# Nutrient Loss in Runoff - Do Cover Crops Make It Better or Worse?

## Annual Report April 2022 – March 2023

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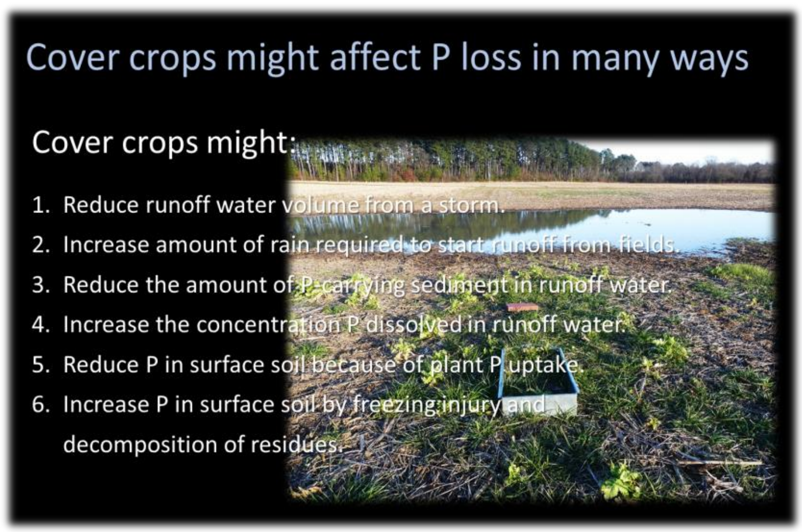


*Figure 1 Mechanisms by which cover crops may increase or decrease the loss of phosphorus in surface runoff. The photo shows a mini-weir used to collect runoff.*

**Background.**

The goal of the proposed research is to provide data on how a range of cover crop practices following both corn and soybean crops impact the loss of phosphorus (P) and nitrogen (N) in surface runoff. Both P and N cause water quality deterioration by eutrophication.

We will investigate several mechanisms by which cover crops could increase or decrease the loss of P, including (Figure 1):

1) Reduce the volume of runoff water from a storm.

2. Increase the amount of rain required to start runoff from fields.

3. Reduce the concentration of P-carrying sediment in runoff water or

4. Increase the concentration of P dissolved in runoff water.

5. Reduce the level of soluble P in the surface soil by taking up available P.

6. Increase the level of soluble P in the surface soil by releasing P from cover crop residues during freeze injury and decomposition.

Most runoff research has been conducted on plowed soils where P attached to sediment is the main pathway of P loss. However, most Maryland farms use some version of no-till soil management which leaves the soil surface undisturbed and mulched with crop residues during the off-season. No-till soil management tends to greatly reduce the amount of soil that erodes and carries away P during intense rain events, but no-till, especially combined with cover cropping, is thought to stratify P near the soil surface, increasing the concentration of P that come into contact with rainwater and can be dissolved in the runoff. Phosphorus in runoff might be reduced by cover crop P uptake but it might be increased by freezing injury that releases soluble P from cover crop tissues. Research has already been published that compares the solubility of phosphorus in live and dead tissues from a wide range of cover crop species. What is lacking, and our research will provide, is data that shows the actual runoff volume and P concentration from single-species or multi-species cover crops in differing soil in a no-till system.

We are generating this data from field plots that represent Maryland's typical long-term no-till crop production with retention of all crop residues and the use of some kind of cover crop during the winter season. The field used to collect runoff from natural rain events has silt loam topsoil with clayey subsoil and somewhat impaired drainage that limits infiltration and favors the production of runoff during heavy rain events. To study runoff from controlled simulated rainfall, this silty field and a field with a similar history but very sandy soils were both used. Both fields have been managed with no-till techniques for most of the years since 1993, with the Maryland nutrient management program since 2000, and have had some kind of cover crop in most years since 2006. The current cover crop treatments were imposed in 2020, so the year covered by this report was the third year of the cover crop treatments. In 2020 a no-cover crop control treatment (**No cover**) was established with only weeds growing between crop harvest in fall and crop planting in spring. This control treatment essentially represents the withdrawal of cover cropping from a system that had cover crops for 15 years, while allowing any winter weeds to grow. The other two cover crop treatments represent the enhancement of the previous system by the extension of the cover crop growing season with earlier planting in fall and later termination in spring. These two cover crop treatments are interseeded several weeks prior to corn or soybean harvest using a high clearance air-seeder with drop tubes that spread the seed on the ground under the senescing crop canopy. The two cover crops treatments intersown were a single-species cover crop of 120 kg/ha of cereal rye seed (**Rye**) and a three-species cover crop mixture (**3-Way**) of 3 kg/ha of forage radish (Rad), 70 kg/ha cereal rye (Rye) and 15 kg/ha crimson clover (Clover).

The project is studying the runoff from both natural and simulated rain events during the cover crop growing season. The runoff from natural rainfall events is captured using mini-erosion weirs that channel the runoff from a 0.3 $m^2$ area into a buried 5-liter jug. Because of the current and historical no-till practices and crop residue cover, the soi is protected from direct raindrop impact and surface sealing. Rather intense rainfall is therefore required to generate any runoff, resulting in sporadic and uneven opportunities to collect runoff from natural rain events. The rainfall simulations can apply water at a controlled rate that is high enough to ensure the production of runoff. Our rain simulations are performed with distilled water in a Cornell sprinkler infiltrometer that provides a controlled drip rate from hundreds of capillary tubes and collects the ponded water through a tube leading to a 1-liter bottle buried downslope that is replaced repeatedly until 5 liters of runoff have been collected.

The project is measuring the effect of the three cover crop treatments (No cover, Rye, and 3-Way) on the amount of runoff generated and the hydraulic properties of the soils as well as the concentrations of the nutrients, nitrogen and phosphorus, in the runoff water.

In late summer 2022 rye or radish-rye-clover cover crops were interseeded into standing corn at senescence and soybeans at first leaf drop. These cover crops were well-established by the time of crop harvest. After harvesting corn in September and soybeans in October 2022 we installed 24 min-erosion weirs (12 in each type of crop residue). The slopes at the weirs ranged from 2.5 to 5.5%. Three weather events in fall 2021, two in October, and one in November caused measurable runoff in our plots, but the

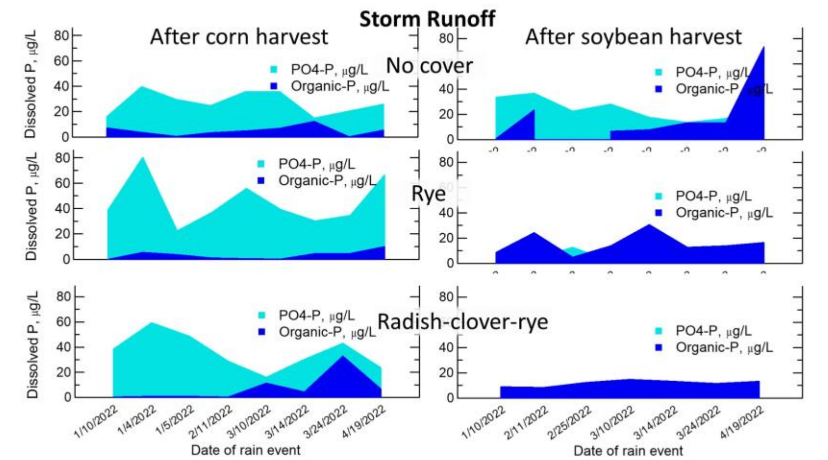


*Figure 2. Dissolved inorganic and organic phosphorus concentrations during the winter-spring of 2022 as affected by the previous cash crop (corn or soybean) and the winter cover crop treatments (No cover, Rye, or 3-Way Radish-clover rye).*

weirs were installed only in the corn plots because of the earlier harvest of that crop. Fourteen runoff events were sampled in January-April 2022 when weirs were installed in both soybean and corn stubble plots. Not every weir gave a runoff sample for every rain event such that a given rainstorm produced runoff in some plots but not in others. This was not surprising as soil hydraulic properties such as infiltration rates are notoriously variable and logarithmically distributed. In preparation for corn and soybean planting in spring 2022, all the weirs and buried jugs were removed from the field at the end of April and the jug burial holes were backfilled with subsoil and topsoil material saved from the original excavation. Much of the spring and summer of 2022 was devoted to analyzing the nutrient concentrations in the runoff samples collected during the previous cover crop growing season.

**Annual Progress.**

Between 01 April 2022 and 30 March 2023, the project made a good deal of progress. Most field activities for this project occur during the fall, winter, and spring when cover crops are in the field. This year's grant began shortly before the time we were removing our metal runoff weirs from the field in preparation for soybean and corn planting in April 2022. Most of our effort since then has been directed toward analyzing the hundreds of runoff water samples that we collected during the winter from October 2021-April 2022, as well as collecting new runoff samples from the winter of 2023.

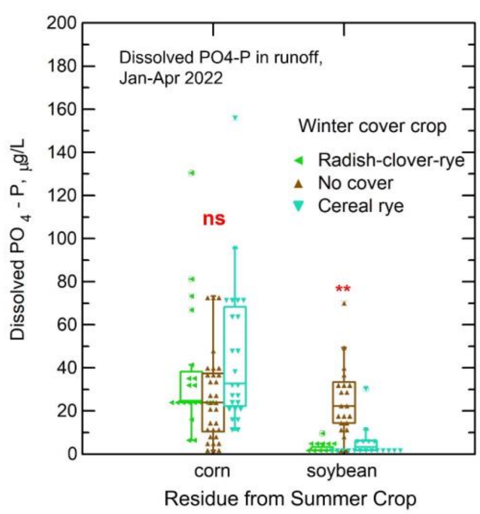


*Figure 3 Dissolved inorganic phosphorus in runoff from natural rain events during winter and spring 2022 as influenced by cover crop treatment (radish-clover rye, no cover, or rye) and the previous crop (corn or soybean).*

The runoff water samples are filtered through a 0.45-micron membrane immediately after collection to separate the dissolved from the particulate constituents. Ammonium-N was determined after filtration using the Endol Blue colorimetric method. Nitrate was determined by the salicylic acid method. An important advance this year is that we are digesting the runoff samples to determine the *total* phosphorous and *total* nitrogen dissolved in them, and not just the inorganic phosphate-P and nitrate-N. This digestion involves "cooking" the samples in a strong alkaline persulfate mixture heated to 120 degrees Celsius under pressure in an autoclave. Total dissolved N and total dissolved P was determined as nitrate and phosphate following alkaline persulfate digestion at 120 $^{o}$C for 30 minutes in an autoclave. Generally, the difference between the total nitrogen or total phosphorus measured after digestion and the inorganic nitrate-N plus ammonium-N or phosphate-P measured before digestion is considered to represent the organic nitrogen or phosphorus:

Total P – Inorganic Phosphate P = Organic P

Total N – (Ammonium + Nitrate N) = Organic N

The results of analyzing several hundred samples collected during the winter show that organic forms represent an important portion of the phosphorus dissolved in runoff water (Figure 2). The proportion of dissolved P in organic forms tended to increase with time during the winter and spring and was considerably higher in plots with soybean residues compared to plots with corn residues. The cover crop treatments did not significantly affect the total dissolved P or the proportion of that in organic forms. However, a more detailed look at just the dissolved inorganic phosphate-P (Figure 3) revealed that, compared to the no cover control, the cover crops suppressed the concentration of dissolved inorganic P in runoff following soybean while having no effect on dissolved inorganic P following corn.

The concentrations of inorganic and organic nitrogen in runoff collected during the winter and spring of 2022 are shown in Figure 4. The total dissolved N concentrations in the runoff tended to average between 4 and 12 mg/L. Unlike for phosphorous, nitrogen concentrations tended to be highest early in the winter and dropped off toward spring. The type of crop residue present had no significant effect on nitrogen in the runoff, except those plots following soybeans and without a cover crop had significantly higher nitrate-N concentrations than where either of the cover crops was growing (Figure 4, upper right panel). Like phosphorus, the majority of dissolved nitrogen in the runoff was in organic forms.

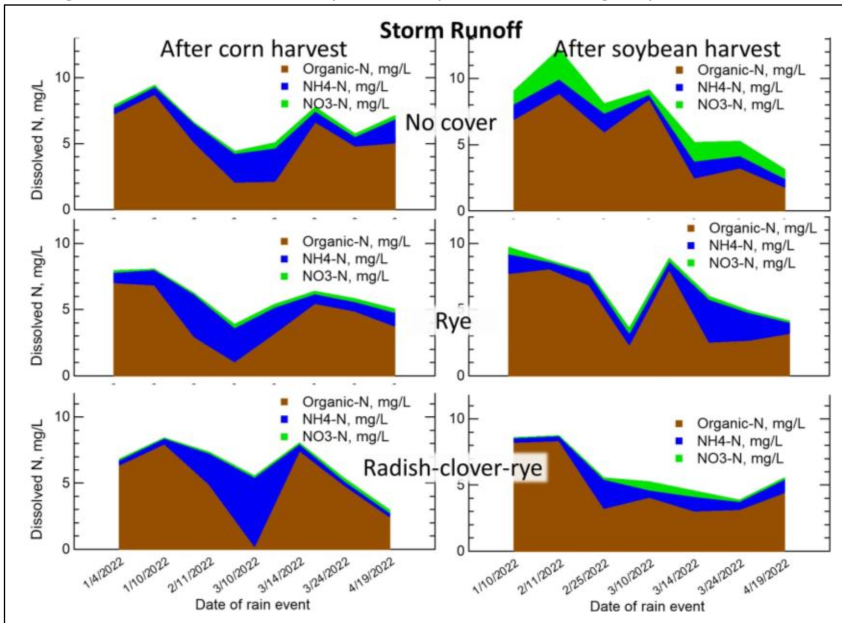


*Figure 4 Dissolved inorganic (nitrate and ammonium) and organic nitrogen concentrations during the winter-spring of 2022 as affected by the previous cash crop (corn or soybean) and the winter cover crop treatments (No cover, Rye, or 3-Way Radish-clover rye).*

Figure 5 shows the percentage of the dissolved nitrogen that occurred in the nitrate, ammonium, and organic forms as influenced by the previous crop (type of crop residue present) and the cover crop treatment. In this relatively low-nitrogen cropland environment without any history of animal manure

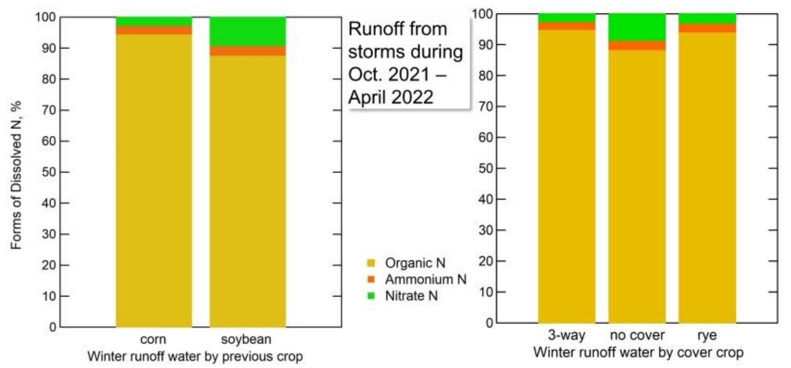


*Figure 5 The percent of total dissolved runoff nitrogen in the forms of nitrate, ammonium, and organic compounds as influenced by previous crop (left panel) and cover crop treatment (right panel).*

application, mineral nitrogen concentrations were low (generally <3 mg/L) and most of the total dissolved nitrogen was in organic forms, regardless of residue or cover crop treatment. In a heavily manured field, one might expect to find higher concentrations of nitrogen, especially inorganic nitrogen forms, in the runoff. Nonetheless, there were significant treatment effects on the nitrate-N concentrations. Plots with soybean residue had more nitrate in the runoff than plots with corn residue (left panel, Figure 5). This would be expected because the higher N soybean residue is less likely to promote microbial immobilization of soluble N. Also, plots with no cover crop had higher nitrate-N, regardless of residue type (right panel, Figure 5), probably as a result of the cover crop uptake reducing the remaining amount of soluble N susceptible to dissolving in runoff water.

These results suggest that measuring only the inorganic nitrate and phosphate in runoff samples is insufficient to understand the nutrient losses by this pathway.

**Results from Simulated Rain Studies.**

*Figure 6 A Cornell Sprinkler Infiltrometer being lowered down to begin simulated rain inside a 24.1 cm I.D. metal ring installed 7.5 cm into the soil.*

During the winter of 2022-2023, we utilized the Cornell sprinkler infiltrometer to generate simulated rainfall and runoff. With this winter being abnormally dry, few events generated natural runoff. Therefore, this simulated rain method which ensures runoff production has been very useful to evaluate the impact of 3 years of enhanced cover crop management on the potential for soils to absorb heavy rainfall and lose nutrients in runoff.

The Cornell sprinkler infiltrometer is a mini rainfall simulator that produces a controlled rain of specified drop size and drip rate. It generates runoff within a confined area defined by a metal ring inserted into the soil and channels it through an outflow hose where the runoff can be measured and collected. Figure 1 shows the sprinkler infiltrometer in use, with the sprinkler being lowered onto the metal ring which has been installed into the soil at a specified depth.

The normal use of this instrument is to measure infiltration rate in soils by determining the volume of runoff collected at set time intervals during a 1-hour simulated rain event. We modified this protocol so that we could collect samples for nutrient and sediment analysis. Instead of sampling at even time intervals, we sampled at even runoff volume intervals. After collecting each 1 L of runoff in a clean bottle, we recorded the time and placed a new clean bottle in the collecting position. For each plot's rainfall simulation, we collected five 1 L bottles of runoff water. The exact volume in each sample bottle was later determined in the lab by weight. To be able to measure any soil nitrogen or phosphorus lost in the runoff, we used highly purified distilled/deionized water for the "rain." The rainfall rate was set for 6 mm/min at field 7E (silty clay) and 7 mm/min. at field 39a (loamy sand). The rain was applied for as long as it took to collect 66-67 mm of runoff (five 1-liter bottles), the rain events generally lasted about 30 minutes but ranged from 15 to 85 minutes (see Figure 7 (a, b).

As can be seen in Figure 7, the initial infiltration rate was very high but declined quickly as the soil became saturated. Generally, within less than half an hour infiltration and runoff reached a steady state that reflected the saturated hydraulic conductivity of the soil. Despite infiltration being one of the most spatially variable soil properties, our simulated rainfalls were consistent enough that we were able to easily detect a significant difference between the two soils on which the simulations were conducted, and in some cases, we detected significant differences among cover crop treatments or between crop residue types.

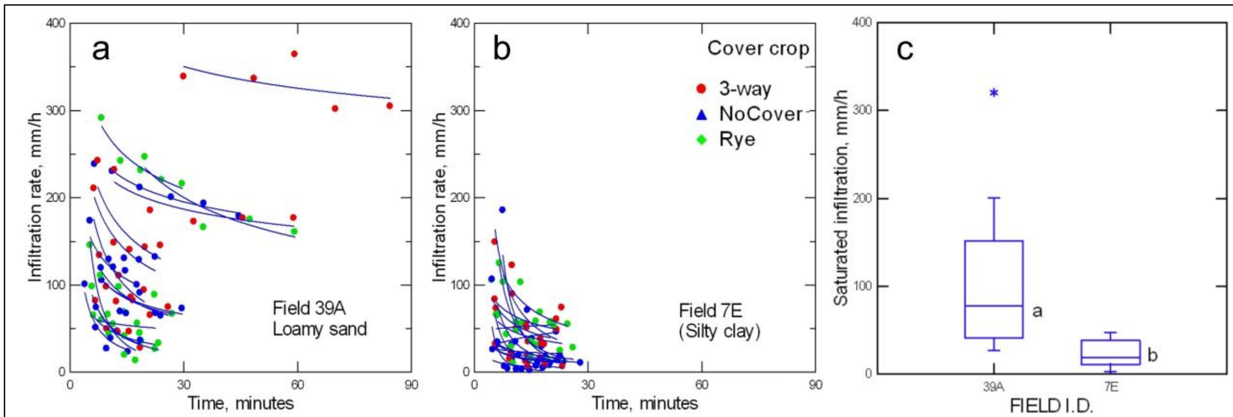


*Figure 7. Infiltration rates for the first five 1-liter increments of runoff in three cover crop treatments during 6-7 mm/h simulated rain events that applied approximately 15 cm of deionized water "rain" in each event.*

The time and volume data allow the calculation of several important soil hydrologic parameters, including:

- time from the start of the rain to the first runoff
- infiltration rate for each increment of runoff
- saturated hydraulic conductivity
- runoff rate
- soil sorptivity
- cumulative sediment loss or erosion rate

During December 2022 through April 2023, we conducted simulated rain on 18 plots in the silty clay field (7E) and on 18 plots in the sandy field (39a) at the Central Maryland Research and Education Center Beltsville facility. The silty clay field (7e) is the same field where we collected runoff from natural rain events whenever it occurs. However, very little natural runoff was generated during the 2022-2023 winter because rainfall was far below normal. The site received only 16 cm of the normal 35 cm of precipitation between 01 January and 16 April 2023 when we removed the runoff weirs in preparation for crop planting.

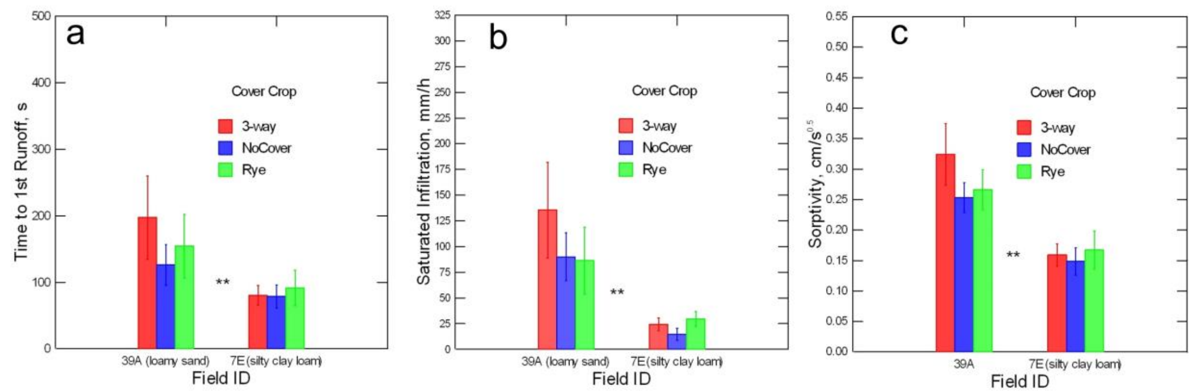


*Figure 8. Time to first runoff, saturated infiltration rate, and soil sorptivity were measured with the Cornell sprinkler infiltrometer on three replications of each treatment in each field (36 runs in total). Field 7e (silty clay) was measured in Dec-Feb, while Field 39a (sandy) was measured in March and April when the cover crops were more actively growing.*

Once the runoff water was collected from a rainfall event, the sample was chilled in a cooler, brought to the lab, and a known volume vacuum filtered through a 0.45-micron filter membrane to remove any suspended particles. The filtrate was frozen for later analysis of dissolved nitrogen and phosphorus. The filter membrane itself was dried and weighed before and after the filtering process to determine the mass of suspended sediment. The sediment collected on the filter membrane was saved for later digestion and determination of its associated nitrogen and phosphorus.

The chemical analyses of the simulated rain runoff samples have yet to be done, but the hydraulic parameters and total mass of sediment have been measured. Figure 3 shows that the type of crop residue (corn or soybean) significantly influenced two important hydrologic parameters. The plots are in a corn-soybean rotation, so the crop residue type indicated in the graphs is the residue from the fall 2022 harvest. Time to first runoff, saturated infiltration rate, and soil sorptivity were determined from measurements made with the Cornell sprinkler infiltrometer on three replications of each crop residue x cover crop treatment combination in each of the two fields (36 runs in total). Field 7e (silty clay) was measured in Dec-Feb, while Field 39a (sandy) was measured in March and April when the cover crops were more actively growing. Due to later than the ideal establishment in fall, cover crop growth before winter dormancy this year was considerably less than in previous years. This is typical of many places in Maryland where conditions for early planting of cover crops were not favorable in the Fall of 2022. The cover crops this year were quite small, covering only 15 to 20% of the ground, during the December through February period when simulated rain runoff was measured on the silty clay field. Once the soil began to warm in late March cover crops greened up and began to grow again. Therefore, the highly

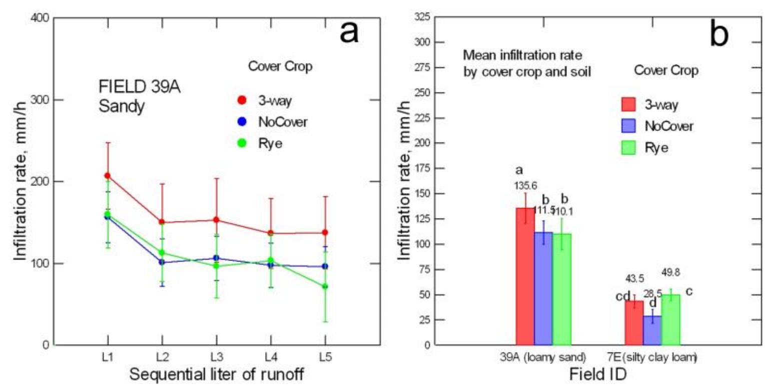


*Figure 9. Infiltration data for each increment of runoff in simulated rain events using the Cornell Sprinkler Infiltrometer on the sandy field. Data shown are means for 3 replications and 2 crop residue types (corn and soy stubble).*

significant differences between the two fields in all parameters shown in Figure 7c and Figure 8 are probably only partly a reflection of the difference in the soil types and possibly also partly due to the difference in the amount of cover crop biomass present during the measurement period for each field. Though not significant at the 95% confidence level for the mean parameters calculated (Figure 8), the 3-Way mix cover crop tended to have a higher saturated infiltration rate and sorptivity on the sandy soil.

Infiltration data for each increment of runoff in simulated rain events using the Cornell Sprinkler Infiltrometer on the sandy field are presented in Figure 9. Data shown are means for 3 replications and 2 crop residue types (corn and soy stubble). When the infiltration rates calculated for each increment of runoff are considered, the effect of the 3-Way cover crop treatment is more apparent, and the infiltration rates are significantly greater under the 3-Way than under either Rye or No cover treatments. Nonetheless, we can conclude that given the long-term no-till managed soil and mulch of decaying residues in all treatments, the effects of the current cover crops on runoff and infiltration rates crop were small and difficult to detect.

*Figure 10. Collection and filtration of runoff to determine runoff volumes and sediment load. (Left) Bottles are used to collect the first five 1-liter increments of runoff. (Center) Vacuum filtration apparatus with ground glass and a 0.45-micron filter membrane is used to separate the runoff solution from the sediment. (Right) These filter membranes with varying amounts of sediment will be dried and weighed to determine the sediment load carried by each liter of runoff.*

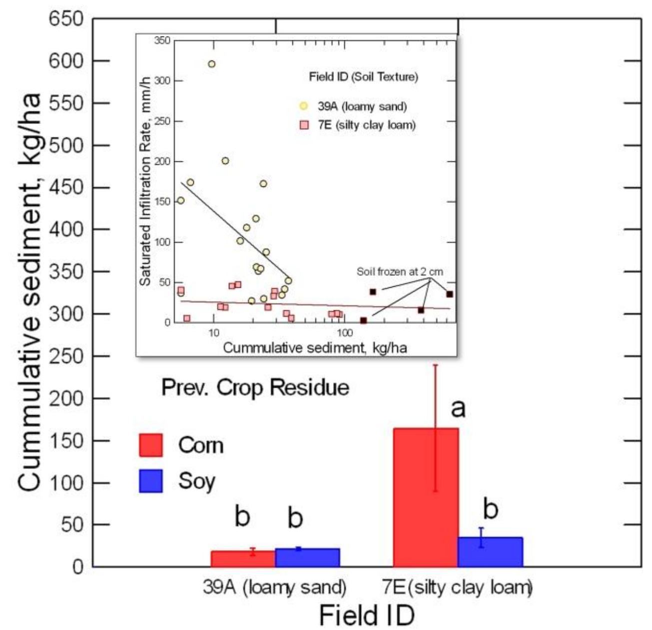


*Figure 11 The effect of crop residue type on the total cumulative sediment load carried by runoff during simulated rain events on two fields with soils of contrasting texture. The inset shows using a log scale several unusually high sediment measurements due to the presence of frozen soil.*

The 0.45-micron filter membranes used to separate the dissolved from the particulate fractions of each runoff sample were dried in an oven and weighed to determine the sediment carried by each 1-liter increment of runoff. The sediment determined for five 1-liter increments was summed to give a total cumulative sediment load for the entire simulated rain event. Total cumulative sediment loss was very low from these plots which were well armored with both crop residue and cover crop growth. The only exception was one date in December 2022 when we ran the rainfall simulations two days after a cold snap when temperatures remained below freezing for 5 days in a row. While doing the rain simulations on that date, we found that the soil was still frozen at a depth of about 2 cm. This resulted in significantly greater sediment loss and slower infiltration (Figure 11, inset) for all treatments on that date. Nevertheless, the sediment loss was significantly greater across the board on the corn residue plots than on the soybean residue plots, when all the data for field &E was analyzed, including measurements of four other dates without frozen soil. As with the nutrient concentrations in natural runoff discussed above, the type of crop residue sometimes had a greater effect on environmental impacts than did the presence of a particular cover crop treatment.

**Conclusions.**

Detecting the effects of cover crops, positive or negative, on runoff volumes and nutrient concentrations was difficult because we were interested in the long-term, no-till cropping situations managed under conservative nutrient management plans as is typical of farming in Maryland. The differences between two soils of contrasting textures, on the other hand, were obvious and highly significant, especially with regard to the rates of infiltration and runoff. Somewhat surprisingly, in a corn-soybean rotation, the previous crop going into the winter had a greater effect on some runoff and nutrient loss parameters than did the presence of a cover crop. Generally, in the systems studied, the nutrient concentrations in the runoff were quite moderate, and dissolved N and P were both present mainly in the rarely measured organic forms.

During the remaining year of this project, we will plan to analyze both inorganic and organic forms of the dissolved nitrogen and phosphorus associated with the runoff from the natural and simulated rain events sampled in the winter-spring of 2023, and assess the long-term impact of enhanced cover cropping on nutrient loss potential.