scientific support for agricultural policymaking compared to either cover crop alone.

Acknowledgements

The authors express their gratitude to Walter Woolfolk, Biological Science Technician, for his processing the samples, organizing, tabulating, and recording data on the computer. This research was supported by the U.S. Department of Agriculture, Agricultural Research Service.

Conflicts of Interest

The authors declare no conflict of interest.

References

[1] Hera, C. (1996) The Role of Inorganic Fertilizers and Their Management Practices. *Fertilizer Research*, **43**, 63-81. https://doi.org/10.1007/bf00747684

[2] Blanco-Canqui, H., Shaver, T.M., Lindquist, J.L., Shapiro, C.A., Elmore, R.W., Francis, C.A., *et al.* (2015) Cover Crops and Ecosystem Services: Insights from Studies in Temperate Soils. *Agronomy Journal*, **107**, 2449-2474. https://doi.org/10.2134/agronj15.0086

[3] Górski, J., Dragon, K. and Kaczmarek, P.M.J. (2019) Nitrate Pollution in the Warta River (Poland) between 1958 and 2016: Trends and Causes. *Environmental Science and Pollution Research*, **26**, 2038-2046. https://doi.org/10.1007/s11356-017-9798-3

[4] Sun, C., Chen, L., Zhai, L., Liu, H., Wang, K., Jiao, C., *et al.* (2020) National Assessment of Nitrogen Fertilizers Fate and Related Environmental Impacts of Multiple Pathways in China. *Journal of Cleaner Production*, **277**, Article 123519. https://doi.org/10.1016/j.jclepro.2020.123519

[5] Smith, P., Martino, D. and Cai, Z. (2007) Agriculture. In: Metz, B., Davidson, O.R., Bosch, P.R., Dave, R. and Meyer, L.A., *Climate Change* 2007: *Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press.

[6] King, A.E. and Blesh, J. (2018) Crop Rotations for Increased Soil Carbon: Perenniality as a Guiding Principle. *Ecological Applications*, **28**, 249-261. https://doi.org/10.1002/eap.1648

[7] Myeni, L., Moeletsi, M., Thavhana, M., Randela, M. and Mokoena, L. (2019) Barriers Affecting Sustainable Agricultural Productivity of Smallholder Farmers in the Eastern Free State of South Africa. *Sustainability*, **11**, Article 3003. https://doi.org/10.3390/su11113003

[8] Adeli, A., Tewolde, H., Jenkins, J.N. and Rowe, D.E. (2019) Cover Crops Used for Managing Broiler Litter Applied to Cotton in the Fall. *Agronomy Journal*, **103**, 200-210.

[9] Tewolde, H., Sistani, K.R. and Adeli, A. (2013) Fall- and Spring-Applied Poultry Litter Effectiveness as Corn Fertilizer in the Mid-Southern United States. *Agronomy Journal*, **105**, 1743-1748. https://doi.org/10.2134/agronj2013.0137

[10] Beckwith, C.P., Cooper, J., Smith, K.A. and Shepherd, M.A. (1998) Nitrate Leaching Loss Following Application of Organic Manures to Sandy Soils in Arable Cropping. I. Effects of Application Time, Manure Type, Overwinter Crop Cover and Nitrification Inhibition. *Soil Use and Management*, **14**, 123-130. https://doi.org/10.1111/j.1475-2743.1998.tb00135.x

[11] Aryal, N., Reba, M.L., Straitt, N., Teague, T.G., Bouldin, J. and Dabney, S. (2018) Impact of Cover Crop and Season on Nutrients and Sediment in Runoff Water Measured at the Edge of Fields in the Mississippi Delta of Arkansas. *Journal of Soil and Water Conservation*, **73**, 24-34. https://doi.org/10.2489/jswc.73.1.24

[12] Jacobs, A.A., Stout Evans, R., Allison, J.K., Kingery, W.L., McCulley, R.L. and Brye, K.R. (2024) Tillage and Cover Crop Systems Alter Soil Particle Size Distribution in Raised-Bed-and-Furrow Row-Crop Agroecosystems. *Soil Systems*, **8**, Article 6. https://doi.org/10.3390/soilsystems8010006

[13] MacLaren, C., Swanepoel, P., Bennett, J., Wright, J. and Dehnen-Schmutz, K. (2019) Cover Crop Biomass Production Is More Important than Diversity for Weed Suppression. *Crop Science*, **59**, 733-748. https://doi.org/10.2135/cropsci2018.05.0329

[14] Blanco-Canqui, H. (2018) Cover Crops and Water Quality. *Agronomy Journal*, **110**, 1633-1647. https://doi.org/10.2134/agronj2018.02.0077

[15] Varco, J.J., Spurlock, S.R. and Sanabria-Garro, O.R. (1999) Profitability and Nitrogen Rate Optimization Associated with Winter Cover Management in No-Tillage Cotton. *Journal of Production Agriculture*, **12**, 91-95. https://doi.org/10.2134/jpa1999.0091

[16] Miguez, F.E. and Bollero, G.A. (2005) Review of Corn Yield Response under Winter Cover Cropping Systems Using Meta-Analytic Methods. *Crop Science*, **45**, 2318-2329. https://doi.org/10.2135/cropsci2005.0014

[17] Büchi, L., Gebhard, C., Liebisch, F., Sinaj, S., Ramseier, H. and Charles, R. (2015) Accumulation of Biologically Fixed Nitrogen by Legumes Cultivated as Cover Crops in Switzerland. *Plant and Soil*, **393**, 163-175. https://doi.org/10.1007/s11104-015-2476-7

[18] Jani, A.D., Grossman, J., Smyth, T.J. and Hu, S. (2016) Winter Legume Cover-Crop Root Decomposition and N Release Dynamics under Disking and Roller-Crimping Termination Approaches. *Renewable Agriculture and Food Systems*, **31**, 214-229. https://doi.org/10.1017/s1742170515000113

[19] Ranells, N.N. and Wagger, M.G. (1996) Nitrogen Release from Grass and Legume Cover Crop Monocultures and Bicultures. *Agronomy Journal*, **88**, 777-882. https://doi.org/10.2134/agronj1996.00021962008800050015x

[20] Bàrberi, P. and Mazzoncini, M. (2001) Changes in Weed Community Composition as Influenced by Cover Crop and Management System in Continuous Corn. *Weed Science*, **49**, 491-499. https://doi.org/10.1614/0043-1745(2001)049[0491:ciwcca]2.0.co;2

[21] Koudahe, K., Allen, S.C. and Djaman, K. (2022) Critical Review of the Impact of Cover Crops on Soil Properties. *International Soil and Water Conservation Research*, **10**, 343-354. https://doi.org/10.1016/j.iswcr.2022.03.003

[22] Thapa, V.R., Ghimire, R., VanLeeuwen, D., Acosta-Martínez, V. and Shukla, M. (2022) Response of Soil Organic Matter to Cover Cropping in Water-Limited Environments. *Geoderma*, **406**, Article 115497. https://doi.org/10.1016/j.geoderma.2021.115497

[23] Muñoz, J.D., Steibel, J.P., Snapp, S. and Kravchenko, A.N. (2014) Cover Crop Effect on Corn Growth and Yield as Influenced by Topography. *Agriculture*, *Ecosystems & Environment*, **189**, 229-239. https://doi.org/10.1016/j.agee.2014.03.045

[24] Wanapat, M., Cherdthong, A., Phesatcha, K. and Kang, S. (2015) Dietary Sources and Their Effects on Animal Production and Environmental Sustainability. *Animal Nutrition*, **1**, 96-103. https://doi.org/10.1016/j.aninu.2015.07.004

[25] Blake, G.R. and Hartge, K.H. (1986) Bulk Density. In: Klute, A., *Methods of Soil Analysis*, *Part* 1—*Physical and Mineralogical Methods*, *Agronomy Monograph*, American Society of Agronomy—Soil Science Society of America, 363-382.

[26] Sumner, M.E. and Miller, W.P. (1996) Cation Exchange Capacity and Exchange Coefficients. In: Sparks, D.L., Page, A.L., Helmke, P.A., Loeppert, R.H., *et al.*, *Methods of Soil Analysis Part* 3—*Chemical Methods*, Soil Science Society of America, 1201-1229.

[27] Issac, R.A. and Kerber, J.D. (1977) Atomic Absorption and Flame Photometry; Techniques and Uses in Soil, Plant, and Water Analysis. In: Walsh, L.M., *Instrumental Methods for Analysis of Soils and Plant Issue*, SSSA, 17-37.

[28] Littell, R.C., Milliken, G.A., Stroup, W.W. and Wolfinger, R.D. (1996) SAS System for Mixed Models. SAS Institute Inc.

[29] Boquet, D.J., Hutchinson, R.L. and Breitenbeck, G.A. (2004) Long-Term Tillage, Cover Crop, and Nitrogen Rate Effects on Cotton: Yield and Fiber Properties. *Agronomy Journal*, **96**, 1436-1442. https://doi.org/10.2134/agronj2004.1436

[30] Clark, A. (2007) Managing Cover Crops Profitably. In: *Sustainable Agriculture Research and Education* (*SARE*) *Handbook Series Book* 9, Sustainable Agriculture Research and Education (SARE) Program, 1-232.

[31] Thurston, C.L., Grossman, J.M., Fudge, R., Maul, J.E., Mirsky, S. and Wiering, N. (2022) Cold Stress Reduces Nodulation and Symbiotic Nitrogen Fixation in Winter Annual Legume Cover Crops. *Plant and Soil*, **481**, 661-676. https://doi.org/10.1007/s11104-022-05667-z

[32] Lucas, M., Nguyen, L.T.T., Guber, A. and Kravchenko, A.N. (2022) Cover Crop Influence on Pore Size Distribution and Biopore Dynamics: Enumerating Root and Soil Faunal Effects. *Frontiers in Plant Science*, **13**, Article 928569. https://doi.org/10.3389/fpls.2022.928569

[33] Seitz, V.A., McGivern, B.B., Borton, M.A., Chaparro, J.M., Schipanski, M.E., Prenni, J.E., *et al.* (2024) Cover Crop Root Exudates Impact Soil Microbiome Functional Trajectories in Agricultural Soils. *Microbiome*, **12**, Article No. 183. https://doi.org/10.1186/s40168-024-01886-x

[34] Shao, Z., Zheng, C., Postma, J.A., Lu, W., Gao, Q., Gao, Y., *et al.* (2021) Nitrogen Acquisition, Fixation and Transfer in Maize/alfalfa Intercrops Are Increased through Root Contact and Morphological Responses to Interspecies Competition. *Journal of Integrative Agriculture*, **20**, 2240-2254. https://doi.org/10.1016/s2095-3119(20)63330-5

[35] Sainju, U.M., Singh, B.P. and Whitehead, W.F. (2000) Cover Crops and Nitrogen Fertilization Effects on Soil Carbon and Nitrogen and Tomato Yield. *Canadian Journal of Soil Science*, **80**, 523-532. https://doi.org/10.4141/s99-107

[36] Kuo, S. and Jellum, E.J. (2002) Influence of Winter Cover Crop and Residue Management on Soil Nitrogen Availability and Corn. *Agronomy Journal*, **94**, 501-508. https://doi.org/10.2134/agronj2002.5010

[37] Lacey, C., Camberato, J. and Armstrong, S. (2023) Field Based 15 N Study: An Investigation of Cereal Rye N Fate and Utilization by the Subsequent Corn and Soybean. *Nutrient Cycling in Agroecosystems*, **125**, 205-217. https://doi.org/10.1007/s10705-022-10226-0

[38] Roth, R.T., Lacey, C.G., Camberato, J.J. and Armstrong, S.D. (2023) Quantifying the Fate of Nitrogen from Cereal Rye Root and Shoot Biomass Using 15n. *Nutrient Cycling in Agroecosystems*, **125**, 219-234. https://doi.org/10.1007/s10705-022-10213-5

[39] Nagumo, F. and Nakamura, K. (2013) Nitrogen Balance under Non-Tillage Maize (*Zea mays* L.) Cultivation after Hairy Vetch (*Vicia villosa* Roth.) Cropping at Sloping Fields. *Soil Science and Plant Nutrition*, **59**, 249-261. https://doi.org/10.1080/00380768.2013.771539

[40] Vidal, M. and López, A. (2005) Cover Crops and Organic Amendments to Prevent Nitrate Contamination under a Wet Climate. *Agronomy for Sustainable Development*, **25**, 455-463. https://doi.org/10.1051/agro:2005043

[41] Shaw, R.H. (1988) Climatic Requirement. In: Sprague, G.F. and Dudley, J.W., *Corn and Corn Improvement*, *Agronomy Monographs*, ASA, CSSA and SSSA, 609-638.

[42] Alvarez, R., Steinbach, H.S. and De Paepe, J.L. (2017) Cover Crop Effects on Soils and Subsequent Crops in the Pampas: A Meta-Analysis. *Soil and Tillage Research*, **170**, 53-65. https://doi.org/10.1016/j.still.2017.03.005

[43] Krstić, Đ., Vujić, S., Jaćimović, G., D'Ottavio, P., Radanović, Z., Erić, P., *et al.* (2018) The Effect of Cover Crops on Soil Water Balance in Rain-Fed Conditions. *Atmosphere*, **9**, Article 492. https://doi.org/10.3390/atmos9120492

[44] Tewolde, H., Shankle, M.W., Way, T.R., Adeli, A., Brooks, J.P. and He, Z. (2015) Enhancing Management of Fall-Applied Poultry Litter with Cover Crop and Subsurface Band Placement in No-Till Cotton. *Agronomy Journal*, **107**, 449-458. https://doi.org/10.2134/agronj14.0266

[45] Sainju, U.M., Singh, B.P. and Whitehead, W.F. (1998) Cover Crop Root Distribution and Its Effects on Soil Nitrogen Cycling. *Agronomy Journal*, **90**, 511-518. https://doi.org/10.2134/agronj1998.00021962009000040012x

[46] Kaspar, T.C. and Bakker, M.G. (2015) Biomass Production of 12 Winter Cereal Cover Crop Cultivars and Their Effect on Subsequent No-Till Corn Yield. *Journal of Soil and Water Conservation*, **70**, 353-364. https://doi.org/10.2489/jswc.70.6.353

[47] Seman-Varner, R., Varco, J. and O'Rourke, M. (2017) Nitrogen Benefits of Winter Cover Crop and Fall-Applied Poultry Litter to Corn. *Agronomy Journal*, **109**, 2881-2888. https://doi.org/10.2134/agronj2016.11.0670

[48] Pantoja, J.L., Woli, K.P., Sawyer, J.E. and Barker, D.W. (2016) Winter Rye Cover Crop Biomass Production, Degradation, and Nitrogen Recycling. *Agronomy Journal*, **108**, 841-853. https://doi.org/10.2134/agronj2015.0336

[49] Qin, Z., Guan, K., Zhou, W., Peng, B., Villamil, M.B., Jin, Z., *et al*. (2021) Assessing the Impacts of Cover Crops on Maize and Soybean Yield in the U.S. Midwestern Agroecosystems. *Field Crops Research*, **273**, Article 108264. https://doi.org/10.1016/j.fcr.2021.108264

[50] Eghball, B., Ginting, D. and Gilley, J.E. (2004) Residual Effects of Manure and Compost Applications on Corn Production and Soil Properties. *Agronomy Journal*, **96**, 442-447. https://doi.org/10.2134/agronj2004.4420

[51] Singh, R., Prasad, R., Balkcom, K., Lamba, J. and Watts, D.B. (2023) Broiler Litter Application Rate and Time Impacts on Corn Ear Mineral Composition. *Agronomy Journal*, **115**, 932-944. https://doi.org/10.1002/agj2.21292

[52] Tewolde, H., Adeli, A., Rowe, D.E. and Sistani, K.R. (2011) Cotton Lint Yield Improvement Attributed to Residual Effect of Repeated Poultry Litter Application. *Agronomy Journal*, **103**, 107-112. https://doi.org/10.2134/agronj2010.0274

[53] Suriyagoda, L.D.B., Ryan, M.H., Renton, M. and Lambers, H. (2014) Plant Responses to Limited Moisture and Phosphorus Availability: A Meta-Analysis. In: *Advances in Agronomy*, Elsevier, 143-200. https://doi.org/10.1016/b978-0-12-800138-7.00004-8

[54] Reisig, D. (2023) Soil Moisture Influence on Nutrient Availability in the Soil. *Global Journal of Plant and Soil Sciences*, **7**, 1-2.