Cover Crops Impact on Biomass, Yield, Soil Health, and Nutrient Loss in a Tile-Terrace Field

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ABSTRACT

Soil erosion by water can be the most important land degradation process on erodible to highly erodible soils. Therefore, different conservation practices can be implemented to address the issue including no-tillage, cover crops (CC), grass filter strips, riparian buffers, and terraces. A field trial was established at the University of Missouri Grace Greenley Research Center near Novelty to evaluate the impact of CC and no-CC (non-treated control, NTC) on crop yields, soil health, and water quality/quantity parameters on a no-tilled terraced field. The experimental design consisted of six parallel terraces (three with CC and three with NTC treatments) that were installed on 120-foot spacings each consisting of an individual tile outlet to evaluate water quality. Additionally, each terrace was split into four landscape positions (shoulder, backslope, footslope, and channel) where yield, CC biomass, and soil health data were collected. Soybean [*Glycine max* (L.) Merr.] was planted in 2016 and 2018. A cost-effective CC blend was overseeded at R6 soybean. Corn (*Zea mays* L.) was planted in 2017 and a post-harvest cereal rye (*Secale cereal* L.) CC was drill-seeded after harvest. Soil health parameters were evaluated at the initiation and completion of the project. Twenty-six grab water samples were taken during storm events. Stage recorders and flumes were used to record discharge per storm event from each tile outlet. The discharge was used to determine total suspended solids (TSS), NO_3-N, and total P (TP) loading throughout the year. In the fall of 2018 soybean yield for CC terraces was 2 bu ac^{-1} higher than NTC. Cover crop biomass was 1870 lbs ac^{-1} ($p<0.10$) greater than the NTC. Cover crop terraces had greater soil Na, potentially mineralizable nitrogen, and bulk density (BD) when compare to the NTC. Terraces planted with CC reduced TSS, TP, and NO_3-N mean loading and event, mean discharge throughout the study period when compared to the NTC. Cumulative discharge in all three cropping seasons: CC in 2016-2017, corn 2017 and CC in 2017-2018 were reduced compared to NTC by more than 58%. Additionally, cumulative TSS and NO_3-N loss were also reduced by CC in two cropping seasons (CC in 2016-2017 and corn 2017). There was no treatment effect on TP loads. Overall, CC planted on terraces improved the water quality and reduced nutrient loss by reducing discharge from the tiles.

INTRODUCTION

Cropping systems with the inclusion of CCs have reported improved soil health, reduced erosion and compaction, improved weed control, and increased commodity yields over time (Myers et al., 2015). Previous research in Missouri has evaluated overseeding a radish CC into standing crop and resulted in no yield difference in rotational crops (Sandler et al., 2015a; Sandler et al., 2015b).

Thousands of cropland acres in Missouri have been terraced to reduce surface water runoff and erosion. Rill erosion within a terraced system may be effectively managed with the addition of CCs in these landscapes (Johnson, 2008). Reducing erosion is critical to the long-term productivity of soils as it causes both in and out of field damages through soil transport and deposition and can be reduced through the implementation of conservation practices such as terraces (Baker et al., 2006). During the construction of terraces, topsoil is removed, terraces are built, and then topsoil is replaced. Integrating CCs with the installation of terraces should synergistically reduce nutrient and sediment loss from agricultural landscapes. Integrating best management practices for CC establishment with erosion management systems should further reduce nutrient loss from agricultural fields. Research in Kansas has evaluated the effects of CCs on pre-existing terraces (Abel, 2013). Abel (2013) reported that multi-year water data is needed to evaluate the effect of CCs on P loss in a terraced field. No known research has evaluated the effects of a CC in a terrace-tile field following terrace construction or evaluated soil health in a terraced field. In-field management to control sediment and nutrient loss (especially nitrogen and phosphorous) should be more cost-effective than the edge of field or water treatment management systems as it would reduce input costs of farmers the following season.

The objective of this research is to evaluate the effect of inclusion of a CC in a corn-soybean rotation on crop production, soil health, and nutrient loss in a terrace-tile field. We hypothesize that in a no-till, terraced field with underground outlet tile systems, 1) less nutrient loss will occur and soil health will increase in a system incorporating CCs compared to a no-till, terraced field with an underground outlet tile system not incorporating CCs, and 2) grain yields will be smaller in the absence of a CC depending on the landscape position, and 3) terrace channels will have lower yields than other landscape positions.

MATERIALS AND METHODS

Field Location and Management

A field trial was initiated in the spring of 2016 at the University of Missouri Grace Greenley Farm of the Greenley Research Center near Novelty, Missouri (39° 57' 27.94"N, 92° 10' 38.88"W). The site had not been in row crop production for over 25 years. With consultation of the local Soil and Water Conservation District (SWCD) and Natural Resources Conservation Service (NRCS) office, state NRCS, and Dr. Allen Thompson (University of Missouri), seven parallel terraces were installed with a 120 ft spacing in 2016 (Fig. 1). The underground tile outlet system (UGO) utilized a 4-in orifice to allow terraces to drain in similar amounts of time and to prevent pressure build-up within UGO tile lines (NRCS, 2013). Tile lines were non-perforated from the inlet riser to the outlet. Six of the seven terraces were utilized for experimental purposes referred as Tile-2 to Tile-7 (Fig. 1). Each terrace was drained individually using six separate non-perforated tile lines (6-in diameter) to evaluate the effect of the cover cropping system on drainage, water flow, and water quality parameters. Crops were managed for high yielding systems for the duration of this project (2016 to 2018) to maximize the efficacy of CCs and crop yields (Nelson et al., 2006; Sandler et al., 2015a; Sandler et al., 2015b)

The experiment includes two treatments 1) CC and 2) no CC (control). Soybean was planted in 2016 (Case IH 1245 Early Riser, Racine, WI). Cover crop terraces were aerially overseeded into standing soybean (Woods Flying Service, Memphis, MO) at R6 (Fehr and

Caviness, 1977) with a blend of 'MFA 2449' wheat (*Triticum aestivum* L.) at 40 lbs ac^{-1}, 'EcoTill' radish (*Raphanus raphanistrum* subsp. Sativus) at 4 lbs ac^{-1}, and 'PurpleTop' turnip (*Brassica rapa* subsp. rapa) at 2 lbs ac^{-1} which took into consideration the cost-effectiveness (\$35.00 ac^{-1}) of the treatment (Table 1). In 2017, corn was no-till planted (Case IH 1245 Early Riser, Racine, WI). Post-harvest cereal rye CC (VNS) was drill seeded (Great Plains, Salina, KS) at 70 lbs ac^{-1} (\$31.50 ac^{-1}) into corn stubble (Table 2).

Landscape Position Classification

The topographic position index (TPI) tool in ArcGIS (v10.6) was used to identify topographic positions. Digital elevation model (DEM) with a raster resolution of 7.25x4.25 ft was generated from elevation data collected from a Veris (Tualatin, OR) electrical conductivity machine. The model used for delineating topographic positions is a direct adaption of the slope position classification model by Evans et al. (2016). The slope position classification model developed by Evans et al. (2016) delineates four topographic positions (e.g., shoulder, backslope, footslope, and a flat slope termed as channel). The TPI in the slope position classification model is the difference of a cell elevation (e) in a DEM from the mean elevation (*m*e) of a user-specified area surrounding e. A radius of 20 ft was used to determine the TPI and a TPI raster was outputted from the DEM. A radius of 20 ft was chosen so that microscale topographic variation within each field could be omitted.

Plant Biomass

Cover crop and weed aboveground biomass was harvested to evaluate biomass. A 1 ft^2 quadrat randomly placed in four locations within each landscape position (shoulder, backslope, footslope, and channel) of each terrace and biomass was collected from within the quadrat. Samples were dried, separated by species, and weighed. Biomass data were collected twice in the spring of 2017, one month prior to planting (17 Mar.) and the day of planting (17 Apr.).

Grain Yield

The primary crop was harvested, and grain yield and moisture were determined in 2016, 2017, and 2018 using a Case IH 5140 or 6140 (Case IH, Racine, WI). Grain yield moisture was adjusted to 15 and 13% for corn and soybean, respectively. A yield monitor equipped combine was used to collect yield. Coordinates including latitude and longitude for yield data points were recorded simultaneously by a GPS receiver of the combine. Unrealistic yield data points that were likely caused by significant positional errors or operating errors such as abrupt changes of speed, partial swath entering the combine, and combine stops and starts-were removed from the data set before the statistical analysis. Data were tested for the normality and outliers were removed. After removing outliers developed yield data sets having latitude and longitude were imported to ArcGIS (v10.6) for extraction of landscape positions and yield features for 2016, 2017, and 2018 that matched each yield point collected by the combine.

Soil Quality

Soil quality parameters were evaluated at project initiation, prior to terrace construction (Table 3a and 3b), and were evaluated again in the spring of 2018. Samples taken prior to terrace construction were sampled where prospective terrace channels and shoulders would be located. Samples following terrace construction were taken at four landscape positions created during construction (Fig. 1 and 2). Following sampling guidelines from the MU Soil Health Assessment

Center (University of Missouri), pooled samples (four rings per landscape position evaluated) were collected from the site and submitted to the MU Soil Health Assessment Center to evaluate soil health indicators as outlined in the Missouri DNR/SWCD CC cost-share program. These soil health indicators included simplified particle size analysis, active carbon, total organic carbon (TOC), potentially mineralizable N (PMN), water stable aggregates (WSA), pH (salt and water), effective CEC plus exchangeable bases, plant available phosphorus, and bulk density. Methods for these parameters can be found in Table 4. Additional soil samples were collected to a 6 inch depth from individual plots prior to construction and each spring after terrace construction to evaluate the effect of cropping systems on soybean cyst nematode (*Heterodera glycines*) egg population densities (MU SCN Diagnostics) and soil chemical properties (MU Soil and Plant Testing Laboratory) (data not presented).

Water

A trapezoidal flume (large, 60-degree) was integrated into the tile flow path of each tile line approximately 25 ft from the tile discharge site. A flow meter was connected to each flume and programmed for flume specifications (Sigma 950 flow meter, Hach Company, Loveland, CO). Flow meters analyzed the stage (depth) of water in the flumes by using an internal air compressor and a bubble line submerged into the flow stream of the flume. Flow meters utilize this data to calculate the discharge from each tile line by using Manning's equation (LMNO Engineering, 2014). Tile flow measurements were recorded every ten minutes.

Additionally, grab samples were collected from the tile outlets during or shortly after each precipitation or flow event. Tile drainage water samples were stored in a refrigerator (41°F) within 1 hour of collection until they were analyzed. Samples of subsurface tile drainage water were analyzed for NO_3-N, TP, and TSS for each individual tile outlet at MU Soil and Plant Testing Laboratory.

To determine the concentration of TSS, 100mL of water from each sample was filtered (1.5 µm, 934-AH; Whatman Glass Microfiber, GE Healthcare Bio-Sciences, Pittsburgh, PA). Solids retained on the filter were used to calculate the concentration of TSS in each sample. Prior to being analyzed for NO_3-N concentration, water samples were filtered (1.5 µm, 934-AH; Whatman Glass Microfiber, GE Healthcare Bio-Sciences, Pittsburgh, PA). Samples were then immediately analyzed for NO_3-N concentration (QuickChem, 10-107-04-1-F, Lachat Instruments, Milwaukee, WI) using an automated ion analyzer (Quick Chem 8000, Lachat Instruments, Milwaukee, WI). In addition, total P was also analyzed.

Nutrient loads were calculated based on storm events. Storm events were separated out from the flow data based on the duration of the rainfall events. Grab water samples were interpolated for stage data collected by flow meters between the start and end of rainfall events. Stage data readings below 0.75 inches were not taken into consideration for load calculations due to high percent error of the trapezoidal flume. Water and nutrient data was divided into seasons. The 2016-2017 CC season spanned from project initiation to CC termination and rotational crop planting in April. The 2017 corn season began at corn planting and was completed following corn harvest in the fall of 2017. The 2017-2018 CC season began when the post-harvest cereal rye CC was drilled and was completed in the spring of 2018 at soybean planting (Table 2).

Statistical Analysis

Prior to the analysis, all variables were tested for the normality of the data using the UNIVARIATE procedure in SAS version 9.4 (SAS Institute, 2014). Based on Shapiro-Wilk and

Kolmogorov-Smirnov tests used for determining the normality of the data, soil health parameter that is PMN and all analytes for water quality load data and discharge were log transformed. Water concentration data were log transformed for TSS and NO_3-N for the spring 2017 CC and fall 2017 corn season, and the spring 2018 CC season. Total P concentrations were log transformed in the spring 2018 CC season. The values were back-transformed to a normal distribution for the presentation of results. All data were analyzed using mixed models in the GLIMMIX procedure of SAS (SAS Institute, 2014). Cover crop treatment and landscape position were treated as fixed factors whereas the replication of the terraces was treated as a random factor. For analyzing the yield data, georeferenced coordinates of each yield data point were added to a random statement that had an exponential spatial covariance structure type=SP(EXP(c-list) that compensated for the spatial autocorrelation of the yield data. To analyze water quality data, a repeated measure statement was added in the mixed model for the storm water collection events. The repeated measure statement had an exponential spatial or temporal covariance structure type=SP(EXP(c-list) which was selected based on the lowest Akaike's Information Criteria (AIC) (Littell et al., 2006). The T-grouping of least square means was used for the comparison of the means at alpha = 0.10.

RESULTS AND DISCUSSION

Grain Yield

Soybean and corn yield grain for 2016 and 2017 were higher for the NTC treatment when compared to the CC treatment (Tables 5 and 6). Shoulder, backslope, and channel landscape positions had greater corn grain yields for the NTC when compared to CC (Table 6). Soybean yield in 2018 was significantly higher (2 bu ac^{-1}) for CC when compared to the NTC (Tables 5 and 6). When CC and NTC treatments were combined, the shoulder position on the terraces had significantly higher grain yields than the footslope and backslope positions for all three years (Table 6). Similarly, Johnson et al. (1998) reported reduced corn yields following soybean overseeded with a rye and oat CC blend. However, other studies have reported that a CC did not reduce subsequent cash crop yields (Curran and Roth, 2013). Myers et al. (2015) reported that CCs may increase commodity yield over time, but these benefits may increase yearly and may not be immediately detected. Terraces are often recognized for their ability to reduce surface water runoff, increase field water availability, and improve field maneuverability (Dickey et al., 1985; Geist et al., 2013; Wheaton and Monke, 1981); however, no literature has shown significantly increased yields in the first 5-10 years following terrace construction (Schottman and White, 1993). Terrace construction created an artificial A horizon on the shoulder and backslope landscape positions encouraging enhanced plant growth (Soil Science Society of America, 2018). Data analyzed in our study only evaluated one year of rotational crop data for each crop and the CC effect on cash crop may have not yet been established. Long-term use of CCs may benefit the crop productivity (Myers et al., 2015).

Biomass

A significant treatment effect was observed in CC biomass in 2017 (Table 7). Plots that received a CC treatment had 1,590 lbs ac^{-1} of biomass compared to plots without a CC treatment that had 570 lbs ac^{-1} of biomass (Tables 7 and 8). This was expected as these plots were seeded with a CC. When data were combined across treatments and evaluated for the landscape position, the footslope position had the highest biomass accumulation followed by the shoulder, backslope, and channel, respectively (Table 8). Combined across treatments, biomass was greater at the second collection (17 Apr.) than at the first collection (17 Mar.). This was expected as a chemical termination treatment was not applied until 18 Apr. 2017. A collection by treatment interaction was observed (Fig. 3). Biomass was greatest at the 17 Apr. collection in the CC treatment. A study in Nebraska comparing various CC species and blends of species reported that spring biomass of cereal rye was greatest compared to CC blends and legume CCs in both early and late planted plots (Koehler-Cole et al., 2016). Kemp and Lyutse (2011) summarized that CCs (species not specified) could produce 4,000-6,000 lbs ac^{-1} of biomass in an average year and up to 10,000 lbs ac^{-1} of biomass in an optimal year during good growing conditions.

Soil Health

Treatment effects were detected in Na, potentially mineralizable nitrogen (PMN), and bulk density soil health parameters (Tables 9 and 10). Landscape position effects were detected in Ca, Mg, Na, K, pH $CaCl_2$, pH H_2O, active C, total organic carbon (TOC), Bray 1 P, and bulk density (Tables 9 and 10). No interaction was present between rotation and landscape position. Cartwright (2016) found the long-term use of CCs can lead to improvements in soil physical and biological properties that can improve overall soil health. No research has been conducted on soil health impacts following terrace construction. However, our results show that terrace construction and the creation of landscape positions, has a significant impact on soil health. When terraces are constructed, topsoil is pushed back and lower layers of soil are important for the construction of the terraces. Topsoil is then put back onto terraces. We believe that terrace construction created an unnatural A horizon on the footslope position encouraging plant growth and microbial activity (Soil Science Society of America, 2018). In an evaluation of Missouri soils at various landscape positions, (Young and Hammer, 2000) reported ridge and shoulder properties to be similar but different from backslope positions. Backslope positions were reported to have lower TOC, pH, base saturation, and less silt. This was not observed in our study as terraces were manmade. Young and Hammer (2000) also concluded that water differences created by slope and stratigraphic conditions often cause soil variability.

Water and Nutrients

Cover crops reduced TSS, TP, and NO_3-N loads compared to the absence of cover crops in all seasons evaluated (Table 11). Furthermore, CCs reduced event mean discharge in each season. Treatment effects were detected for NO_3-N concentration in corn (Table 11). In the spring 2018 CC season, treatment effects were detected for TSS, TP, and NO_3-N concentration. Similarly, Her et al. (2017) reported that CCs reduced TSS, nitrogen (N), and phosphorus (P) loss from fields in the Midwest. Increased concentration of TSS during the spring 2018 CC season was possibly due to increased soil disturbance when drill-seeding the cereal rye CC. However, reduced event mean discharge during the same season, and lower TSS loading (Table 11) indicates that though planting the CC caused a disturbance, less loss occurred with a CC than in the non-treated control. Previous research has reported that when used separately, terraces and CCs assist in conserving soil moisture (Al-Kaisi, 2001; Basche and DeLonge, 2017). Abel (2013) reported that CCs terminated earlier had water content like fallow ground at planting and that earlier terminated CCs would likely have less impact on rotational crop growth and yield. Our research demonstrates that terraced plots with a CC had reduced water discharge when compared to terraced plots without a CC. This confirms that there was a synergistic effect when combining the conservation practices of terracing and cover cropping.

A significant reduction in cumulative water discharge was observed during the 2016-2017 and 2017-2018 CC seasons (75%, 37%) and the corn season (43%) (Fig. 4). Cover crops reduced cumulative nitrate losses in the 2016-17 CC season and during the 2017 corn season by 78% and 60%, respectively. In a similar rotation, Strock et al. (2004) reported an 11% reduction in subsurface drainage discharge. During the 2017-2018 CC season, cereal rye CC did not have an impact on NO_3-N loss; however, only one CC season of cereal rye was evaluated. In a study examining NO_3-N loss from subsurface drainage discharge, cereal rye was found to be an effective tool one in four years. Its low success rate is attributed to years with the low potential for nitrate leaching as well as unsuitable environmental conditions for establishment (Strock et al., 2004). No significant reduction of cumulative total phosphorus was observed during the study period. Cover crops reduced cumulative TSS loss by 77% and 61% during the 2016-2017 CC season and 2017 corn season, respectively. Similarly, studies have reported a reduction in erosion with CC use (Blanco-Canqui et al., 2015; Martens, 2001; Myers et al., 2015).

SUMMARY

Unlike CCs, terraces are a long-term and permanent conservation practice. Therefore, the impact of landscape positions on yield is an important factor for producers when considering the impacts terrace construction on yield variability. We expect that as the soil profile reestablishes following construction over time, the influence of landscape position on grain yield will not be as great. Along with a reduced influence on yield, we expect plots containing a CC to have increased soil health over time, when compared to non-treated control plots. In 2016 and 2017, CC's effected yield. In 2018, use of CCs in a tile-terraced field reduced nutrient loss and water discharge without affecting cash crop yields. A synergistic effect between conservation practices (CCs and terraces) was evaluated. In 2018, Northeast Missouri experienced severe-exceptional drought conditions. Higher yield in 2018 was attributed to CC's water conservation properties. Combined over treatments, the channel landscape position in 2016, 2017, and 2018 was the lowest yielding position. Yield's influence on economic returns impacts producer's conservation management strategies.

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Fig. 1. Design of the six parallel terraces constructed at the University of Missouri Grace Greenley Farm in 2016. Plots 101, 202, and 301 received a cover crop treatment. Plots 102, 201, and 302 are non-treated controls.

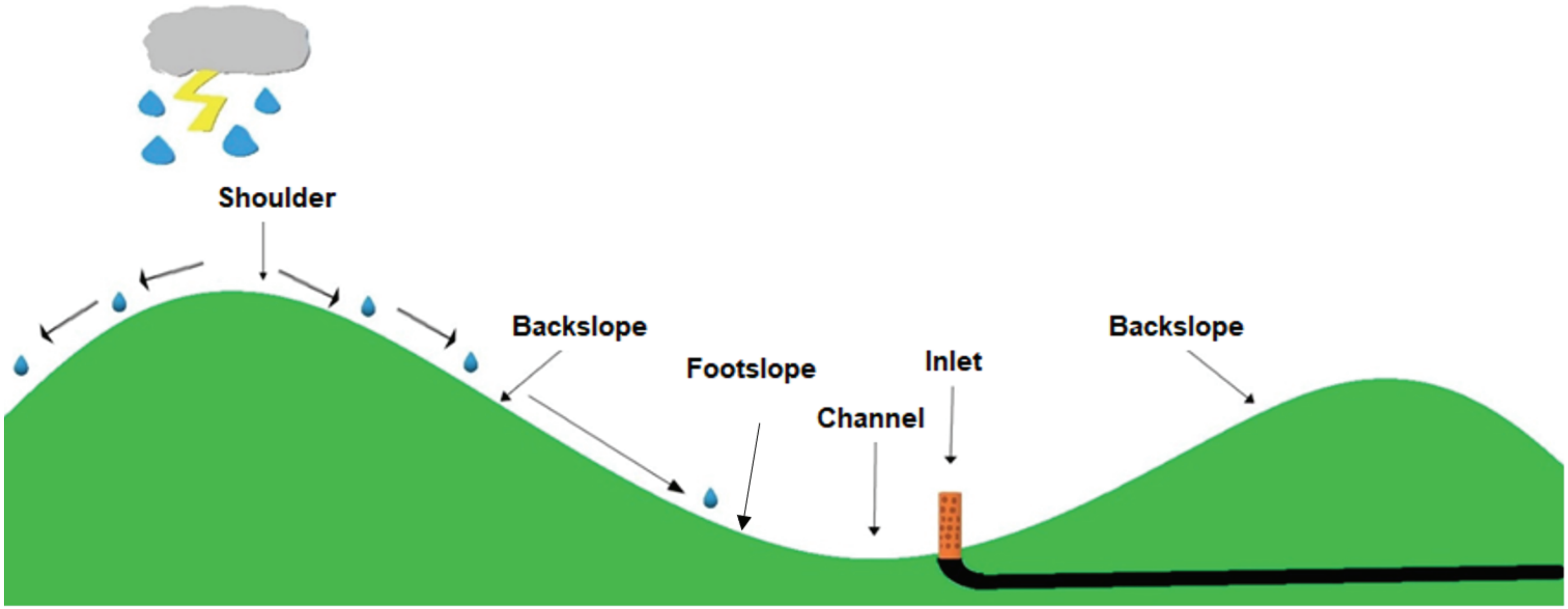

Fig. 2. Soil and biomass samples were taken at the summit, shoulder, channel, and back slope positions in the terraced field. Arrows illustrate terrace construction’s effect on water flow.

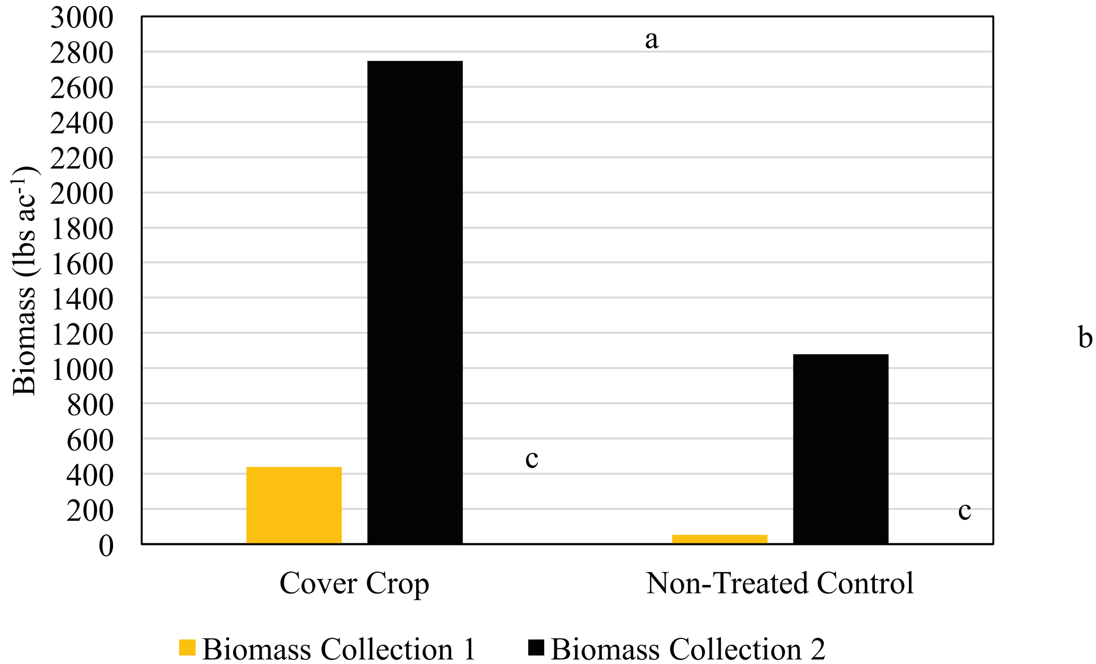

Fig. 3. Aboveground cover crop plus weed biomass for two timing collections in 2017. Biomass was harvested one month prior to planting (17 Mar. 2017) and the day of planting (17 Apr. 2017). Bars followed by the same letter are not statistically different (α = 0.10).

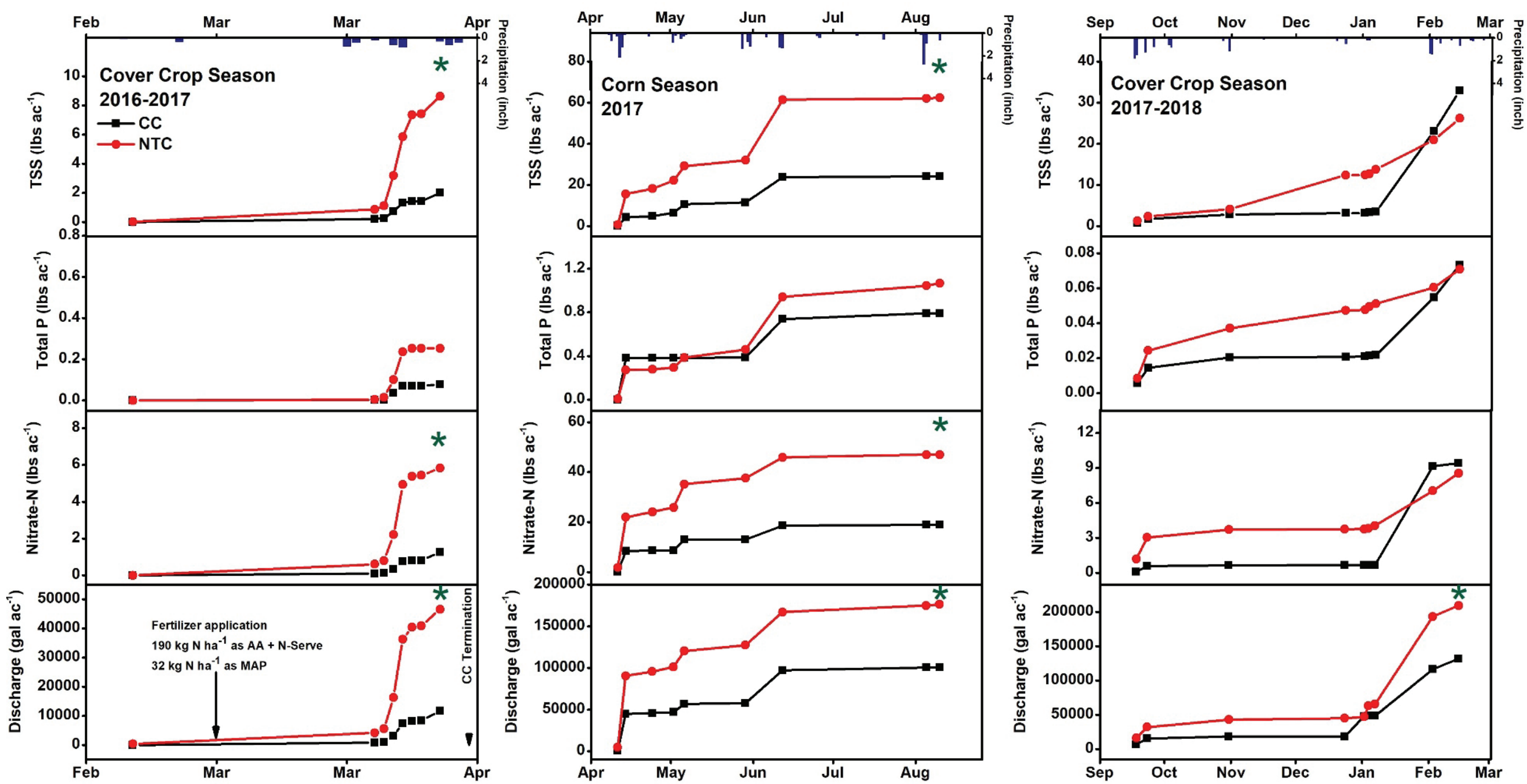

Fig. 4. Precipitation data, cumulative nutrient loss, and water discharge in the cover crop (CC) treatments and non-treated control (NTC). Parameters were observed during cover crop and rotational crop (corn) cropping seasons. Asterisks indicate significant differences between treatment means (α = 0.10).

Table 1. Cover crop management in 2016, 2017, and 2018.

	2016		2017		2018	
Cover crop	Soybean		Corn		Soybean	
		Cover crop cultivar		Cover crop cultivar		Cover crop cultivar
Species	Winter wheat Radish Turnip	MFA2449 EcoTill PurpleTop	Cereal rye	VNS	Winter wheat Radish Turnip	MFA2449 EcoTill PurpleTop
Rate (lbs ac^{-1})	40:4:2		70		40:4:	
Application timing	R6 Soybean		Post-harvest		R6 Soybean	
Application method	Aerial overseeded		Drill seeded		Aerial overseeded	
Seeding date	8 Sep. 2016		2 Oct. 2017		15 Aug. 2018	
Plots	101, 202, 301		101, 202, 301		101, 202, 301	

Table 2. Crop rotations and cover crop treatments from 2016 to 2018. Cover crops were overseeded into standing soybean at R6 in 2016 and 2018 and soybean was harvested in October. A cereal rye cover crop was drill seeded following corn harvest in 2017. Intermediate gold shading indicates a period of soybean and cover crop cohabitation.

	2016												2017												2018											
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D
Treatment																																				
CC						Soybean					CC Blend					Corn						Cereal Rye CC							Soybean				C C		Blend	
NTC						Soybean										Corn													Soybean							

*Abbreviations: CC, cover crop; NTC, non-treated control.

Table 3a. Total organic carbon (TOC), soil organic matter (SOM), water stable aggregates (WSA), active carbon (AC), pH_s (salt pH), pH_w (water pH), P, and potentially mineralizable N (PMN) and P soil health analysis prior to terrace construction in 2016. Samples were collected where the terrace channel and summits were located (Figure 2).

Sample	TOC	†SOM	WSA	AC	pH	pH	Bray 1 P	PMN	‡Bray 1 P
	g kg^{-1}			mg kg^{-1}	salt	water	kg ha^{-1}	mg L^{-1}	
Channel-CC¶	27.0	46.3	590	559	6.1	6.5	29.53	127.7	13.6
Channel-NTC	26.3	45.3	620	529	5.9	6.2	29.53	131.2	9.7
P-value	0.63	0.68	0.48	0.57	0.0	0.1	1.00	0.72	0.07
Shoulder-CC	26.3	46.3	567	533	5.7	6.1	33.68	141.5	15.2
Shoulder-NTC	27.7	47.3	567	532	5.9	6.2	35.93	137.2	16.1
P-value	0.06	0.62	1.00	0.98	0.4	0.2	0.73	0.85	0.68

†Soil organic matter estimated by multiplying total organic carbon values by 1.72
‡Estimated by multiplying Bray 1 P values by 2 (Buchholz et al., 2004).
§Soil health was rated and interpreted with methods outlined by Buchholz et al. (2004).
¶Abbreviations: CC, cover crop; NTC, no cover crop.

Table 3b. Calcium, magnesium, sodium, potassium, aluminum, cation exchange capacity (CEC), base saturation (BS), clay, silt, sand, and soil texture soil health analysis prior to terrace construction in 2016. Samples were collected where the terrace channel and summits were located (Figure 2).

	Ca	Mg	Na	K	CEC	Clay	Silt	Sand	Texture
	g kg^{-1}								
Channel-CC	17.6	2.50	0.07	0.33	20.47	221	678	101	SL
Channel-NCC	15.2	2.27	0.03	0.33	19.53	208	650	142	SL
P-value	0.21	0.32	0.42	1.0	0.10	0.26	0.39	0.32	-
Shoulder-CC	14.8	2.43	0.10	0.33	20.37	221	679	993	SL
Shoulder-NCC	16.1	2.30	0.03	0.37	19.53	204	671	125	SL
P-value	0.31	0.42	0.42	0.42	0.41	0.08	0.52	0.23	-

†Soil health was rated and interpreted with methods outlined by Buchholz et al. (2004).
‡Abbreviations: CC, cover crop; NCC, no cover crop; SL, silt loam.

Table 4. Soil health testing methods used by University of Missouri Soil Health Assessment Center. Soil health parameters evaluated follow guidelines outlined in the Missouri DNR/SWCD cover crop cost-share program. Soil health was evaluated prior to terrace construction in 2016, and again in the spring of 2018.

Soil Health Parameter†	Method	Reference
Particle size	Modified pipette method	NRCS, 2004
Active Carbon	1. Potassium permanganate added to 5-g of soil 2. Sample shaken (two min) then allowed to stand undisturbed (5-10 min) 3. portion of the sample is diluted with reverse osmosis water 4. absorbance read (550 nm) with a spectrophotometer	Weil et al. (2003)
Exchangeable Bases	1. Bases extracted from soil using 1 M NH_4Cl 2. Atomic adsorption spectrophotometer used to analyze base concentrations 3. Extracted soil flushed with C_2H_6O 4. Extracted soil analyzed with FOSS Kjeltec™ 8200 automatic distillation apparatus to analyze for ammonium thereby determining the cation exchange capacity	NCRS, 2004
TOC	Leco C-144	
PMN	1. Place 20 g of soil into a 125-mL extraction bottle 2. Add 25 mL of distilled water to the bottle and stir. Add another 25 mL to rinse sides of the bottle 3. Create an air tight seal over the mouth of the bottle 4. Incubate sample at 40°C for 7 days 5. Remove sample from the incubator and add 50 mL of 2 M KCl. Replace plastic covers 6. Shake sample. Place sample on a mechanical shaker for 1 hour before filtering through Whatman No. 42 paper into acid rinsed filter vials 7. Determine the NH_4-N content using a spectrophotometer	Anderson et al. (2010)
Water stable aggregates	1. Soil dispersed on 0.5 -mm sieve 2. Sample submerged in RO water overnight 3. Sample agitated	NRCS (2004)
pH_w	1. Soil sample mixed with RO water (1:1 w:v). 2. Samples stand 1 hour and occasionally stirred. 3. Sample stirred 30 seconds and pH measured with the pH-reference electrode (Brinkmann Instruments, Inc., Westbury, NY)	NRCS (2004)
pH_s	Procedures 1-3 for determining pH_w are performed and 0.02 *M* $CaCl_2$ (same volume as water) is added.	NRCS (2004)
CEC	1. Exchange sites saturated with NH_4^+. 2. soil washed free of excess saturated salt 3. NH_4^+ displaced and quantified	Holmgren et al. (1977)

Table 4. Continued

Bulk density	1. Soil Sample was taken with Humbolt H-4203DT.3 bulk density ring (4 subsamples) (Humbolt Mfg Company Elgin, IL). 2. A subsample of soil placed into a pre-tared moisture tin. Moisture and weight of subsample is recorded. 3. Sub-sample oven-dried overnight and mass recorded the following day. The remainder of the sample is set out to air dry. 4. Moist: dry mass ratio used to convert the entire sample moist mass to dry mass. 5. The oven-dried portion is ground and sieved to retrieve coarse fragments (> 2 mm in diameter). Coarse fragments are weighed and recorded. The oven-dried soil is discarded. 6. After drying remaining sample, coarse fragments are removed, weighed, and recorded as with the oven-dry sample. 7. Tare weights and course fragment mass subtracted from oven dry sample. Oven-dry mass of 4 rings is divided by the internal volume of 4 sample rings.	Soil Health Assessment Center
Bray I P	1. 25 mL of Bray P-1 extracting soln + 2.5-g soil sample shaken for 15 min. 2. Sample centrifuged until free of soil mineral particles. Clear extracts are collected. 3. 2-mL of collected soln is diluted with 8-mL of ascorbic acid molybdate soln 4. The absorbance of soln is read using a spectrophotometer (882 nm)	Bray and Kurtz (1945)

†Abbreviations: min, minutes; RO, reverse osmosis; soln: solution.

Table 5. Probability values (p-values) and numerator degrees of freedom (df) associated with the sources of variation in the statistical analysis of corn and soybean grain yields.

Source of Variation	df	Soybean 2016	Corn 2017	Soybean 2018
			p-values	
Rotation	1	<0.001	<0.001	0.0184
Landscape Position	3	<0.001	<0.001	<0.0001
R x P†	3	0.1174	<0.001	0.7583

†Abbreviations: R, Rotation; P, Landscape Position.

Table 6. Mean values of grain yield in cover crop (CC) terraces and in non-treated control (NTC) terraces determined by treatment main effects, landscape position main effects, and interactions. Within a column, means followed by the same letter are not statistically different (α = 0.1).

Rotation†	Landscape Position	Soybean‡ Fall 2016	Corn§ Fall 2017	Soybean‡ Fall 2018
			bu ac^{-1}	
NTC		73a	128a	52b
CC		64b	120b	54a
	Shoulder	78a	149a	57a
	Backslope	74b	139b	56a
	Footslope	69c	116c	51b
	Channel	52d	92d	49c
NTC	Shoulder	81	153a	56
	Backslope	80	147b	55
	Footslope	75	115d	49
	Channel	57	98e	51
CC	Shoulder	75	146b	57
	Backslope	69	131c	57
	Footslope	64	117d	50
	Channel	49	87f	52

†Abbreviations: CC, cover crop; NTC, non-treated control.
‡Cover crops were overseeded into standing soybean at R6 in 2016 and 2018. Soybean was harvested in October.
§Cover crop was drill-seeded after corn harvest.

Table 7. Probability values (p-values) and numerator degrees of freedom (df) associated with the sources of variation in the statistical analysis of aboveground cover crop (CC) and weed biomass.

Source of Variation[†]	df	Aboveground Biomass CC+Weeds
		p-values
Rotation	1	<0.0001
Landscape position	3	0.0240
R x LP	3	0.4899
Collection	1	<0.0001
C x R	1	0.0009
C x T	3	0.3020
C x R x LP	3	0.8498

[†]Source of variation: rotation (R), landscape position (LP), collection (C).

Table 8. Mean values of aboveground biomass (lbs ac^{-1}) of cover crop (CC) plus weeds in CC terraces and weeds in non-treated control (NTC) terraces determined by treatment, landscape position, and collection timing. Within a column, means followed by the same letter are not statistically different ($\alpha = 0.1$).

Rotation	Landscape Position	Collection	Aboveground Biomass
			lbs ac^{-1}
NTC			570b
CC			1590a
	Shoulder		1190ab
	Backslope		920bc
	Footslope		1480a
	Channel		720c
		1	250b
		2	1910a

Table 9. Probability values (p-values) and numerator degrees of freedom (df) associated with the sources of variation in the statistical analysis of soil health data in 2018.

Source of Variation†	df	Ca	Mg	Na	K	CEC	pH $CaCl_2$	pH H_2O	Active C
Rotation	1	0.1392	0.5510	0.0653	0.6351	0.1490	0.5749	0.3063	0.8549
Landscape position	3	0.0269	0.0104	0.0299	0.0070	0.3802	0.0262	0.0503	0.0004
R x LP	3	0.8310	0.2560	1.0000	0.4136	0.4917	0.6877	0.9307	0.5007
		TOC	Clay	Silt	Sand	WSA	PMN	Bray 1 P	Bulk Density (BD)
Rotation	1	0.1215	0.8251	0.2497	0.1587	0.1587	0.0639	0.6937	0.0188
Landscape position	3	0.0094	0.0086	0.2733	0.7084	0.7084	0.1198	0.0171	0.0298
R x LP	3	0.9845	0.1748	0.8591	0.9437	0.9437	0.7258	0.3899	0.2398

†Source of variation: rotation (R), landscape position (LP)

Table 10. Mean soil health values evaluated in the spring of 2018 determined by cover crop (non-treated control, NTC; and cover crop, CC) treatment main effects and landscape position main effects. Within a column and within a given factor, means followed by the same letter are not statistically different (α = 0.1).

Rotation	Landscape Position	Ca	Mg	Na	K	CEC	pH $CaCl_2$	pH H_2O	Active C
				meq 100 g^{-1}					mg C kg^{-1}
NTC		12	2.3	0.08a	0.4	18	5.7	6.0	350
CC		12	2.4	0.05b	0.4	18	5.7	6.1	350
	Shoulder	12b	2.3c	0.05b	0.3b	17	5.7a	6.2a	340bc
	Backslope	12.b	2.4ab	0.05b	0.4b	18	5.7a	6.2ab	350b
	Footslope	13a	2.2bc	0.05b	0.4b	19	5.9a	6.3a	420a
	Channel	12b	2.63a	0.12a	0.5a	18	5.5b	5.8b	310c
		TOC	Clay	Silt	Sand	WSA	PMN	Bray 1 P	Bulk Density
				g kg^{-1}			ppm		g $cm^{3\ -1}$
NTC		14	250	560	190	220	37b	16	1.3a
CC		15	250	580	160	260	45a	17	1.3b
	Shoulder	15ab	240b	580	170	230	39b	14b	1.3a
	Backslope	15bc	260b	560	190	260	39b	14b	1.3a
	Footslope	17a	240b	590	160	250	51a	15b	1.3a
	Channel	13c	270a	550	180	230	35b	23a	1.2b

Table 11. Event mean load values and p-values of nutrient loads including total suspended solids (TSS), total phosphorous (TP) and nitrate-N (NO_3-N) cover crop (CC) and non-treated control (NTC) treatments. Within a column and within a given factor, means followed by the same letter are not statistically different (α = 0.1).

Rotation	Cover Crop Season† Spring 2017				Corn‡ Spring 2017				Cover Crop Season§ Spring 2018			
	TSS	TP	NO_3-N	Event Mean Discharge	TSS†	TP	NO_3-N	Event Mean Discharge	TSS†	TP	NO_3-N	Event Mean Discharge
	----------g ha^{-1}----------			m^3 ha^{-1}	----------g ha^{-1}----------			m^3 ha^{-1}	----------g ha^{-1}----------			m^3 ha^{-1}
CC	268b	6b	162b	13b	3070b	103b	2450b	105b	5384b	11b	1625b	137b
NTC	1267a	69a	849a	53a	7783a	190a	5857a	183a	5747a	13a	2071a	218a
p-value	<0.0001	0.0075	0.0003	<0.0001	0.0021	0.0142	0.0011	0.0124	0.0784	0.0457	0.0016	0.0066

†Event mean loads of 8 storm events
‡Event mean loads of 9 storm events
§Event mean loads of 9 storm events

Table 12. Mean values and p-values of the nutrient concentration of drainage water including total suspended solids (TSS), total phosphorous (TP) and nitrate-N (NO_3-N) for cover crop (CC) and non-treated control (NTC) treatments. Within a column and within a given factor, means followed by the same letter are not statistically different (α = 0.1).

Rotation	Cover Crop Season† Spring 2017			Corn‡ Spring 2017			Cover Crop Season§ Spring 2018		
	TSS	TP	NO_3-N	TSS†	TP	NO_3-N	TSS†	TP	NO_3-N
	----------mg L^{-1}----------			----------mg L^{-1}----------			----------mg L^{-1}----------		
CC	24.24	0.8103	13.06	63.55	1.0041	21.67b	71.59a	0.1727b	5.85b
NTC	24.45	0.7887	12.31	53.03	1.0858	30.30a	70.43b	0.1790a	10.01a
p-value	0.7433	0.9093	0.3240	0.8233	0.6506	0.0270	0.0490	0.0796	0.0005

†Event mean concentrations of 8 storm events
‡Event mean concentrations of 9 storm events
§Event mean concentrations of 9 storm events