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Evaluation of Best Management Practices at an Edge-of-Field Site in the Eagle Creek Watershed, Ohio, 2012–20



Scientific Investigations Report 2026–5037

U.S. Department of the Interior
U.S. Geological Survey

Cover. Surface site gage of study with tractor and attached early riser planter, Eagle Creek watershed, Ohio, June 2018. Photograph by Chad Toussant, U.S. Geological Survey.

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By Chad A. Toussant and Brittany R. Hanrahan

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Conversion Factors

U.S. customary units to International System of Units

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.4047	hectare (ha)
	Volume	
cubic foot (ft^3)	0.02832	cubic meter (m^3)
	Flow rate	
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
	Mass	
pound, avoirdupois (lb)	0.4536	kilogram (kg)
	Application rate	
pound per acre (lb/acre)	1.121	kilogram per hectare (kg/ha)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F = (1.8 \times °C) + 32.$$

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

$$°C = (°F - 32) / 1.8.$$

Datum

Horizontal coordinate information is referenced is North American Datum of 1983 (NAD 83).

Supplemental Information

A water year (WY) is the 12-month period from October 1 through September 30 of the following year and is designated by the calendar year in which it ends.

Abbreviations

ANOVA	analysis of variance
BMP	best management practice
CC	cover crop
GLRI	Great Lakes Restoration Initiative
HUC	hydrologic unit code
MAP	Monoammonium phosphate
NOAA	National Oceanic and Atmospheric Administration
NRCS	Natural Resources Conservation Service
P	phosphorus
PO_4^{3-}	orthophosphate
PP	particulate phosphorous
PW	priority watershed
SLR	simple linear regression
SS	suspended sediment
TP	total phosphorous
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
VRT	variable rate technology

Evaluation of Best Management Practices at an Edge-of-Field Site in the Eagle Creek Watershed, Ohio, 2012–20

By Chad A. Toussant and Brittany R. Hanrahan

Abstract

In 2010, the U.S. Geological Survey worked in partnership with the Great Lakes Restoration Initiative and the Natural Resources Conservation Service to identify farm fields in priority watersheds—watersheds critically important to Great Lakes health. Intensive best management practices were implemented in five States to test the efficacy of best management practices, also referred to as agricultural conservation practices, to reduce sediment and nutrient runoff on agricultural fields. These fields were chosen as representatives of the priority watersheds because their farming practices and geographical conditions were common among farms in those watersheds. A farm site located near Findlay, Ohio, in the Eagle Creek watershed used two conservation practices, cover crop (Natural Resources Conservation Service practice standard 340) and variable rate technology (VRT; Natural Resources Conservation Service practice standard 590), which represent common practices in the Maumee priority watershed. This study monitored surface runoff and subsurface tile runoff at the Eagle Creek watershed site.

The effects of cover crop and VRT nutrient application on sediment and nutrient runoff were assessed from October 2012 to September 2020. Cover crops were applied in fall of 2016, 2017, and 2018, coinciding with VRT applications. The following parameters were analyzed as part of the study: runoff discharge; peak discharge; and concentrations and loads of total phosphorus, particulate phosphorus, dissolved reactive phosphorus, and suspended sediment. High peak runoff events disproportionally affected nutrient concentrations and loads in runoff. A threshold of the 85th percentile of the peak discharge was chosen to assess the effect of cover crop and VRT nutrient application on nutrient mitigation at each gage. Runoff events below the 85th percentile were considered small, and runoff events over the 85th percentile were considered large. Concentrations from collected water-quality samples were used for the analysis; estimated concentrations were excluded from the statistical evaluation.

All surface runoff parameters during small runoff events, except surface runoff volume, were significantly lower in the period with cover crops and VRT implementation. Contrarily, subsurface runoff parameters during small events were not statistically different between the periods with and without cover crops and VRT implementation. Surface and subsurface parameters during large events were also not statistically different between the periods with and without cover crops and VRT implementation. These results indicate cover crops and VRT may improve water quality during small runoff events, but additional best management practices that mitigate large runoff events may lead to greater water-quality improvement given the contribution of large events to overall losses.

Introduction

In 2010, the Great Lakes Restoration Initiative (GLRI) was established to coordinate restoration efforts in the Great Lakes region by confronting its most serious threats, including nonpoint source pollution, toxic substances, and invasive species (U.S. Environmental Protection Agency, 2024). Five focus areas were developed at GLRI's inception to address these major threats, and this report falls under Focus Area 3, which is centered on nonpoint pollution and nearshore health (GLRI, 2024a). An objective of Focus Area 3 is to reduce nutrient loads from agricultural watersheds through implementation of conservation practices. Thus, the priority watershed (PW) program was developed through partnerships between GLRI, the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS), and the U.S. Geological Survey (USGS) to evaluate the effectiveness of conservation practices in targeted watersheds with high densities of agricultural land use and water-quality impairments (fig. 1). All PWs are associated with designated areas of concern, which are waters of significant environmental degradation as defined by the USDA NRCS (USGS, 2019).

Within the larger PWs (hydrologic unit code [HUC] 4 watersheds) that were first identified, the NRCS and USGS selected smaller watersheds (HUC 12) to focus monitoring efforts at the edge-of-field scale. In this portion of the PW program, targeted, watershed-based, voluntary conservation practices were used to address agricultural nonpoint nutrient losses (USGS, 2016). The NRCS used GLRI funding to accelerate implementation of conservation practices on private land by providing financial and technical assistance



Figure 1. Map showing the U.S. Geological Survey Great Lakes Restoration Initiative priority watersheds.

(GLRI, 2024b) for PW producers (farmers). The number of acres receiving financial or technical assistance was used as a measure of progress under GLRI Action Plan IV, Focus Area 3, objective 3.1 (GLRI, 2024a), but decisions about which practices were implemented were left to NRCS technical design standards and specific goals or constraints of the participating producers. Implementation of conservation practices was coordinated between private producers and NRCS personnel or through agreements supported by NRCS. As a result, various conservation practices have been implemented under the PW program, including (but not limited to) nutrient management systems (variable rate technology [VRT]), erosion control (cover crops), conservation tillage, and buffers (NRCS, 2011). The portion of the PW program that is the focus of this study, namely an edge-of-field assessment within a HUC 12 watershed nested within a HUC 4 watershed, focused on monitoring the most common conservation practices in the proximal landscape.

According to NRCS, a conservation practice is "a structural or vegetative measure, or management activity used to protect or reduce the degradation of soil, water, air, plant, animal, or energy resources" (U.S. Department of Agriculture, 2022, p. 3). The effectiveness of conservation practices to reduce nutrient and sediment loss from agricultural fields often depends on site-specific environmental conditions, soil composition, and management factors (Liu and others, 2019; Badon and others, 2022; Srivastava and others, 2023; Kaur and others, 2024). For example, studies examining conservation practices in corn-soybean rotations—the crop rotation used in the edge-of-field site in this study—have

reported that conservation practices increase, decrease, and have no effect on nutrient loss (Liu and others, 2019; Badon and others, 2022; Kaur and others, 2024). Liu and others (2019) examined the effects of cover crops in cold climates, where frost periods were abundant, and found that cover crops became a source of dissolved reactive phosphorus during frost periods. Phosphorous concentrations were also heavily influenced by herbicide application and precipitation timing (Liu and others, 2019). Kaur and others (2024) found that a monoculture cover crop reduced total phosphorus (TP) and dissolved reactive phosphorus loads by 70 percent and 73 percent, respectively, whereas a mixed species cover crop had no effect. Badon and others (2022) analyzed the effect of minimal tillage and winter cover crops on nitrogen and phosphorus transport in poorly drained soils in Mississippi and concluded that neither nitrogen nor phosphorus was reduced throughout the study. Hanrahan and others (2026) evaluated the effect of conservation practices implemented at 12 edge-of-field sites in 4 PWs—the Saginaw River Basin (Michigan), the Genesee River Basin (New York), the Fox River Basin (Wisconsin), and the Maumee River Basin (Indiana and Ohio)—and found that sediment and nutrient loss varied among sites and with the parameters of interest (for example, nitrate as nitrogen, dissolved phosphorus, and so on), which further highlights the importance of site-specific characteristics and conservation effects.

This report compares the water quality of rainfall-driven surface-water runoff and subsurface tile runoff (hereafter, rainfall-runoff occurrences are called “events”) before and after the implementation of cover crops (NRCS practice standard 340) and nutrient application using variable rate technology (VRT; NRCS practice 590) at an agricultural site in Eagle Creek watershed in northwestern Ohio, from 2012 to 2020. Cover crops are seasonal plants grown between commodity crop seasons. VRT applies lime, monoammonium phosphate (MAP) or phosphorus, and potash or potassium chloride fertilizer of various quantities and rates of release based on biennial soil tests conducted across a field (U.S. Department of Agriculture, 2019). Cover crops can provide many benefits, including improved nutrient cycling, soil moisture capacity, and weed suppression (Bowman and Wallander, 2021). Nutrient application via VRT can increase the precision of matching nutrient application to soil nutrient levels, reducing overapplication in agricultural fields overall.

For this study, metrics of water quantity and quality included runoff total discharge, runoff peak discharge, and concentrations and loads of total phosphorus (TP), particulate phosphorus (PP), dissolved reactive phosphorus (orthophosphate), and suspended sediment (SS). These water-quantity and -quality metrics were then analyzed for periods before and after the implementation of the conservation practices during runoff events that were greater than or equal to the 85th percentile of peak discharge of events (hereafter, large events) and runoff events with peak discharge less than the 85th percentile (hereafter, small events). This distinction between large and small events was selected because previous work has shown large events are significant drivers of water-quality degradation in water bodies (Kalkhoff, 2018). Cover crops have the potential to slow surface runoff, which can increase infiltration and evapotranspiration and result in smaller sediment and nutrient loads. For this study, the effects of the combination of cover crops and VRT were most pronounced during the months between cover crop planting (November) and termination (March), a period also referred to as the cover crop season, in years when best management practices (BMPs) were implemented, resulting in less sediment and phosphorus loss during these times because of the bare soil conditions, which lead to high concentration runoff.

Physical Setting

The study site for this analysis was near Findlay, Ohio, in the upper reaches of the Eagle Creek watershed within the larger Maumee PW (fig. 2) and consisted of one surface monitoring site and one subsurface tile runoff monitoring site, both at the edge of an agricultural field and positioned to receive as much of the water draining from the field, through their respective paths, as feasible. The surface site gage was USGS station 405051083391201, GLRI Eagle Creek waterway 1 near Williamstown, Ohio, and the subsurface gage was USGS station 405051083391001, Eagle Creek tile 1 near Williamstown, Ohio. The surface gage was in a grassed waterway near a gravel-packed driveway and pole barn. The subsurface gage was about 150 feet away, where runoff drained into a large retention pit (fig. 3).

Drainage areas differed between the surface runoff and subsurface tile runoff sites (fig. 3). The subsurface tile drainage area (7.9 acres) extends to the east, outside the surface site’s watershed; the surface drainage area (8.1 acres) extends to the north and west of the tiled area. The tile drainage area includes the topographical drainage area that drains towards the underlying tile system drainage. This topographic area was designated as a contributor to the tile drainage because, during saturated conditions, precipitation could flow down to a more level area on top of saturated soil and be absorbed into the ground and released through the tile underlying the level topographical area. For both monitoring locations, the field characteristics were considered the same, with all drainage coming from part of a large agricultural field with some influence from a driveway, a storage shed, and a patch of forest; these non-field areas together accounted for less than 5 percent of the surface catchment area. The predominant soil type was Blount silt loam ground moraine, and the average slope in the drainage area was 0.61 percent (Fermanich and others, 2023).

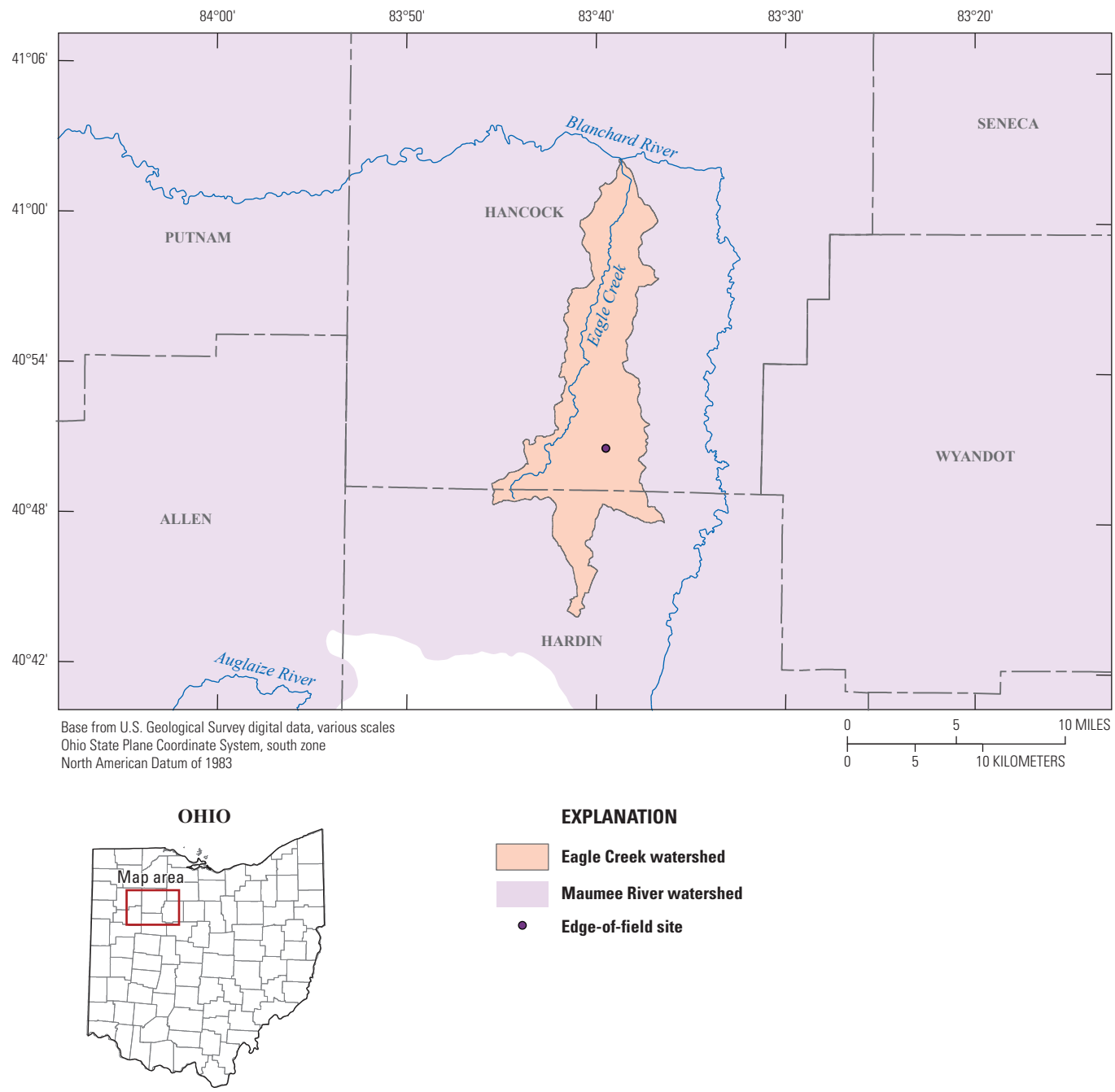


Figure 2. Map showing location of the edge-of-field site consisting of two gages used in the evaluation of cover crops and variable rate technology as conservation practices within the Eagle Creek watershed, Ohio, 2012–20.

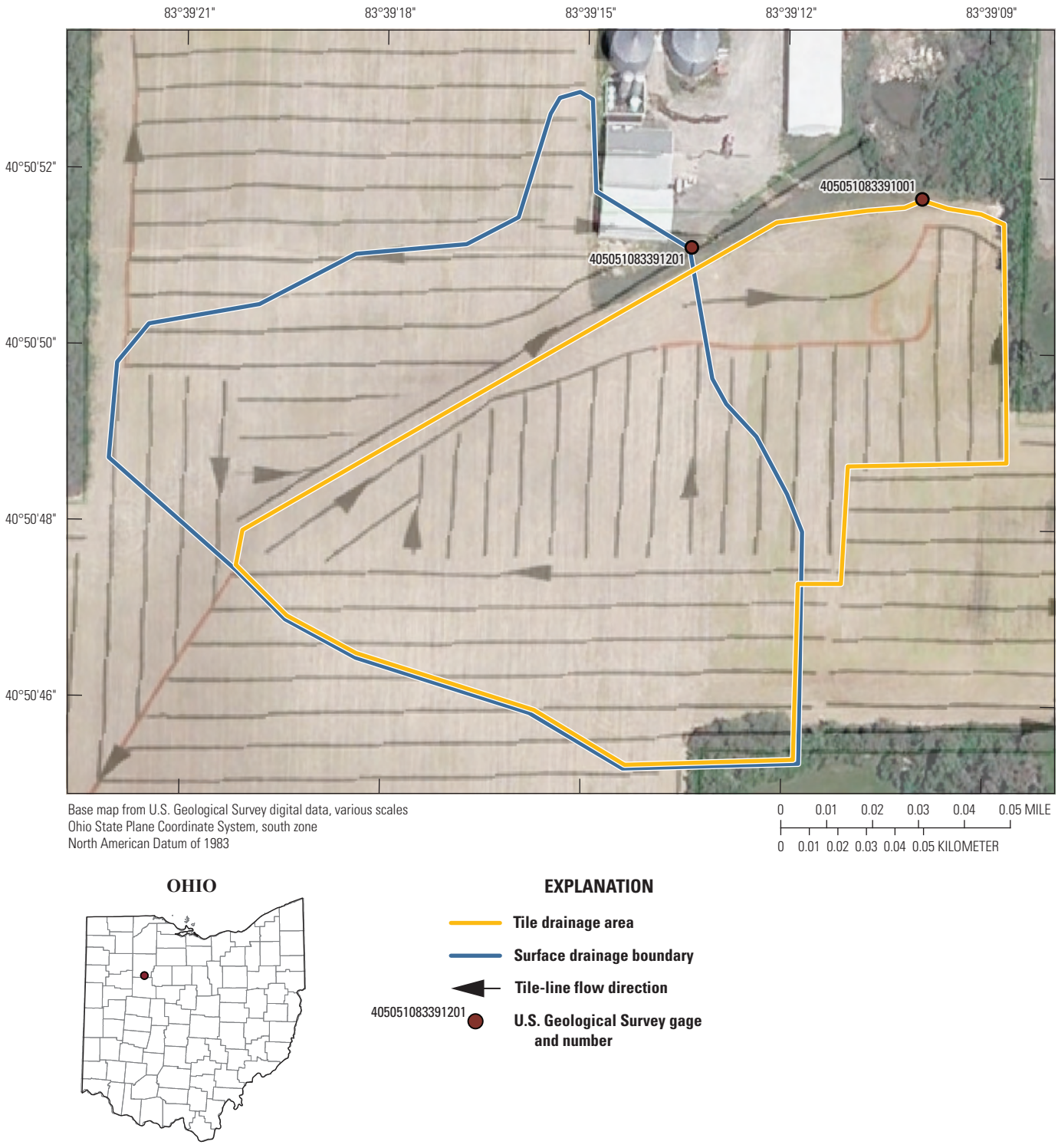


Figure 3. Aerial view of the edge-of-field site used in the evaluation of cover crops and variable rate technology as conservation practices in the Eagle Creek watershed, Ohio, 2012–20. The blue boundary represents the surface study area. The yellow outline represents the surface area contributing to the subsurface tile lines.

On-Farm Data

An alternating crop rotation of soybeans (2012, 2014, 2016, 2018, 2020) and corn (2013, 2015, 2017, 2019) was used for the entirety of the study. All crops were grown to completion and harvested according to the producer's normal farming practices. Soybeans were planted no-till in the spring. The fields were tilled once during the preceding fall after the soybean crop was harvested, and the fields were tilled again in the spring before the corn was planted. Fertilizers and soil amendments were applied throughout the study; a summary of this is provided in table 1.

Cooperating with privately owned farms to evaluate conservation effects was a critical component of the edge-of-field PW initiative. The edge-of-field program coordinated with local NRCS offices to maintain a record of on-field practices through communications with the producer. This documentation tracked planting, cultivation, fertilizer application, harvesting, and other field management activities that may have affected the data and was annually collected by a NRCS representative and shared with USGS personnel. The USGS deployed cameras at the study site, which helped corroborate dates and times of field management activities (Toussant, 2026). A summary of the on-farm field activities is presented in table 1.

Table 1. Timeline of field activities on the edge-of-field study area used in the evaluation of cover crops and variable rate technology as conservation practices in the Eagle Creek watershed, Ohio, 2012–20.

[The complete record of field activities is not publicly available or has limited availability owing to restrictions (landowner privacy according to agreement between Hancock County Natural Resources Conservation Service and producer).* ATT, ammonium thiosulfate (200 pounds per acre); lb, pound; K, potassium; P, phosphorus; VRT, variable rate technology; MAP, monoammonium phosphate; —, no information]

Year	Season	Crop	Tillage	Treatment
		Pre-best management practices		
2012	Spring	Soybeans planted (May 6)	—	ATT 200 lb (May 15)
	Fall	Soybeans harvested (October 15)	Deep ripped (November 20)	K (150 lb), P (150 lb) (October 20)
2013	Spring	Corn planted (May 1)	Field cultivated (May 14)	ATT (200 lb) (May 15)
	Fall	Harvested corn (October 9)	—	—
2014	Spring	Soybeans planted (May 6)	—	—
	Fall	Harvested soybeans (October 6)	Deep ripped (October 20)	K (150 lb), P (150lb) (October 12)
2015	Spring	Corn planted (April 16)	Broadcast and deep ripped (April 15)	3-gallon seed starter (April 17)
	Fall	Corn harvested (October 15)	Broadcast and turbo till (November 12)	VRT application K (150 lb), P (100 lb) (November 10)
2016	Spring	Soybeans planted (May 15)	—	Broadcast
	Fall	Soybeans harvested (October 15); winter wheat flown (October 20)	Deep ripped (October)	Lime VRT (October 17)
		Post-best management practices		
2017	Spring	Corn planted (April 19)	Field cultivated (April 15)	—
	Fall	Harvested (October 7); winter wheat flown (October 13—estimated)	—	Lime VRT (October 17)
2018	Spring	Soybeans planted (April 15)	—	—
	Fall	Harvested (September 19); winter wheat flown (October 23—estimated)	Broadcast and deep ripped	MAP and potash; lime VRT (October 18)
2019	Spring	Corn (planted June 8)	Field cultivated (June 1)	Anhydrous (June 1)
	Fall	Corn harvested (October 29)	—	—
2020	Spring	Soybeans planted (May 12)	—	—
	Fall	Soybeans harvested (October 11)	—	—

*For more information, contact Hancock County Natural Resources Conservation Service, Megan Burgess, at 419-422-6569.

Monitoring Methods

The annual period of record for the study was concurrent with the water year (WY), which begins on October 1 and continues to September 30 of the following calendar year. For example, this project began in WY 2013 because data collection started on October 1, 2012. The sites were monitored year-round from October 1, 2012, through September 30, 2020. The first conservation practice was implemented in WY 2017 (VRT on October 17, 2016 [table 1]); therefore WYs 2017–19 were designated as the years with conservation practices, and all other years were designated as years preceding conservation practices.

Site establishment and data collection followed the methods described in Stuntebeck and others (2008). Stage data at the surface and subsurface tile site were collected with nonsubmersible pressure transducers in the flumes. Water-quality samples were collected in each flume by a peristaltic pump and stored in a refrigerated sampler until the samples could be collected and analyzed. A datalogger activated the refrigerated sampler to collect water-quality samples over the course of events and during base-flow periods, at preset stage and time intervals. All equipment was housed in a structure adjacent to the flume at each site.

To ensure that all runoff was monitored at the surface site (fig. 4), wingwalls and earthen berms were added to the upstream side to direct all flow through the flume. A surface runoff event was defined as a period when the stage rose by more than 0.05 feet in less than 60 minutes and the 0.05-foot increase was sustained for at least 60 minutes. Similarly, the subsurface tile site (fig. 4) used a trapezoidal flume mounted to the tile at a release point. However, different criteria were used to define a subsurface tile runoff event than a surface runoff event because stage in the subsurface tile flume rose more slowly after a rain event but then stayed elevated for longer. A subsurface tile runoff event was defined as a 0.05-foot increase in gage height over a 6-hour (or less) period that was sustained for more than 48 hours without another meaningful rise. Precipitation may fall in one window of time or multiple windows over a period. When precipitation fell in multiple windows of time, and if the initial rise in stage and the second rise were similar in magnitude and a separate period of precipitation could be attributed to the second rise, then the precipitation periods were considered separate runoff events regardless of a time factor.

Samples collected during storm events from each site were composited based on flow and time to produce a flow-weighted, event-mean concentration that represented the runoff event (fig. 5). The compositing of samples was conducted by the Water and Environmental Analysis Lab, University of Wisconsin-Stevens Point, using USGS-supplied composite volumes from each sample bottle collected during the event.

Runoff events that were not represented by collected samples for reasons including, but not limited to, equipment malfunctions, short-duration runoff events, and loss of electricity were estimated. Discharge values for unsampled events were estimated by using sampled event values from preceding and subsequent periods, responses of concentrations and loads to event size in previous years, precipitation intensity, and field conditions to interpret discharge between recorded values. Constituent concentrations for unsampled events were estimated based on sample concentrations of events similar in size (magnitude and duration of runoff

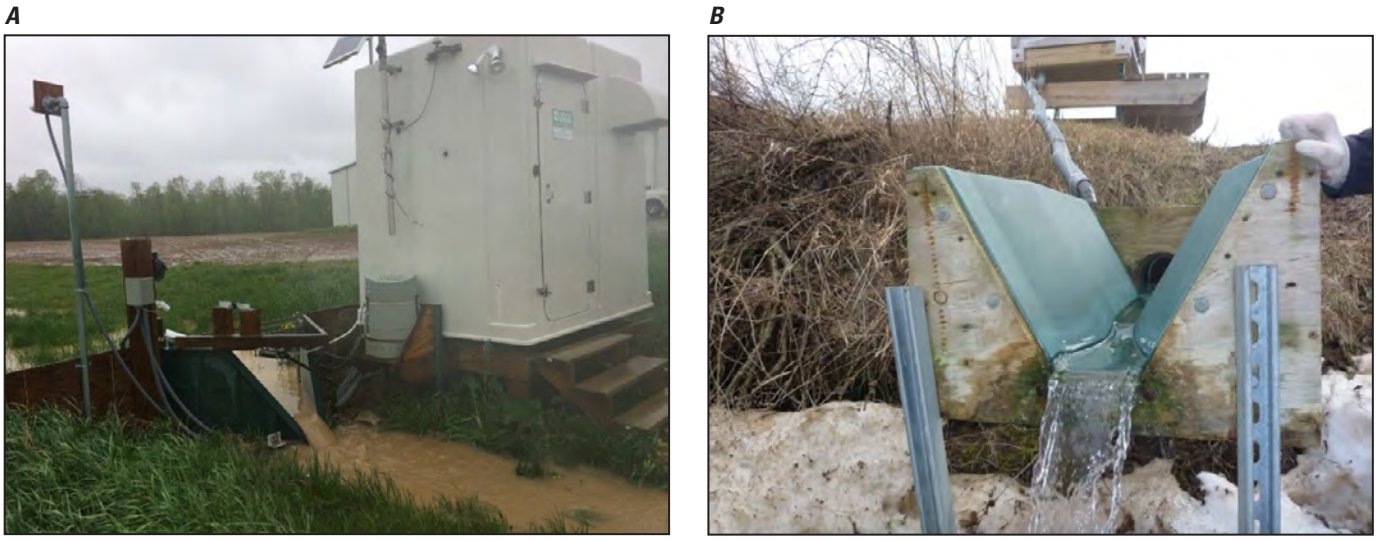


Figure 4. Photographs showing gage setup at the sites used in the evaluation of cover crops and variable rate technology as conservation practices in the Eagle Creek watershed, Ohio, 2012–20. *A*, Surface runoff site 405051083391201, Eagle Creek waterway 1 near Williamstown, Ohio. *B*, Subsurface runoff tile line 405051083391001, Eagle Creek tile 1 near Williamstown, Ohio. Photographs by Chad Toussant, U.S. Geological Survey.

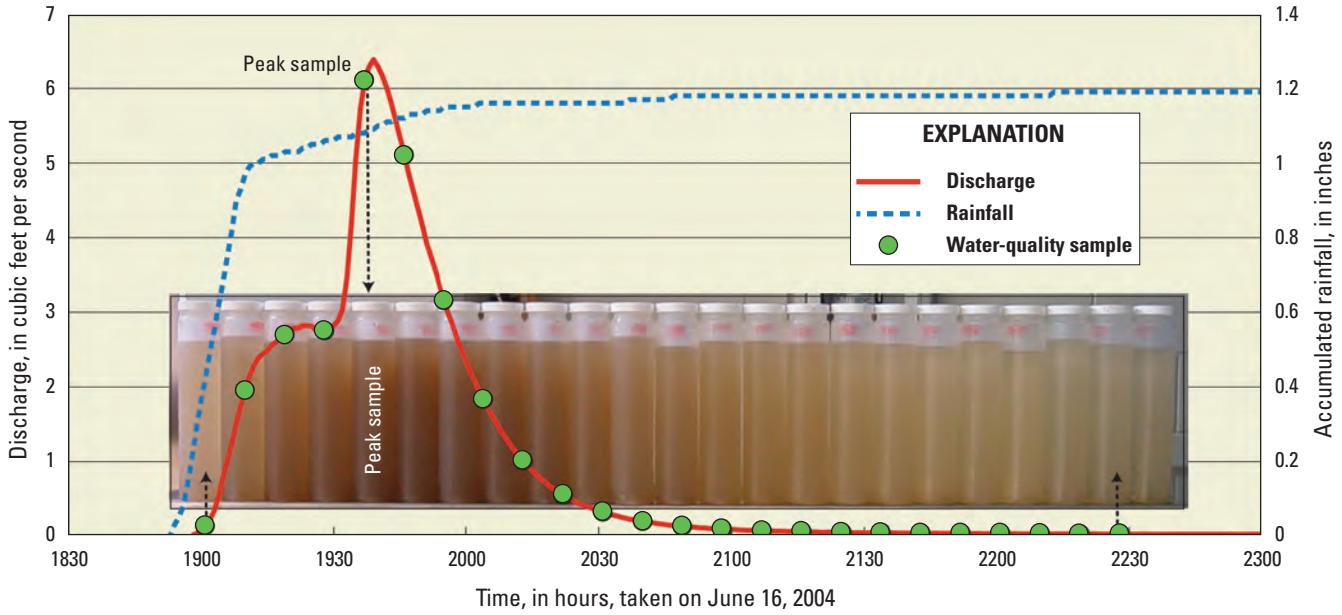


Figure 5. Example of the timing of samples during a runoff event. Figure modified from U.S. Geological Survey (2016); public domain.

events) and time of year. All concentrations—sampled and estimated—were independently reviewed and approved (Komiskey and others, 2021).

Precipitation was also monitored year-round at the edge-of-field site (fig. 6). Individual rainfall events were measured by using a nonheated tipping bucket. These data were published by Komiskey and others (2021). Rain-gage calibration checks were conducted biannually (spring and fall) to ensure accuracy. The precipitation gage did not have a heating element, so all measured thawing from frozen precipitation was redacted from the precipitation record. Snow accumulation data were from National Oceanic and Atmospheric Administration (NOAA) station USW00014825, where snow depth was used to calculate snow water equivalence (NOAA, 2024).

Soil temperatures were monitored throughout the study. Frozen periods were defined as when the near-surface temperature sensor recorded a temperature of 0.5 degrees Celsius or colder. Soil moisture was collected by a sensor buried 30 centimeters beneath the top of the ground at the study site. During the study, runoff events were so infrequent during frozen periods that analyzing frozen and nonfrozen events separately, similarly to Komiskey and others (2021), was not necessary.

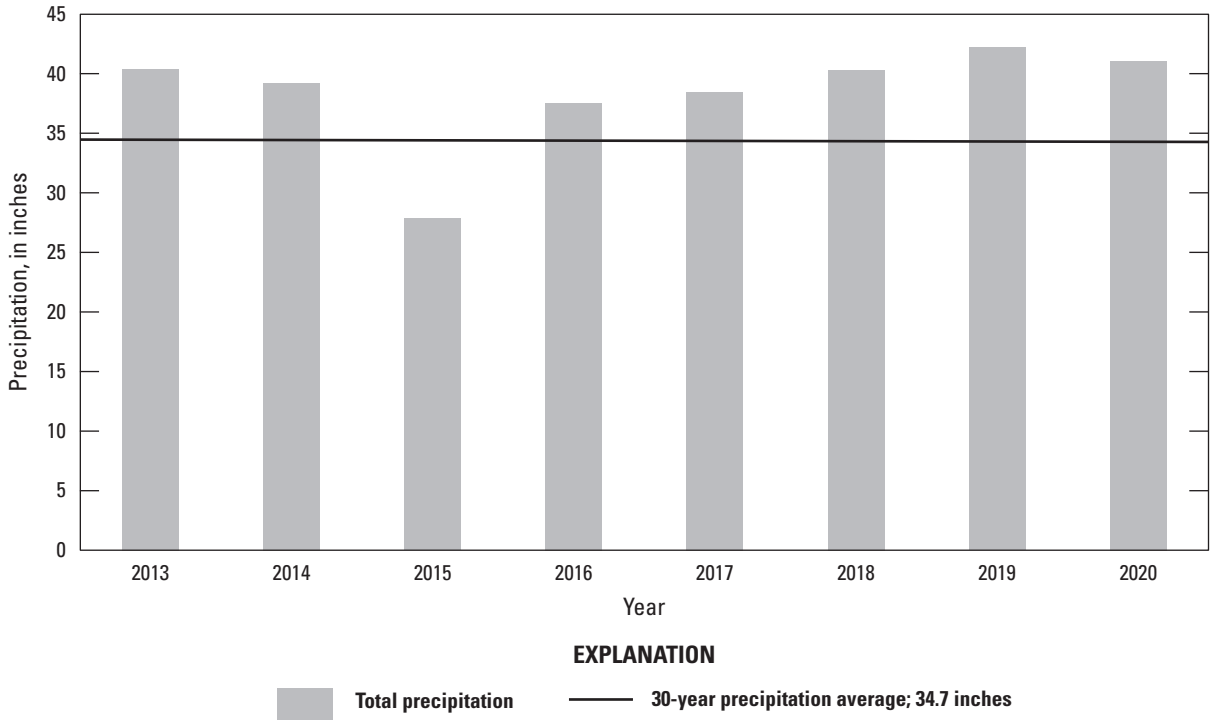


Figure 6. Graphical presentation of annual total precipitation at the study site in the Eagle Creek watershed, Ohio, comparing yearly rainfall from 2013 to 2020 to the 30-year average (1990–2020) precipitation. Data from National Oceanic and Atmospheric Administration (NOAA) station USW00014825 (NOAA, 2024).

Conservation Approach

The study site had a grass waterway along the edge of the field, and no-till practices had been used for several years prior to this study. The producer agreed to adopt two additional conservation practices: cover crop planting during the nongrowing season and VRT. According to the NRCS practice "Cover Crop" (code 340), a "selected species must be planted within the listed planting date window . . . or up to 2 weeks after the last planting date listed if the seeding rate must be increased by 20 [percent]" (U.S. Department of Agriculture, 2017, p. 3). For this site, *Triticum aestivum* (common wheat) was selected as the cover crop and was aerially seeded. Aerial broadcast seeding is a method of spreading cover crop seeds via airplane, helicopter, or high-clearance vehicle when field or crop conditions are not conducive to drill seeding (NRCS, 2010).

During the same years in which cover crops were planted (2017–19), an additional BMP, VRT, was used. Nutrient application rates can vary greatly under VRT; for example, on the 100-acre field where the study was conducted, application of MAP varied from 12.8 lb/acre (pounds per acre) to 140.3 lb/acre. The 8.1-acre study area had a much narrower range of applications, from 93.2 to 101.9 lb/acre. For Potash, rates ranged from 20.7 to 222.2 lb/acre. To receive Environmental Quality Incentives Program funding for a nutrient management program, the producer had to agree to a 3-year contract (U.S. Department of Agriculture, 2019).

Common wheat seeds were aerially deposited in October 2016, 2017, and 2018 (table 1). As previously stated, cameras were used to confirm many of the field activities during the study. According to the photographic documentation (fig. 7) and notes made at site visits, only the seeding in fall of 2017 (for the 2018 crop year) provided visible cover; the cover crop grew 2–3 inches before the cold weather set in and then continued growing in the spring.



Figure 7. Series of photographs of the study site in the Eagle Creek watershed, Ohio, during winter and spring, showing the cover crop growth during 2017, 2018, and 2019 after cover crops and variable rate technology were applied the previous fall (fall 2016, 2017, 2018). Imagery from Toussant (2026). *A*, February 1, 2017. *B*, April 14, 2017. *C*, February 1, 2018. *D*, May 3, 2018. *E*, January 6, 2019. *F*, May 11, 2019.

Methods of Data Analysis

The study used an experimental design involving periods with and without the application of cover crops and VRT (hereafter referred to as CC+VRT) to evaluate the effects of BMP implementation. This experimental design consisted of a period preceding implementation to establish baseline runoff prior to the application of conservation practices, a 3-year period when the two conservation practices were applied, and a subsequent period of 1 year when cover CC+VRT application stopped. Statistical analyses are used to determine changes, if any, that can be attributed to the conservation practice. The period of study preceding implementation was from October 1, 2012, to October 26, 2016. Common wheat was first aerially applied on October 26, 2016, which designated the start of the 3-year period of application ending September 30, 2019. The additional year of nutrient monitoring was from October 1, 2019, to September 30, 2020. To measure changes in water quality coinciding with the implementation of the conservation practices, this study focused on discharge (as peak discharge) and cumulative runoff (as runoff volume), as well as concentrations and loads of sediment, orthophosphate (PO_4^{3-}), particulate phosphorus (PP), and total phosphorus (TP). Loads (the mass of a constituent passing through a point per unit of time) are calculated by multiplying a concentration representing a time interval by the volume of water for that same period (Donaghy, 2014).

For both surface and tile runoff events, data from sampled events were sorted by peak-flow percentile and divided into events with peak flows greater than the 85th percentile (large events) and events with peak flows less than the 85th percentile (small events). The 85th percentile was chosen as the line of demarcation because it was the highest percentile that included more than one event per year for both surface and subsurface tile runoff. Only concentration data from sampled events at the surface and subsurface tile sites were used for the analysis of water-quality improvement. Data from large and small events, both surface and tile, were then analyzed separately.

Several types of statistical analyses were used to evaluate the event data collected in this study. First, simple linear regressions were used to determine if increases in peak discharge were associated with corresponding increases in concentrations and loads of dissolved reactive phosphorus, PP, TP, and suspended sediment (SS). For each parameter, peak discharge was defined as the predictor variable (x) and concentration, or load was defined as the response variable (y). A regression was considered statistically significant when the *p*-value was less than 0.05, indicating that peak discharge was a meaningful predictor of the parameter being evaluated. The coefficient of determination (R^2) was then used to describe how much of the variation in concentration or load could be explained by changes in peak discharge. These analyses were conducted separately for large and small events and for both surface and tile drainage to characterize how relations between peak discharge and concentration or load varied across event types and flow pathways.

Next, average concentrations and loads of dissolved reactive phosphorus, PP, TP, and SS were analyzed across periods without or with the implementation cover crops and VRT, and across months when these practices were considered inactive (April through October) or active (November through March). To do this, water years were first grouped into water years without CC+VRT (2013–16, 2020) and with CC+VRT (2017–19). Because common wheat is typically planted in the fall and terminated in the spring, two seasonal categories were also defined: a season without CC+VRT (April–October) and a season with CC+VRT (November–March). For years when no cover crops were planted (2013–16, 2020), the CC+VRT season still represented the nongrowing season (in other words, bare soil), and for years when common wheat did not establish successfully (2017, 2019), those months were still classified as the CC+VRT season for analytical consistency. A two-way analysis of variance (ANOVA) was then used to test whether mean concentrations and loads differed between years without and with CC+VRT and between seasons with or without CC+VRT. The two-way ANOVA included the interaction between year type and season, which was the primary focus of the analysis because it indicates whether the seasonal effect on water quality differed after CC+VRT implementation. When the interaction (year and season) was significant ($p<0.05$), a post-hoc Tukey test was used to determine which specific combinations of year and season were statistically different. All concentration and load data were log-transformed to meet ANOVA assumptions, and all statistical analyses were performed in R (R Core Team, 2023).

Results

At the surface site, 273 runoff events were measured over the 8-year study. Peak discharge for this 8-year period ranged from 0.004 to 8.12 cubic feet per second (ft^3/s). The 85th percentile of peak discharge equated to 0.84 ft^3/s. At the surface site, 40 events were greater than 0.84 ft^3/s and considered large events. The number of large events ranged from 2 in 2015 to 9 in 2019, accounting for between 6 and 20 percent of total annual events. At the surface site, 18 large events occurred during the 3 years with CC+VRT; 22 large events occurred during years without CC+VRT.

At the subsurface tile site, 460 events were measured over the 8-year study. Peak discharge for this 8-year period ranged from 0.001 to 0.39 ft^3/s. The 85th percentile of peak discharge equated to 0.148 ft^3/s. In total, 69 events were greater than this peak-discharge threshold at the subsurface site. The number of large events ranged from 3 in 2013 to 11 in 2019, accounting for between 5 and 22 percent of total annual events. At the subsurface tile site, 33 large events were recorded during the 3 years with CC+VRT; 36 large

events occurred during years without CC+VRT. Combining WY 2020 into the non-CC+VRT years can be misleading with respect to the trends at the subsurface site. More than 50 percent of runoff events at the subsurface site exceeded the 85th percentile of peak discharge from water years 2018–20; this resulted in 68, 60, and 58 percent, respectively, of events during these years met this threshold.

Overall, large events accounted for 15 percent of all surface and subsurface events but contributed the most runoff volume and loads, indicating that large runoff events contributed disproportionately to phosphorus and sediment loss. At the surface site, most dissolved reactive phosphorus left the field in small events (table 2), but at the subsurface site, most dissolved reactive phosphorus left the site during large events (table 3). There was more loss of all other forms of phosphorus and SS from large events than from small events.

At the surface site, 135 of the 273 discharge events were sampled for concentrations of water-quality parameters (hereafter referred to as "sampled events"). Only sampled

Table 2. Summed annual loads of 273 events for tested parameters in surface runoff during large events (greater than the 85th percentile of peak discharge) and small events (less than the 85th percentile of peak discharge) at the Eagle Creek watershed, Ohio.

[Data from Komiskey and others (2021)]

Water year	Runoff volume, in cubic feet		Orthophosphate load, in pounds		Particulate phosphorus load, in pounds		Total phosphorus load, in pounds		Suspended sediment load, in pounds	
	In large events	In small events	In large events	In small events	In large events	In small events	In large events	In small events	In large events	In small events
2013	49,200*	45,300	0.1	0.2	7.1*	2.8	7.2*	3.2	5,200*	1,590
2014	140,000*	115,000	2.2*	1.6	3.2*	1.1	7.1*	3.4	3,740*	530
2015	31,400	73,500	0.2	1.2	4.8*	1.2	5*	2.5	5,010*	546
2016	42,800*	23,400	1*	0.4	2.9*	2.6	4*	3	1,900	2,090
2017	102,000*	15,100	0.7*	0.3	39.2*	1.9	39.9*	2.4	16,900*	1,860
2018	28,000	83,000	1.8	8.6	0.5	2.3	2.3	11.1	230	749
2019	186,000*	70,600	3*	1.6	12.8*	4.1	19.7*	6.6	16,000*	3,280
2020	57,000*	56,100	1.3	2.7	6.2*	3.3	7.5*	6.2	6,660*	2,450
Total	636,400*	482,000	10	17	77*	19	93*	38	55,640*	13,095

*Greater than 50 percent of the runoff or load for that year and constituent in large events (additionally indicated by cell shading as a visual aid).

Table 3. Summed annual loads of 460 events for tested parameters in subsurface tile drainage during large events (greater than the 85th percentile of peak discharge) and small events (less than the 85th percentile of peak discharge) at the Eagle Creek watershed, Ohio.

[Data from Komiskey and others (2021)]

Water year	Runoff volume, in cubic feet		Orthophosphate load, in pounds		Particulate phosphorus load, in pounds		Total phosphorus load, in pounds		Suspended sediment load, in pounds	
	In large events	In small events	In large events	In small events	In large events	In small events	In large events	In small events	In large events	In small events
2013	27,100	108,000	0.05	0.18	1.79	2.07	1.84	2.25	934*	488
2014	65,100	89,400	0.18	0.54	1.02*	0.83	1.21	1.37	303*	262
2015	70,900*	57,600	0.32*	0.19	0.86*	0.72	1.18*	0.90	261*	164
2016	96,300*	64,900	0.58*	0.27	1.83*	0.49	2.41*	0.76	683*	146
2017	45,400	81,400	0.18	0.24	1.18*	1.16	1.36	1.40	452	564
2018	136,000*	65,100	1.20*	0.25	2.64*	0.61	3.83*	0.86	532*	181
2019	150,000*	101,000	1.45*	0.63	4.46*	1.58	5.92*	2.21	2,386*	762
2020	69,500*	50,400	1.53*	0.79	2.16*	0.45	3.69*	1.23	924*	117
Total	660,300*	617,800	5*	3	16*	8	21*	11	6,475*	2,685

*Greater than 50 percent of the runoff or load for that year and constituent in large events (additionally indicated by cell shading as a visual aid).

events were used in the statistical analyses. Over the course of the 8-year study, 35 of the 135 discharge events were greater than the 85th percentile and 15 discharge events took place in the CC+VRT years. At the subsurface site, 183 of the 460 discharge events were sampled; 61 of those were greater than the 85th percentile, and 29 took place in the CC+VRT years. The substantial drop in events included in the analysis for the subsurface site is due to many low-flow or base-flow periods that had estimates associated with them.

Tables 2 and 3 present annual loads for all events (including estimated) during the 8-year study, and tables 4 and 5 present annual loads for all sampled events during the 8-year study. At the surface site, years when large events contributed over 50 percent of runoff, most load totals were also from large events, with exceptions of orthophosphate in 2013 and 2020 and suspended sediment in 2016 (table 4). Most loads from the subsurface site moved in large events regardless of if most of the runoff came from large events. The exceptions were orthophosphate in 2013 and 2014, particulate phosphorus in 2013, and total phosphorus in 2013 (table 5).

Table 4. Summed annual loads of 135 events for tested parameters in surface runoff during large events (greater than the 85th percentile of peak discharge) and small events (less than the 85th percentile of peak discharge), using non-estimated data, at the Eagle Creek watershed, Ohio.

[Data from Komiskey and others (2021)]

Water year	Runoff volume, in cubic feet		Orthophosphate load, in pounds		Particulate phosphorus load, in pounds		Total phosphorus load, in pounds		Suspended sediment load, in pounds	
	In large events	In small events	In large events	In small events	In large events	In small events	In large events	In small events	In large events	In small events
2013	49,200*	38,800	0.1	0.2	7.1*	2.8	7.2*	2.9	5,200*	1,470
2014	119,000*	87,500	1.9*	1.2	3.2*	1.1	5.1*	2.3	2,520*	308
2015	31,400	65,600	0.2	1	4.8*	1.2	5*	2.2	5,010*	529
2016	42,800*	22,800	1*	0.4	2.9*	2.6	4*	3	1,900	2,080
2017	102,000*	12,200	0.7*	0.2	39.2*	1.9	39.9*	2.1	16,900*	1,750
2018	27,900	71,900	1.8	7.9	0.5	2.3	2.3	10.2	230	662
2019	118,000*	57,700	2.1*	1.3	12.8*	4.1	14.9*	5.4	12,000*	2,700
2020	57,000*	51,800	1.3	2.5	6.2*	3.3	7.5*	5.8	6,660*	2,300
Total	547,300*	408,300	9.10	14.70	76.70*	19.30	85.90*	33.90	50,420*	11,799

*Greater than 50 percent of the runoff or load for that year and constituent in large events (additionally indicated by cell shading as a visual aid).

Table 5. Summed annual loads of 183 events for tested parameters in subsurface tile drainage during large events (greater than the 85th percentile of peak discharge) and small events (less than the 85th percentile of peak discharge) using non-estimated data.

[Data from Komiskey and others (2021)]

Water year	Runoff volume, in cubic feet		Orthophosphate load, in pounds		Particulate phosphorus load, in pounds		Total phosphorus load, in pounds		Suspended sediment load, in pounds	
	In large events	In small events	In large events	In small events	In large events	In small events	In large events	In small events	In large events	In small events
2013	27,100	75,200	0.05	0.13	1.79	1.89	1.84	2.03	934*	473
2014	56,900	62,700	0.16	0.47	0.88*	0.55	1.04*	1.02	247*	181
2015	70,900*	48,800	0.32*	0.17	0.86*	0.68	1.18*	0.85	261*	158
2016	90,100*	62,900	0.53*	0.26	1.80*	0.48	2.34*	0.74	648*	144
2017	51,700	74,000	0.22*	0.20	1.19*	1.14	1.41*	1.34	543*	469
2018	136,000*	61,300	1.20*	0.23	2.64*	0.56	3.83*	0.79	532*	161
2019	105,000*	74,400	1.13*	0.49	3.58*	1.16	4.71*	1.65	1,783*	705
2020	64,400*	46,400	1.44*	0.72	2.12*	0.46	3.57*	1.18	923*	109
Total	602,100*	505,700	5*	3	15*	7	20*	10	5,871*	2,400

*Greater than 50 percent of the runoff or load for that year and constituent in large events (additionally indicated by cell shading as a visual aid).

Relations Between Peak Discharge, Sediment, and Phosphorus

In large surface events, loads of PP, TP, and SS increased as peak discharge increased (simple linear regression [SLR], $p<0.05$; table 6); peak discharge explained 29–38 percent of the variation in these loads. In small surface events, concentrations of PO_4^{3-}, PP, and SS, as well as loads of PO_4^{3-}, PP, TP, and SS, also increased as peak discharge increased (SLR, $p<0.05$; table 7). Peak discharge explained only 3–7 percent of the variation in concentrations during small events, but it explained 12–46 percent of the variation in loads. Overall, these results indicate that peak discharge strongly

Table 6. Summary of statistical results from simple linear regressions examining relations between log-transformed response variables and peak discharge during large surface events (greater than the 85th percentile of peak discharge), including estimates for linear regression intercepts, slopes, and coefficients of determination (R^2).

[Data from Komiskey and others (2021). Values of significance for R^2, specifically $p<0.05$, are bolded and denoted by asterisks (*)]

Response variable	Intercept			Slope			Coefficient of determination	
	Estimate	*t*	*p*	Estimate	*t*	*p*	R^2	*p*
Orthophosphate, in milligrams per liter	−1.67	−6.94	<0.001	−0.13	−0.46	0.65	−0.02	0.65
Particulate phosphorus, in milligrams per liter	0.19	0.63	0.53	0.47	1.35	0.19	0.02	0.19
Total phosphorus, in milligrams per liter	0.61	2.63	0.01	0.26	0.97	0.34	0.00	0.34
Suspended sediment, in milligrams per liter	6.65	20.22	<0.001	0.67	1.75	0.09	0.06	0.09
Orthophosphate, in pounds	−2.42	−6.84	<0.001	0.51	1.23	0.23	0.01	0.23
Particulate phosphorus, in pounds	−0.57	−2.32	0.03	1.10	3.86	<0.001	**0.29***	**<0.001***
Total phosphorus, in pounds	−0.14	−0.71	0.48	0.90	3.88	<0.001	**0.29***	**<0.001***
Suspended sediment, in pounds	5.90	24.56	<0.001	1.31	4.68	<0.001	**0.38***	**<0.001***

*Value of significance ($p<0.05$).

Table 7. Summary of statistical results from simple linear regressions examining relations between log-transformed response variables and peak discharge during small surface events (greater than the 85th percentile of peak discharge), including estimates for linear regression intercepts, slopes, and coefficients of determination (R^2).

[Data from Komiskey and others (2021). Values of significance for R^2, specifically $p<0.05$, are bolded and denoted by asterisks (*)]

Response variable	Intercept			Slope			Coefficient of determination	
	Estimate	*t*	*p*	Estimate	*t*	*p*	R^2	*p*
Orthophosphate, in milligrams per liter	−1.60	−8.01	<0.001	−0.23	−2.14	0.03	**0.03***	**0.03***
Particulate phosphorus, in milligrams per liter	0.01	0.04	0.97	0.28	2.30	0.02	**0.03***	**0.02***
Total phosphorus, in milligrams per liter	0.38	1.96	0.05	0.14	1.34	0.18	0.01	0.18
Suspended sediment, in milligrams per liter	6.50	19.92	<0.001	0.57	3.31	0.001	**0.07***	**0.001***
Orthophosphate, in pounds	−2.46	−7.58	<0.001	0.74	4.29	<0.001	**0.12***	**<0.001***
Particulate phosphorus, in pounds	−0.86	−3.36	0.001	1.24	9.22	<0.001	**0.40***	**<0.001***
Total phosphorus, in pounds	−0.49	−1.91	0.06	1.10	8.12	<0.001	**0.34***	**<0.001***
Suspended sediment, in pounds	5.63	20.30	<0.001	1.53	10.45	<0.001	**0.46***	<0.001*

*Value of significance ($p<0.05$).

influenced phosphorus and sediment export in surface runoff, and event-scale loads were more closely tied to peak discharge than concentrations were.

For tile flow, similar patterns were observed. In large tile events, concentrations of PO_4^{3-} and loads of PO_4^{3-}, PP, TP, and SS increased as peak discharge increased (SLR, $p<0.05$; table 8). Peak discharge explained 14 percent of the variation in PO_4^{3-} concentration during large tile events, and 10–29 percent of the variation in loads. In small tile events, all concentrations and loads of PO_4^{3-}, PP, TP, and SS also increased as peak discharge increased (SLR, $p<0.05$, table 9); peak discharge explained 11–40 percent of the variation in concentrations and 42–69 percent of the variation in loads. Collectively, these findings demonstrate that peak discharge was a consistent and influential driver of phosphorus and sediment losses across both surface and subsurface pathways, though the strength of these relations varied by event size and parameter.

Table 8. Summary of statistical results from simple linear regressions examining relations between log-transformed response variables and peak discharge during large subsurface tile events (greater than the 85th percentile of peak discharge), including estimates for linear regression intercepts, slopes, and coefficients of determination (R^2).

[Data from Komiskey and others (2021). Values of significance for R^2, specifically $p<0.05$, are bolded and denoted by asterisks (*)]

Response variable	Intercept			Slope			Coefficient of determination	
	Estimate	*t*	*p*	Estimate	*t*	*p*	R^2	*p*
Orthophosphate, in milligrams per liter	−0.67	−1.30	0.20	1.15	3.28	0.00	**0.14***	**0.002***
Particulate phosphorus, in milligrams per liter	−1.06	−2.08	0.04	−0.01	−0.02	0.98	−0.02	0.98
Total phosphorus, in milligrams per liter	−0.46	−1.04	0.30	0.18	0.61	0.54	−0.01	0.54
Suspended sediment, in milligrams per liter	5.07	7.68	0.00	0.20	0.45	0.65	−0.01	0.65
Orthophosphate, in pounds	0.11	0.18	0.86	2.10	5.02	0.00	**0.29***	**<0.001***
Particulate phosphorus, in pounds	−0.28	−0.58	0.57	0.94	2.84	0.01	**0.11***	**0.01***
Total phosphorus, in pounds	0.33	0.77	0.44	1.13	3.95	0.00	**0.20***	**<0.001***
Suspended sediment, in pounds	5.86	9.55	0.00	1.15	2.76	0.01	**0.10***	**0.01***

*Value of significance ($p<0.05$).

Table 9. Summary of statistical results from simple linear regressions examining relations between log-transformed response variables and peak discharge during small subsurface tile events (greater than the 85th percentile of peak discharge), including estimates for linear regression intercepts, slopes, and coefficients of determination (R^2).

[Data from Komiskey and others (2021). Values of significance for R^2, specifically $p<0.05$, are bolded and denoted by asterisks (*)]

Response variable	Intercept			Slope			Coefficient of determination	
	Estimate	*t*	*p*	Estimate	*t*	*p*	R^2	*p*
Orthophosphate, in milligrams per liter	−2.27	−14.08	<0.001	0.23	5.88	<0.001	**0.11***	**<0.001***
Particulate phosphorus, in milligrams per liter	0.57	2.54	0.01	0.77	13.75	<0.001	**0.40***	**<0.001***
Total phosphorus, in milligrams per liter	0.34	2.01	0.05	0.57	13.63	<0.001	**0.40***	**<0.001***
Suspended sediment, in milligrams per liter	6.41	22.92	<0.001	0.87	12.48	<0.001	**0.36***	**<0.001***
Orthophosphate, in pounds	−2.83	−12.78	<0.001	0.78	14.21	<0.001	**0.42***	**<0.001***
Particulate phosphorus, in pounds	0.01	0.03	0.98	1.31	23.38	<0.001	**0.66***	**<0.001***
Total phosphorus, in pounds	−0.23	−1.23	0.22	1.11	23.89	<0.001	**0.67***	**<0.001***
Suspended sediment, in pounds	6.14	24.43	<0.001	1.54	24.75	<0.001	**0.69***	**<0.001***

*Value of significance ($p<0.05$).

Differences During Large and Small Surface Runoff Events

The influence of CC+VRT implementation on surface event parameters during large events was first evaluated. For all parameters examined, there was no evidence that the effect of CC+VRT season differed between years without and with CC+VRT (year and season, $p>0.05$ for all; table 10). This indicated that, during large surface runoff events, mean discharge and mean concentrations and loads of PO_4^{3-}, PP, TP, and SS during the CC+VRT season were similar regardless of whether cover crops and VRT were implemented in a particular year (fig. 8).

Contrasting results were found for small surface events. For peak discharge and runoff volume, the effect of CC+VRT season was similar in years without and with CC+VRT (year and season, $p>0.05$; table 11). However, for concentrations of PP, TP, and SS, the effect of the CC+VRT season differed between years with and without CC +VRT (year and season, $p<0.05$ for all; table 9). Post-hoc comparisons showed that, in years when CC+VRT was implemented, mean PP, TP, and SS concentrations were significantly lower in the CC+VRT season than in the non-CC+VRT season (fig. 9). For loads of PP, TP, and SS, the effect of CC+VRT season also differed between years with and without CC+VRT (year and season, $p<0.05$; table 11), but post-hoc comparisons did not identify any significant differences in mean loads between the CC+VRT seasons in years with and without CC+VRT. These within-year differences likely reflect typical nongrowing season hydrology rather than the effects of CC+VRT implementation. Taken together, these findings indicate that CC+VRT implementation was associated with lower PP, TP, and SS concentrations during small surface events but did not produce detectable reductions in PP, TP, and SS loads.

Differences During Large and Small Peak Discharge Subsurface Tile Events

The influence of CC+VRT implementation on tile event parameters during large and small events was also evaluated. For both large and small tile events, the effect of the CC+VRT season was similar in years with and without CC+VRT (year and season, $p>0.05$ for all; tables 12 and 13). This indicated that, across all tile events, mean discharge and mean concentrations and loads of PO_4^{3-}, PP, TP, and SS during the CC+VRT season were similar regardless of whether cover crops and VRT were implemented in a particular year (figs. 10 and 11). Overall, CC+VRT implementation did not produce detectable reductions in concentrations or loads of PO_4^{3-}, PP, TP, or SS in subsurface tile drainage during either large or small events.

Table 10. Summary of statistical results from two-way analysis of variance tests examining the influence of cover crop year, cover crop season, and the interaction of cover crop year and season on response variables during large surface events (greater than the 85th percentile of peak discharge), including estimates for *F* statistics and associated *p*-values.

[Data from Komiskey and others (2021). Values of significance, $p<0.05$, are bolded and denoted by asterisks (*)]

Response variable	Cover crop year (CC_year)		Cover crop season (CC_season)		Interaction (CC_year and CC_season)	
	F	*p*-value	*F*	*p*-value	*F*	*p*-value
Peak discharge, in cubic feet per second	**6.96***	**0.01***	0.72	0.4	2.15	0.15
Runoff volume, in cubic feet	0.54	0.47	**8.17***	**0.01***	0.01	0.92
Orthophosphate, in milligrams per liter	1.2	0.28	2.01	0.17	0.54	0.47
Particulate phosphorus, in milligrams per liter	0.33	0.57	1.74	0.2	1.1	0.30
Total phosphorus, in milligrams per liter	1.45	0.24	1.31	0.26	0.45	0.51
Suspended sediment, in milligrams per liter	0.04	0.85	**5.07***	**0.03***	0.86	0.36
Orthophosphate, in pounds	1.58	0.22	**8.13***	**0.01***	0.22	0.64
Particulate phosphorus, in pounds	1.25	0.27	0.47	0.5	1.32	0.26
Total phosphorus, in pounds	3.65	0.07	2.13	0.16	0.6	0.44
Suspended sediment, in pounds	0.08	0.78	0.19	0.67	1.06	0.31

*Value of significance (additionally bolded as a visual aid).

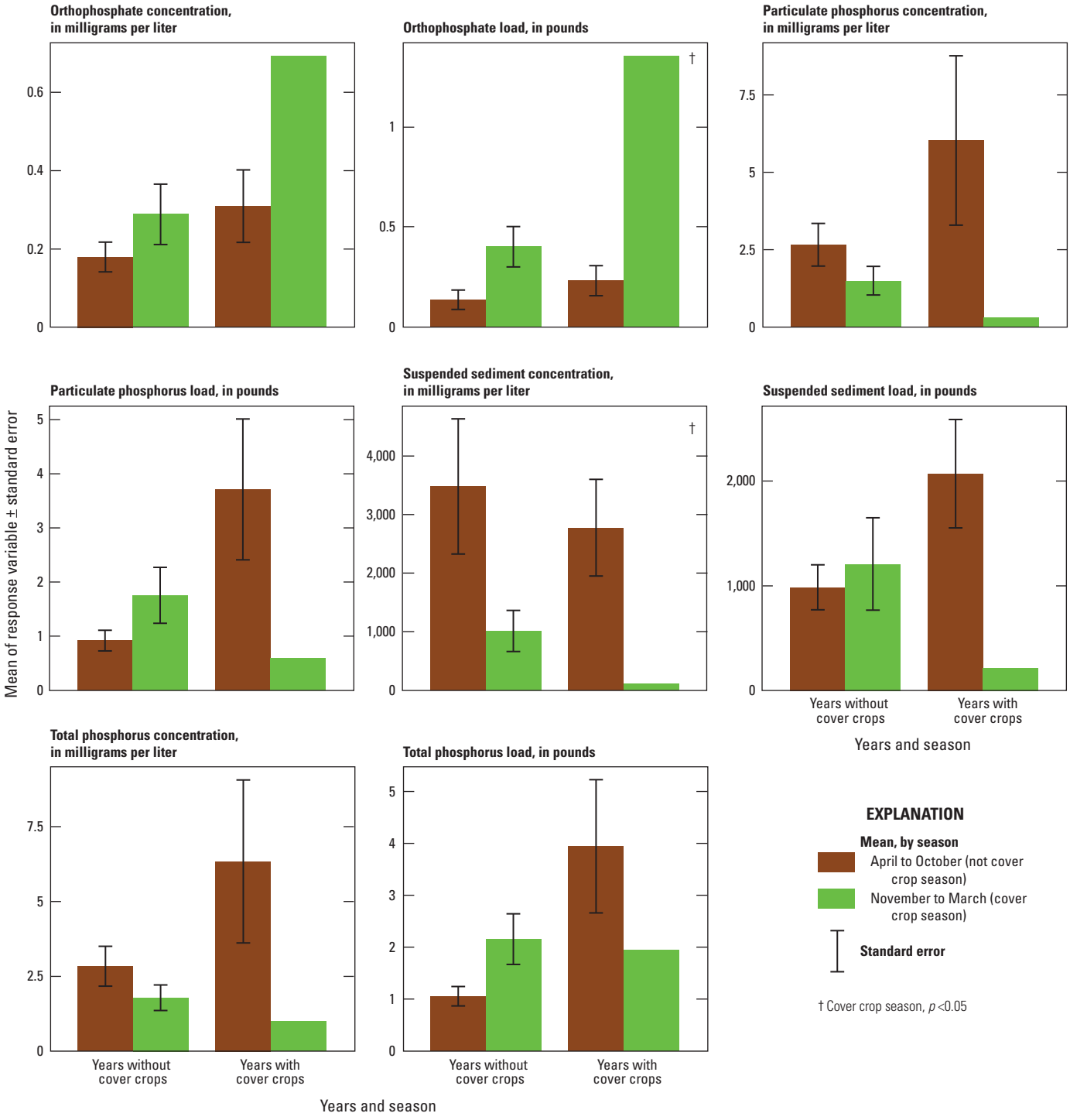


Figure 8. Graphs showing surface runoff means of response variables and the conditions that were significant for events greater than the 85th percentile of peak discharge, by cover crop season and for years with and without cover crops and variable rate technology, Eagle Creek watershed, Ohio, 2012–20. Data from Komiskey and others (2021).

Table 11. Summary of statistical results from two-way analysis of variance tests examining the influence of cover crop year, cover crop season, and the interaction of cover crop year and season on response variables during small surface events (greater than the 85th percentile of peak discharge), including estimates for *F* statistics and associated *p*-values.

[Data from Komiskey and others (2021). Values of significance, $p<0.05$, are bolded and denoted by asterisks (*)]

Response variable	Cover crop year (CC_year)		Cover crop season (CC_season)		Interaction (CC_year and CC_season)	
	F	*p*-value	*F*	*p*-value	*F*	*p*-value
Peak discharge, in cubic feet per second	0.01	0.93	2.85	0.09	0	1
Runoff volume, in cubic feet	1.09	0.3	**28.91***	**<0.001***	0.04	0.85
Orthophosphate, in milligrams per liter	**11.3***	**0.001***	1.47	0.23	0.14	0.71
Particulate phosphorus, in milligrams per liter	**7.63***	**<0.001***	**15.12***	**<0.001***	**15.69***	**<0.001***
Total phosphorus, in milligrams per liter	**17.28***	**<0.001***	**10.96***	**0.001***	**18.73***	**<0.001***
Suspended sediment, in milligrams per liter	**5.6***	**0.02***	**35.91***	**<0.001***	**8.38***	**0.01***
Orthophosphate, in pounds	1.47	0.23	**26.66***	**<0.001***	0.01	0.94
Particulate phosphorus, in pounds	0.89	0.35	3.38	0.07	**5.81***	**0.02***
Total phosphorus, in pounds	1.94	0.17	**7.91***	**0.01***	**4.95***	**0.03***
Suspended sediment, in pounds	1.23	0.27	0.8	0.37	**4.45***	**0.04***

*Value of significance (additionally bolded as a visual aid).

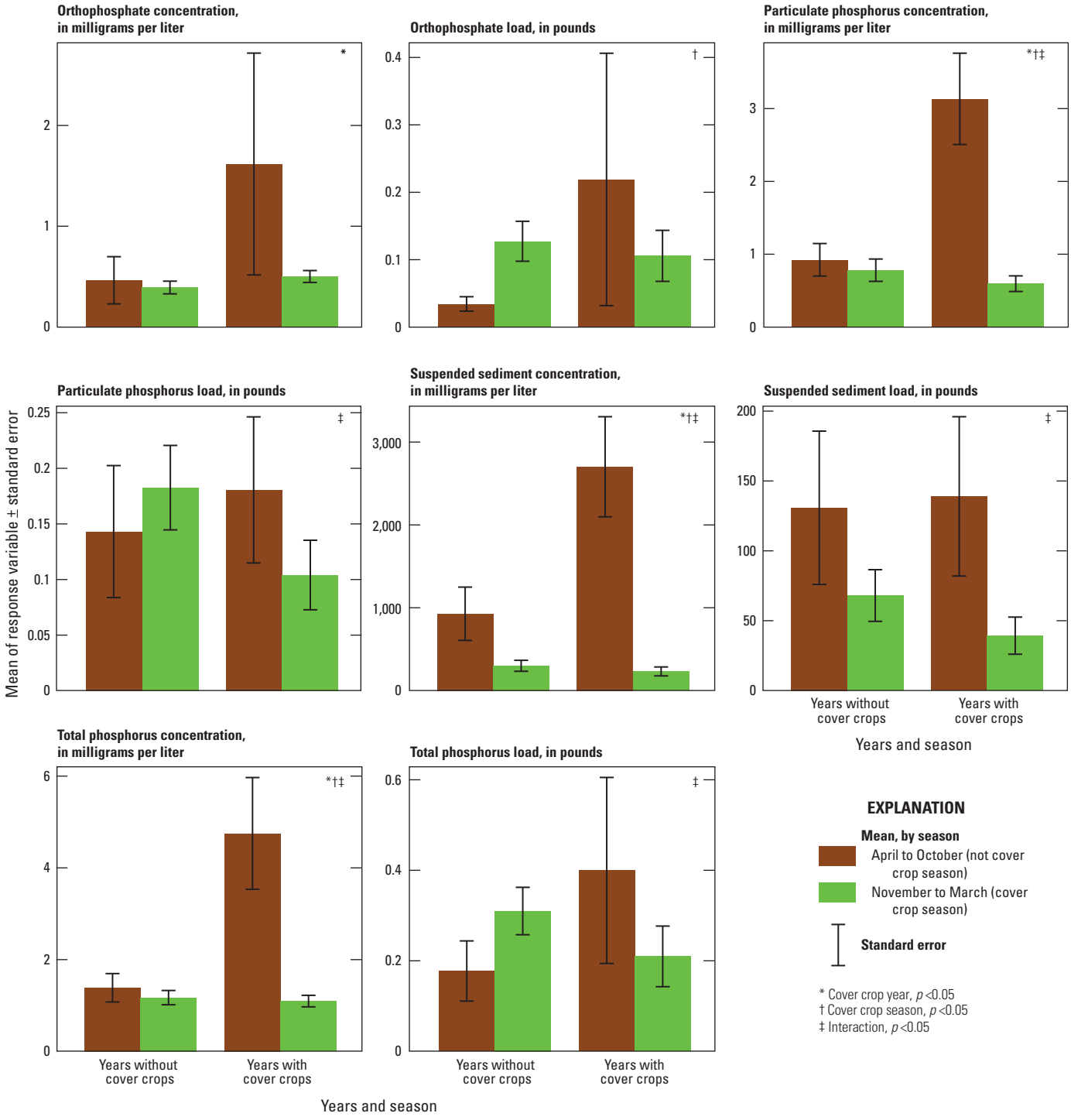


Figure 9. Graphs showing surface runoff means of response variables and the conditions that were significant for events less than the 85th percentile of peak discharge, by cover crop season and for years with and without cover crops and variable rate technology, Eagle Creek watershed, Ohio, 2012–20. Data from Komiskey and others (2021).

Table 12. Summary of statistical results from two-way analysis of variance tests examining the influence of cover crop year, cover crop season, and the interaction of cover crop year and season on response variables during large subsurface tile events (greater than the 85th percentile of peak discharge), including estimates for *F* statistics and associated *p*-values.

[Data from Komiskey and others (2021). Values of significance, $p<0.05$, are bolded and denoted by asterisks (*)]

Response variable	Cover crop year (CC_year)		Cover crop season (CC_season)		Interaction (CC_year and CC_season)	
	F	*p*-value	*F*	*p*-value	*F*	*p*-value
Peak discharge, in cubic feet per second	0.08	0.78	0.01	0.92	0.18	0.68
Runoff volume, in cubic feet	0.20	0.66	0.88	0.35	0.01	0.93
Orthophosphate, in milligrams per liter	1.68	0.20	**10.44***	**0.00***	2.91	0.09
Particulate phosphorus, in milligrams per liter	0.40	0.53	0.10	0.76	0.12	0.73
Total phosphorus, in milligrams per liter	0.17	0.68	1.41	0.24	0.04	0.84
Suspended sediment, in milligrams per liter	0.34	0.56	1.73	0.19	0.60	0.44
Orthophosphate, in pounds	1.48	0.23	**8.64***	**0.00***	1.50	0.23
Particulate phosphorus, in pounds	0.93	0.34	1.02	0.32	0.17	0.68
Total phosphorus, in pounds	0.58	0.45	3.62	0.06	0.02	0.90
Suspended sediment, in pounds	0.72	0.40	0.60	0.44	0.53	0.47

*Value of significance (additionally bolded as a visual aid).

Table 13. Summary of statistical results from two-way analysis of variance tests examining the influence of cover crop year, cover crop season, and the interaction of cover crop year and season on response variables during small subsurface tile events (greater than the 85th percentile of peak discharge), including estimates for *F* statistics and associated *p*-values.

[Data from Komiskey and others (2021). Values of significance, $p<0.05$, are bolded and denoted by asterisks (*)]

Response variable	Cover crop year (CC_year)		Cover crop season (CC_season)		Interaction (CC_year and CC_season)	
	F	*p*-value	*F*	*p*-value	*F*	*p*-value
Peak discharge, in cubic feet per second	2.72	0.10	2.17	0.14	0.09	0.76
Runoff volume, in cubic feet	1.20	0.27	**3.81***	**0.05***	0.05	0.82
Orthophosphate, in milligrams per liter	0.02	0.89	3.10	0.08	3.18	0.08
Particulate phosphorus, in milligrams per liter	0.93	0.34	3.34	0.07	0.10	0.75
Total phosphorus, in milligrams per liter	0.42	0.52	1.91	0.17	1.62	0.20
Suspended sediment, in milligrams per liter	0.35	0.56	**25.32***	**0.00***	1.73	0.19
Orthophosphate, in pounds	0.65	0.42	**6.81***	**0.01***	0.76	0.39
Particulate phosphorus, in pounds	1.97	0.16	0.04	0.84	0.09	0.77
Total phosphorus, in pounds	1.45	0.23	0.23	0.63	0.46	0.50
Suspended sediment, in pounds	0.67	0.42	**9.20***	**0.00***	0.82	0.37

*Value of significance (additionally bolded as a visual aid).

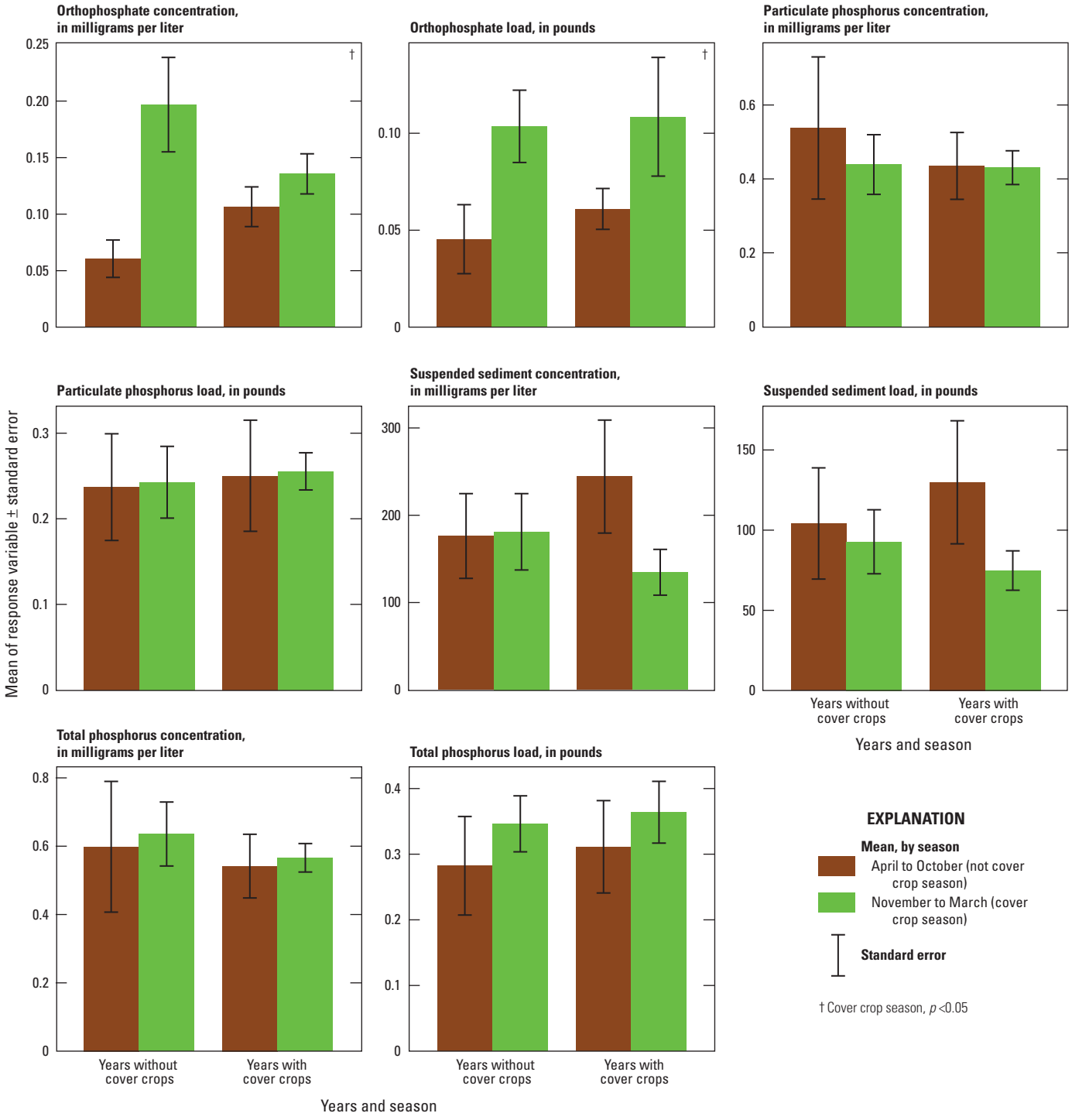


Figure 10. Graphs showing subsurface tile line runoff means of response variables and the conditions that were significant for events greater than the 85th percentile of peak discharge, by cover crop season and for years with and without cover crops and variable rate technology, Eagle Creek watershed, Ohio, 2012–20. Data from Komiskey and others (2021).

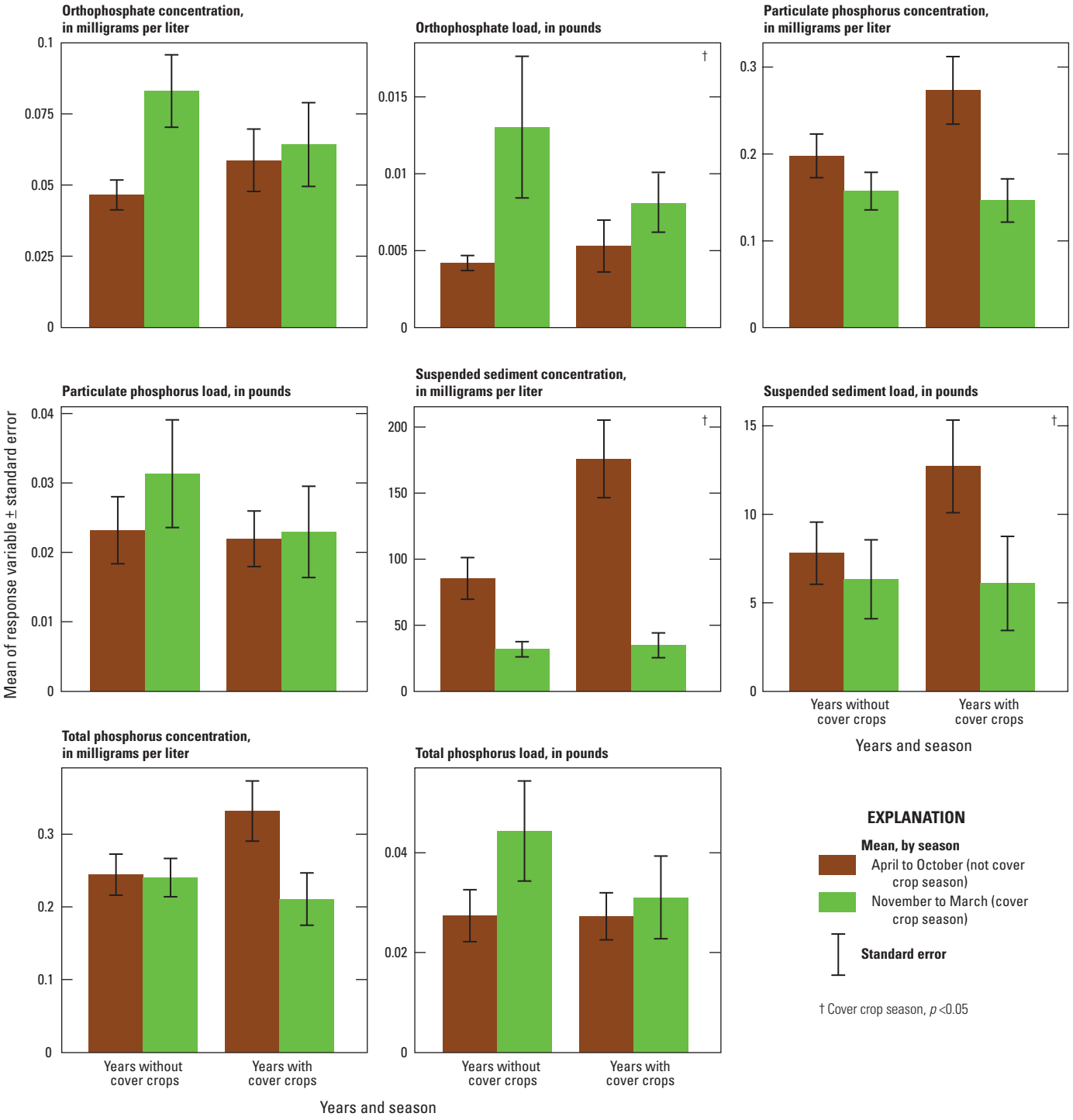


Figure 11. Graphs showing subsurface tile line runoff means of response variables and the conditions that were significant for events less than the 85th percentile of peak discharge, by cover crop season and for years with and without cover crops and variable rate technology, Eagle Creek watershed, Ohio, 2012–20. Data from Komiskey and others (2021).

Summary and Conclusions

This study, conducted by the U.S. Geological Survey in cooperation with the Great Lakes Restoration Initiative and the Natural Resources Conservation Service, was designed to determine the effects of cover crops and variable rate technology (VRT) on sediment and phosphorus loss at a field site in the Eagle Creek watershed near Findlay, Ohio, selected as representative of the Maumee priority watershed. Over the course of the study, from 2012–20, field cultivations, plantings, and fertilizer applications were documented through notes from the producer or from visual observations through a camera network deployed by the U.S. Geological Survey. These activities were viewed independently and evaluated as predictors of field observations. Precipitation and soil conditions were evaluated throughout the study to ensure that observed conditions were not statistically different between the periods with and without cover crops and VRT.

A cover crop was planted in fall of 2016, 2017, and 2018, coinciding with water years 2017, 2018, and 2019, respectively. According to records, the producer followed all Natural Resources Conservation Service guidelines for flying in a common wheat cover crop; however, the cover crop grew to an appreciable height (5 inches) only after fall 2017 seeding (2018 crop year). VRT was applied during the fall, coinciding with the cover crop application(s). VRT was determined by biennial soil testing, and the application of nutrients was based on those soil results. The lack of cover crop growth in water years 2017 and 2019 can be used to evaluate current Natural Resources Conservation Service protocols for northwestern Ohio cover crop applications to determine if they are sufficient for successful establishment before the first frost.

The analysis for this study site focused on the effect of cover crops and VRT applications on sediment and phosphorus loss during large and small events in surface runoff and subsurface tile flow. A threshold of 85 percent of peak discharge was used to divide events into the categories "large" and "small." Surface runoff results indicated no effect of cover crops and VRT on phosphorus or sediment loss during large events. When small surface events were evaluated, the results indicated that particulate phosphorus, total phosphorus, and suspended sediment concentrations and loads were significantly lower in the season with cover crops and VRT (November–March) than in the season without cover crops and VRT during years with cover crops and VRT implementation. When subsurface tile runoff events were evaluated, results for large events indicated no effect by cover crops or VRT implementation, and in the results for small events, suspended sediment loads and concentrations and orthophosphate loads were the only statistically significant different response variables. These results indicated that sediment and phosphorus loss were similar among seasons and years with or without cover crops and VRT.

Analyses indicated that, during the final 3 years of evaluation (water years 2018–20), more than 50 percent of runoff events at the subsurface site exceeded the 85th percentile of peak discharge; 68, 60, and 58 percent of events during these years met this threshold. This pattern indicates that runoff leaving the field via the tile drainage system may have been transmitted more rapidly during the later years of the study than in the early years. Although the specific mechanisms driving this response were not directly evaluated, the study results indicate that, over time, tile drainage at the study site may be exhibiting behavior increasingly like that of surface water, as evidenced by the higher proportion of extreme peak-discharge events observed during the final 3 years than in previous years. Although macropore flow was beyond the scope of this study, future edge-of-field investigations could incorporate assessments of preferential flow pathways to better characterize their influence on tile drainage dynamics.

The correlations observed between peak flow and both suspended sediment and phosphorus-based constituents indicate that additional best management practices targeting peak-flow attenuation may be effective in reducing nutrient and sediment transport. Future research could further explore these relationships to clarify the governing hydrologic and biogeochemical processes and to determine whether management practices, including cover crops, can be optimized to reduce nutrient loading through enhanced attenuation of peak flows or modification of flow pathways.

Conducting edge-of-field evaluations on working agricultural lands presents inherent challenges due to the dynamic and unpredictable nature of farming systems. These studies can be used to quantify the environmental effects of agricultural practices but must account for numerous interacting variables that can influence outcomes. Field conditions and management practices frequently change in response to weather variability, soil moisture conditions, crop development, and operational decisions, all of which can substantially affect runoff generation and transport processes. Careful consideration of these factors can improve the interpretation of results from edge-of-field monitoring studies.

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