Phosphorus runoff from no-till soils - do cover crops make it better or worse?

FINAL REPORT FOR APRIL 2020 TO MARCH 2021 RESEARCH

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Background

While cover crops can provide many benefits to the farmer, the Maryland cover crop program is primarily focused on the reduction of nitrogen (N) loading to the Chesapeake Bay. The main pathway for nitrogen losses from farm fields is via groundwater contaminated with soluble nitrogen by leaching. Research, including our work sponsored by the Maryland Soybean Board, have clearly shown that cover crops can be very effective in reducing such nitrogen leaching and that their effectiveness is dependent on early cover crop establishment in fall.

Water quality troubles in the Chesapeake Bay are related to both nitrogen and phosphorus (P), but much less is known about the impacts of cover crops on phosphorus losses than on nitrogen losses. The main pathway for phosphorus transport from croplands to bodies of water is via surface runoff during intense rainstorms or heavy snowmelt. A secondary pathway in areas of poorly drained sandy soils is the leaching of phosphorus to drainage ditches. There is little research on how cover crops impact phosphorus losses. Some studies suggest that cover crops might increase soluble phosphorus at the soil surface where it would be susceptible to becoming dissolved in runoff water.

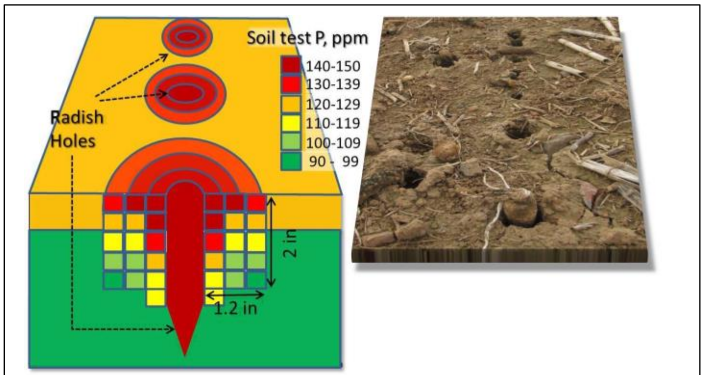

Figure 1 Concentration of soil test P near soil surface and radish root holes in spring after winter-killed forage radish cover crop. White and Weil, 2011.

In fact, cover crops can be an important tool for increasing P availability and crop yields in the phosphorus-deficient soils found in many parts of the world where there has been little application of P (Hallama et al., 2019). Cover crop mechanisms that cycle P and make soil P more soluble and plant–available may also allow high productivity on Maryland farms with lower levels P fertilization. This could be part of a long-term strategy to make farming more sustainable both economically and environmentally. The goal of the proposed research is to provide data on how selected cover crop practices impact the loss of phosphorus by surface runoff. Cover crops can affect the loss of phosphorus by several, somewhat contradictory, mechanisms. Cover crops might:

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 amount of P-carrying sediment lost in runoff water.
4. Increase the concentration P dissolved in surface soil and runoff water by P cycling.

5. Reduce phosphorus in surface soil and runoff water because of plant P uptake.
6. Release of soluble phosphorus from cover crop tissues during frost injury.

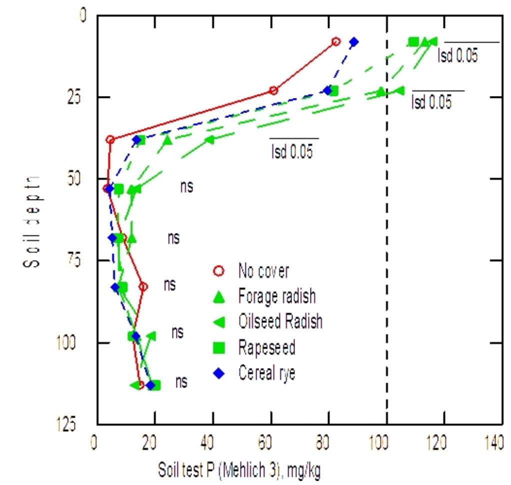

Figure 2 Soil test P stratification in no-till silt loam soil at Wye REC as amplified by three years of cover cropping. Grove, et al., 2007.

Research has already been published that compares the solubility of phosphorus in live and dead tissues from a wide range of cover crop species (Cober et al., 2018; Miller et al., 1994). Winter-killed brassica cover crops have been shown (Figure 1) to concentrate soil test extractable P at the soil surface in spring (White and Weil, 2011). Other cover crops, such as cereal rye, also have been shown to increase soil test P near the soil surface (Figure 2) in the absence of P applications, if to a lesser extent than brassicas (Grove et al., 2007).

A few studies around the world have investigated cover crop effects of P runoff, but we found none in Maryland and none using multi-species cover crops. A perennial forage vegetative cover during winter in Manitoba, Canada, resulted in more than double the soluble P and total P loads in runoff from snowmelt as compared to dead annual crop residue cover (Liu et al., 2014). The increase was attributed to P dissolving out of the frost-injured green plant tissue. A study on soybeans in Missouri (Zhu et al., 1989) reported that runoff volume from erosion plots was reduced by 44 to 53% by the presence of three grass cover crops, but soluble P concentration in the runoff was increased by 161 to 286%, resulting in less runoff water but more soluble P loading from the cover cropped plots. A recent study (Korucu et al., 2018) in Iowa (on a no-till Mollisols) reported that a rye cover crop, despite having only modest biomass and being planted up- and down-slope, reduced both runoff volume and P concentration in the runoff from a 65 mm simulated rain. The runoff was 27 mm with bare soil between corn stover and only 9.5 mm with a cereal rye cover crop. The total dissolved P concentration in the runoff water was reduced from 21 mg/L to 9.3 mg/L, thus reducing the total soluble P loss from almost 6 to less than 1 kg P/ha. These values should be viewed in the context of the 0.05 mg/L dissolved P environmental limit for streams flowing onto lakes. A study in Kansas (Carver et al., 2018) comparing no-till soils (again, Mollisols) with and without the use of winter cover crops showed that cover crop dramatically reduced the loss of sediment-bound P, but increased the amount of dissolved P lost. The net effect was significantly reduced total P loss during the cover crop fall-spring growth period, but an increased loss of total P in runoff that occurred during the cash crop growing season after cover crop termination.

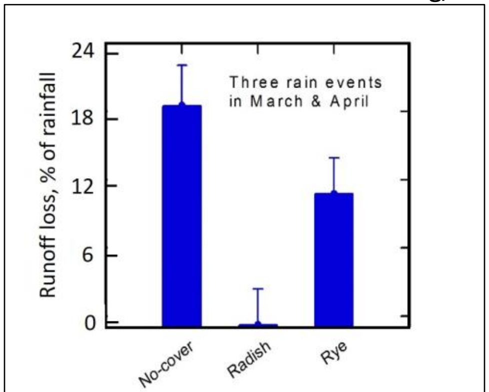

Figure 3 Cover crop effects on runoff volume from three rainfall events in early spring on a farm in central Maryland with conventionally tilled silt loam soil (Weil, unpublished)

Preliminary studies done by the PI some years ago, suggest that even though they released P when they winterkill, radish cover crops leave large root holes after they die that may effectively reduce runoff from moderate storms more than other cover crops (Figure 3).

Circumstantial evidence suggests that increased adoption of conservation tillage in Ohio may have increased soluble reactive P runoff loads in the Sandusky River (compared to the Maumee or Raisin Rivers) during 1998-2014 (Jarvie et al., 2017). Results from simulated rain runoff in an Indiana study suggest that cover crops did not decrease or increase soluble P loading (Smith et al., 2017). However, the project in Indiana also showed (Table 1) that incorporation P sources, such as knifed-in or surface dribbled liquid polyphosphate fertilizer, may pose a lower risk of P loss to surface water than surface applied, especially dry fertilizers (Smith et al., 2016).

From a P management perspective, different site indices and fate-and-transport models used in various parts of North America to assess risks of P loss to water have had only limited success in dealing with manure and P fertilizer, let alone cover crop effects (Kleinman et al., 2017). Our research will help provide data on how runoff volume and P concentration from individual rainstorms are affected single species or multi-species cover crops under Maryland soil and climatic conditions. Our research generate this data from research plots and farm fields using simulated and natural rain events during the cover crop season (October-May). In the future, we plan to also make some measurements during the summer season.

Table 1 Phosphorus loss in runoff from a simulated rainfall event in Indiana as influenced by P source material and method of application (surface or incorporated). Smith et al. 2016.

Fertilizer source	Placement	P Rate kg ha^{-1}	Soluble P load mg	P loss relative to applied %
Monoammonium phosphate	Surface	112	89.3 a	17.4 a
Diammonium phosphate	Surface	127	84.6 a	16.5 a
Triple super phosphate	Surface	127	97.3 a	19.0 a
Polyammonium phosphate liquid	Surface	172	**2.1 d**	0.17 d
Single super phosphate	Surface	324	66.8 b	13.0 b
Bone meal	Surface	417	8.6 d	1.45 d
Rock phosphate	Surface	1945	3.0 d	0.37 d
Poultry litter	Surface	1459	25.5 c	4.80 c
Unfertilized control	–	–	**1.2 d**	–
Monoammonium phosphate	Banded	112	**1.8 d**	**0.13 d**
Polyphosphate liquid knifed-in	Banded	172	**1.5 d**	**0.12 d**
Poultry Litter	Banded	1459	**4.0 d**	**0.57 d**

Research objectives:

1. Determine the effect of individual species and mixed cover crop on:
    a. The runoff volume generated as a percent of rainfall.
    b. The time and rain volume required to cause runoff to begin.
    c. The concentration of total and dissolved phosphorus in runoff water.
    d. The total P load lost to runoff during a single storm and all storms in a whole season.
2. Determine the effect of early interseeding establishment of multispecies cover crop on runoff volume and P content, as compared to cover crop drilled after crop harvest and no cover crop.
3. Compare the effect of multispecies cover crop on runoff at different times of the year:

Research approach:

We have used two main tools to measure cover crop impacts on phosphorus runoff from no-till fields. The two tools are shown in Figure 4, namely the portable Cornell rainfall simulator and the semi permanently installed mini runoff weir. Both are small-scale instruments that measure runoff as affected by field conditions. The runoff weirs are installed in non-wheel tracked areas of representative cover crop growth after the cover crop emerges since research (Kaspar et al., 2001) has shown that compaction due to wheel traffic can have a greater effect on runoff than cover crops. The big advantage of such small-scale measurements is that they can be replicated on a number of sites and treatments. The disadvantage is that they represent only the crop-soil conditions and not the whole field watershed properties. The cost to instrument a whole field water for runoff is prohibitive for this program (>$20,000 for a single watershed treatment with flumes and ISCO samplers). We plan to bridge this gap in the second year of the study by installing replicated mini-weirs within one or two large, established instrumented watersheds such as those at the Wye Research and Education Center (Staver and Brinsfield, 2001) so that results can be compared and correlated for several storms with regard to P concentrations and volumes of runoff.

Figure 4 (Left) A Cornell Rainfall Simulator set up to measure infiltration and runoff and collect runoff samples. (Right). A mini-erosion weir installed in a 3-species cover crop that was interseeded into no-till soybean before harvest. The weir collects runoff from natural rain events on a 0.31 m^2 area. The tube on the left carries the runoff and sediment to a 2-gallon buried jug located 1 m downslope from the weir. An initial set of nine of these weirs were installed in October 2018 in anticipation of this project.

The Cornell rainfall simulator can be moved from plot to plot and is not permanently installed in the field. It does not depend on natural rainfall events but provides its own simulated rain at a set intensity using deionized water. This apparatus was developed at Cornell University and involves about 100 small tubes that provide droplets that simulate the impact of rainfall at a controlled rate. All of the rain is confined so that the runoff has to leave the soil surface through a tube that leads to a collection bottle at a lower elevation. Using a constant rainfall rate, the simulator can determine hydrologic parameters such as time after rain initiation when runoff begins and soil infiltration capacity. It also allows for the collection of the runoff water to measure its volume and analyze its contents.

The PI’s lab currently has three of these Cornell rainfall simulators, two of them purchased with current MSB funds from this project. They can be most efficiently used two at a time in tandem. The rainfall simulators will be used where 1) a large number of treatments are involved, 2) metal weirs would interfere with farm operations, and/or 3) where the travel time to sample after each natural rain event is prohibitive.

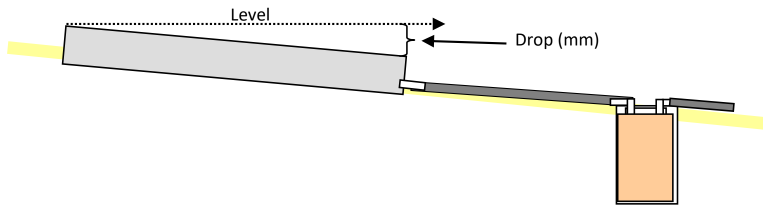

Figure 6. Schematic of erosion weir installation. The field site must have a slope greater than 5% for this apparatus to work effectively. The collection jug is sized (8 L) to collect all the runoff anticipated from a 5 cm (2 inch) storm. Additional collection jugs can be added in series.

The mini erosion weirs are 75 cm long and 40 cm wide. They are installed facing downslope, 5 cm below the ground with 10 cm above the ground. They are designed to collect the runoff from a 0.33 m^2 area. They were installed immediately after the last cover crop planting for an experiment in the fall, generally in October and left in the ground until spring planting in late April or early May. In some cases, they may be removed and reinstalled after planting to measure runoff from early-season (May-June) storms when the summer crop has not created a full canopy and the cover crop residue still plays an important role. A set of 12 of these weirs was used successfully to collect preliminary runoff data from three rainstorms during an earlier spring period (see Figure 3). The PI currently has 16 of these mini erosion weirs installed in cover crop treatment plots in anticipation of continuation of this project (Figure 14).

Figure 5. Runoff and erosion weirs were installed in soybean before harvest. The combine header was lifted to avoid damaging the weirs during harvest. Plot in right from is a no-cover control. Plot in rear-left was interseeded with a cover crop. Photo taken 5 December 2020.

<u>Analysis of samples.</u>

Runoff water samples from both types of apparatus will be analyzed for the following parameters.

1. The volume of runoff expressed as millimeters (or inches) as well as percent of rainfall.
2. The amount of sediment in the runoff expressed as grams per square meter or pounds per acre.

3. The concentration of nitrogen (nitrate and ammonium) expressed as ppm or mg per liter
4. The concentration of total phosphorus as ppm or mg per liter
5. The concentration of dissolved reactive phosphorus as mg per liter
6. The concentration of dissolved organic phosphorus as mg per liter

Prior to the determination of dissolved phosphorus the runoff water, samples were vacuum-filtered through a 0.45 micron polycarbonate membrane. Organic phosphorus is to be determined as the difference in dissolved reactive phosphorus before and after persulfate digestion (Johnes and Heathwaite, 1992). All phosphorus and nitrogen analyses were run on a Lachat flow autoanalyzer using an ortho-phosphate manifold and a modification of the ascorbic acid method (Watanabe and Olsen, 1965). The runoff and sediment samples are currently being prepared and digested for total and dissolved organic P determination. Loading of the various forms of phosphorus can be calculated as P concentration x runoff volume and expressed as mg/m^2 or pounds/acre.

Results are reported for individual rainfall events great enough to generate runoff. For the experiments with mini erosion weirs installed, we also calculate the cumulative total phosphorus loss for the season.

Cover crop treatments in 2020-2021.

The cover crop treatments that were tested for impact on P in runoff from no-till fields were as follows:

1. Cereal Rye
2. 3-species mix (Radish + Rye + Crimson Clover)
3. No cover control

The monitored sites were on coastal plain soils (one silt loam underlain by silty clay loam, the other a loamy sand underlain by sandy loam) at the CMREC facility at Beltsville Maryland. The slope of the land where runoff was collected varied from 5 to 6% in the 2020-2021 plots. However, two commercial fields with medium to high phosphorus risk soils (average soil phosphorus Fertility Index Value of 200-300) on the lower Eastern Shore will also be investigated using the portable Cornell rainfall simulator in 2021-2022, which can be done on land with very little slope.

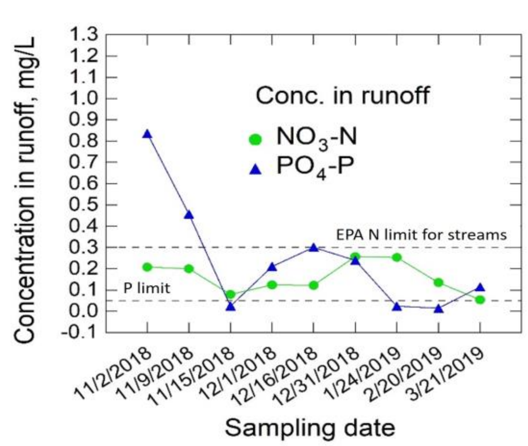

Figure 7. Concentrations of nitrate-N and phosphate-P dissolved in runoff water from cover crop plots in winter 2018-2019. Means of 3 reps and 3 cover crop treatments on sandy soil following no-till soybeans at Beltsville, MD. USEPA N and P limits from (Litke, 1999; USEPA, 2002). Data of Weil, unpublished.

Results from 2018-2019 season:

In the first year of this project, we established cover crop plots in a full-season soybean field and installed 9 runoff weirs. The cover crop treatments were 1) no cover control, 2) 3-way mix interseeded into soybeans at leaf drop, and 3) 3-way mix drilled after soybean harvest. Figure 9 shows a typical runoff weir in the interseeded treatment. The slope ranged from 6 to 9% and the soil had a loamy sand surface texture. The field had a history of no-till corn-soybean rotation. Between 4 November 2018 and 23 March 2019 nine rainfall events produced runoff. Except for the first two events, the nitrate-N concentrations in the runoff were below the USEPA

0.3 mg/L limit for stream water. However, the dissolved phosphate –P tended to be slightly above the 0.05 USEPA limit for total dissolved P in stream water (Figure 7).

The cover crop treatments did not have a significant effect on N and P concentrations in the runoff water. However, they did affect the amount of runoff water and therefore the amount of P lost per unit area of land. Figure 8 shows the cumulative runoff volume, soil loss, and phosphate –P loss for the entire cover crop season. The interseeded cover crop treatment had the least soil loss and the drilled cover crop treatment had the greatest runoff volume and P losses. We ascribe these greater losses to the smaller cover crop growth due to later planting combined with the soil residue cover disturbance by the no-till drilling operation.

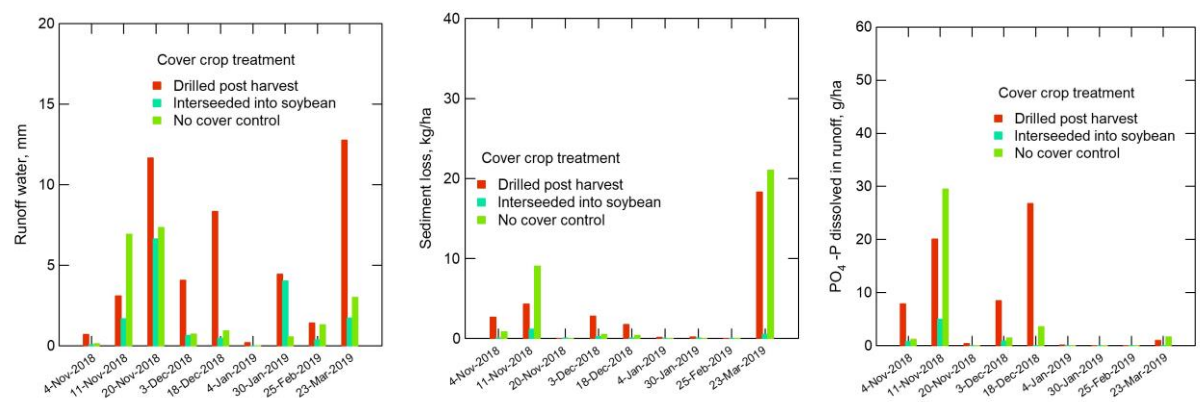

Figure 9 Runoff water volume, sediment loss and phosphate-P loss during nine runoff-producing rain events between 04 November 2018 and 23 March 2019 on sandy soil after soybeans in continuous notill corn-soybean system at Beltsville, MD.

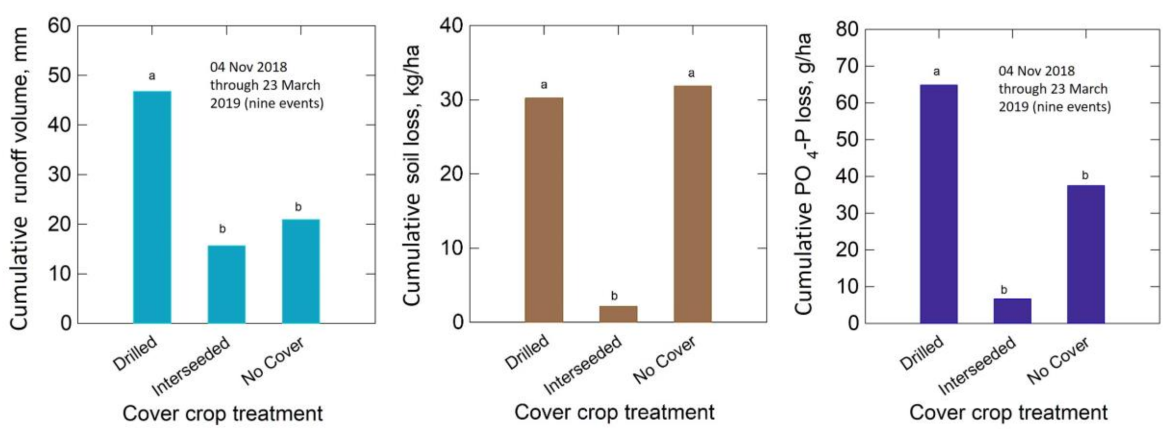

Figure 8. Cumulative runoff water volume, sediment loss and phosphate-P loss between 04 November 2018 and 23 March 2019 (nine runoff-producing rain events) on sandy soil after soybeans in continuous notill corn-soybean system at Beltsville, MD.

Results from the 2019-2020 Season.

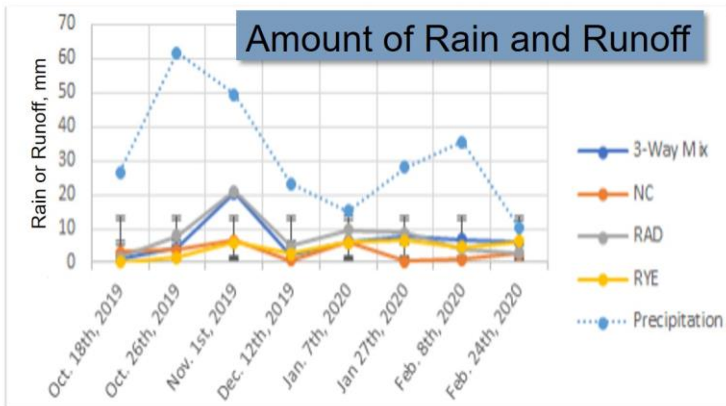

Figure 10. The amount of runoff produced during eight rain events sampled between 18 October 2019 and 24Feb. 2020.

Figure 10 shows the amount of rainfall for the eight events sampled between October 18th, 2019 and February 24th 2020. The latter was the last event sampled before the COVID-19 restrictions came into play and prevented sampling of later events. In early March, the runoff weirs and other equipment items were all removed from the fields so they would not interfere with cover crop termination and crop planting while our University student labor team was in lockdown. As expected for runoff, the data are quite variable. However, even after transforming the data, analysis of variance showed that none of the cover crop treatments had a significant impact on the amount of water lost as runoff.

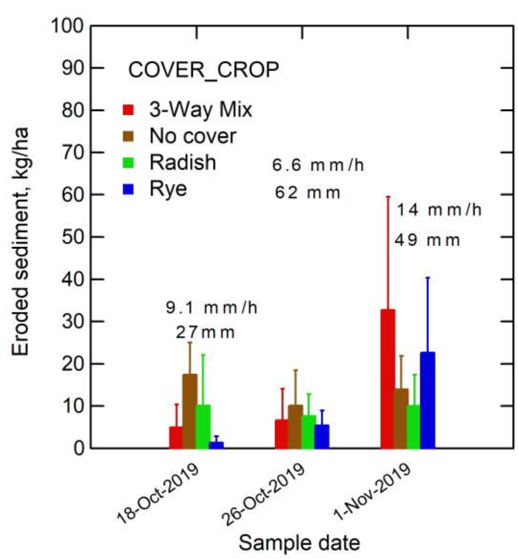

Figure 11. Sediment loss from the sandy no-till soil during the first three storms sampled were very low and not significantly affected by any cover crop treatment. The total amount and maximum hourly intensity for each event are shown above the bars.

Figure 11 shows the amount of eroded settlement for each of the first three runoff producing rain events in falls 2019. The figure also shows the rainfall amounts for each event and the maximum one-hour intensity. Because of Highly protective nature of a long term no tell residue covered soil as well as the highly variable nature runoff and erosion data no significant effect of cover drop could be discerned. It appears that the amount of sediment produced was more closely related to the one-hour intensity then the total amount of rain falling in the three events. All cover crops were no till drilled so there was no comparison this year with a broadcast seating and any effect of the disturbance of the soil by the drill could not be discerned. Samples from the other five runoff generating rain events still await analysis for sediment and P associated with the sediment. In any event, the amounts of sediment generated by these storms was very low, even for the plots with no cover crop. Research in the literature usually reports far greater sediment loses from comparable storms where soil tillage is routinely used. These low sediment loss rates are not unexpected from long term no-till soil with nearly complete residue cover, as is typical for many Maryland farms.

The concentrations of phosphate (PO_4) phosphorus dissolved in the runoff from the first five runoff producing rain events is shown in the upper graph in Figure 11a. As a reference, US Geologic Survey guidance for eutrophication in flowing stream water is about 0.1 mg P/L. The dissolved PO_4-P was generally below 0.2 mg/L for all plots, but the concentrations in the runoff from the 18 October 2019 samples were considerably higher than for the later dates. We speculate that the first rain after 7 weeks of hot dry weather resulted in a flush of microbial activity releasing P from soil organic matter and crop residues on the soil surface, leading to the higher levels of P in the first runoff event sampled. Despite the large variability in P concentrations on that date, the runoff from the rye cover crop plots had a significantly lower P concentration than that from the 3-way mix cover crop plots. This difference in concentration was at least partially due to the fact that the highest concentrations that occurred were associated with the lowest runoff volumes. For this reason, the *amount* of PO_4-P lost in the runoff sampled 18 October did *not* differ among cover crop treatments. In fact, Figure 13 shows there was no significant cover crop effect on the amount of P lost in runoff (g P/ha) on any of the five dates analyzed at the time of this writing.

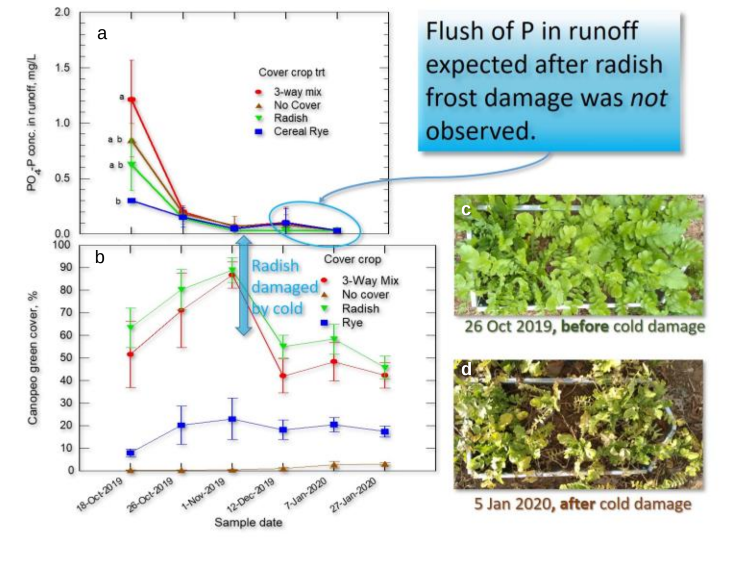

Figure 12. Phosphate-P concentration in runoff (a) and living leaf groundcover percentage (b) for the four cover crop treatments and the appearance of the radish plants before (c) and after (d) cold injury which occurred in November 2019.

Figures 11b-d show that the radish plants in both the 3-way mix and in the sole species radish cover crop were severely injured (but not killed) in November (on November 9 and 13 night temperatures went down to -7 °C = 20°F). Most of the radish foliage was killed and many of the fleshy roots were also injured as shown in the images of Figure 9c-d. This damage was quantified by the CANOPEO estimates of green groundcover percentage which dropped dramatically for the radish and 3-way mix (but not for the Rye) between 1 November 12 December 2019.

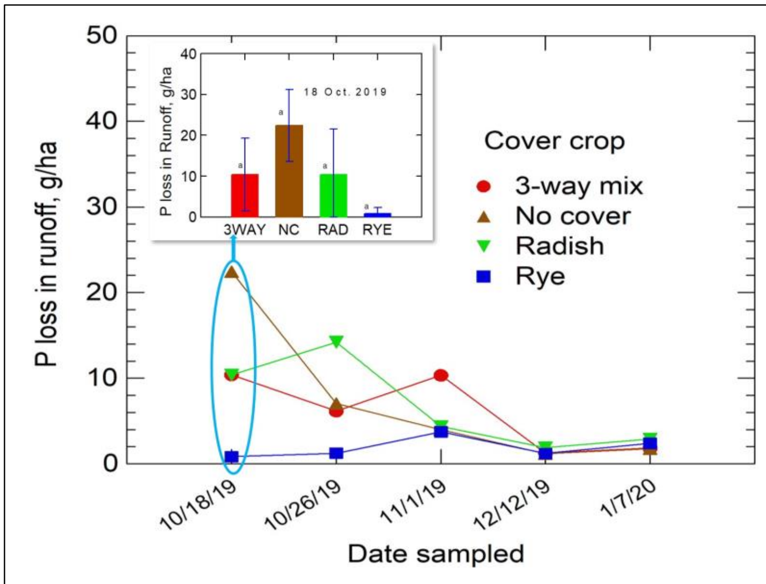

Figure 13. The amount of PO_4-P lost in runoff produced during five rain events sampled between 18 October 2019 and 01 January 2020. There was no effect of cover crop on any date sampled. Inset shows data variance and lack of significant any differences in the 18 October samples.

One of the main hypotheses motivating this research was the expectation that cold injury or death of frost susceptible cover crops such as radish would release large amounts of phosphorus from injured cells and that this soluble P would result in a large spike in P concentration in runoff water from the rain events following such winter-injury of the radish plants. However, it is clear from the data in Figure 9a that no such spike occurred in the concentrations of P in runoff after the radishes were injured. To the contrary, the concentration of P in runoff from all treatments remained very low.

The results of this year's runoff research are perhaps best summarized by the data presented in Figure 11 which show the cumulative amounts of runoff water, sediment loss and phosphate-P loss in runoff for all the samples analyzed to date. Between 18 October 2019 and 24 February 2020, an average of 12.8% to 30.2% of the rainfall was lost as runoff during eight runoff-generating events totaling 250 mm of precipitation. This is not counting several rain events that were too light to cause any runoff from any of the plots. Cumulative sediment losses from the first three events were very modest, ranging from 32 to 53 kg sediment per hectare. To put these values in perspective, since they were from only three storms over two months, we could multiply these losses by 6 times to estimate annual rates of sediment loss between 192 and 315 kg/ha. These figures can be compared to the 2 to 4,000 kg/ha annual loss that is considered "tolerable" (T-value) for similar soils by the USDA/NRCS. The amount of dissolved phosphate-P lost in the runoff from the first five events over 4.5 months ranged from 8 to 36 grams of P per hectare (0.1 to 0.5 ounces/acre). If we again assumed a similar rate of P loss through the year, the annual loss of dissolved phosphate-P would range from 21 to 107 g P/ha. While other forms of P (organic and sediment-bound) in the runoff remain to be analyzed, these very low levels of dissolved phosphate-P loss in runoff from moderately high P fertility soils (Mehlich3 P ~ 150) under no-till management with crop residue cover should be encouraging.

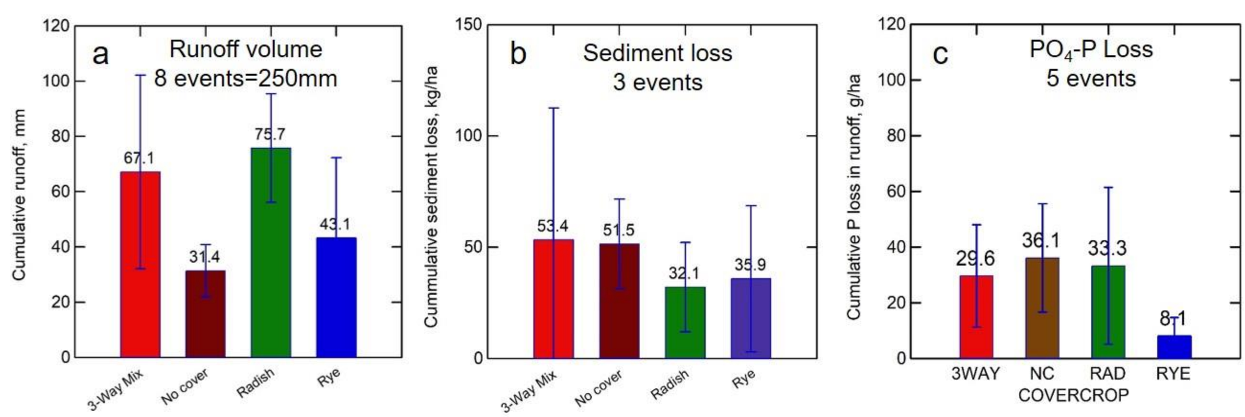

Figure 14. Cumulative runoff amount (a), sediment loss (b), and dissolved PO_4-P loss (c) during the 2019-2020 study period. The number of runoff -generating rain events included for each parameter differs because the Covid19 restrictions imposed in March 2020 delayed completion of sediment and P analyses for some sample-dates.

Results from the 2020-2021 Season.

Covid-19 restrictions which were imposed by the State if Maryland and the University of Maryland in March-April 2020 severely hampered the research from the onset of this grant period. Rather than attempt to travel around the state and region, we focused on the CMREC Beltsville site which was near enough to campus that the limit of one person per vehicle was not too burdensome.

In May 2020 we established corn and soybean plots on two sites at the Beltsville research station, one site having sandy soils and the other site having silt loam and silty clay loam soils. Both sites were moderate to high in soil phosphorus. Excellent stands of both corn and full-season soybean were established at both sites. Rye and a mixed species cover crop were drill-interseeded into the corn in June. The cover rye and mixed cover crops were air-seeded into soybeans at early leaf drop or the cover crops was drilled immediately after harvest. Harvest on the fine-textured soil was delayed until mid-October due to wet soil conditions. On the fine-textured site, excellent cover crops were established for both rye and mixed species. On the sandy site, excellent cover crops were established in the corn and where cover crops were drilled after soybean harvest, but the air-seeded cover crop in soybean produced a poor stand.

Since cover crops were present, we attempted to begin runoff measurements as early in the fall as possible. Therefore, we began installing metal erosion weirs and buried runoff collection jugs shortly *before* harvest of the cash crops. The runoff weirs are slightly less wide than the 30-inch crop row width so we could install them between crop rows. In most cases, we were able to run the harvest combine over the weirs between wheel tracks without damaging them. However, conditions were very wet in one of the replications on the fine-textured soil and the combine created some serious ruts and damaged one of the weirs. After harvest, we continued to install more weirs. We now have 18 weirs installed on the fine-textured soil and six on sandy soil.

Runoff sample collection began in November and is continuing throughout winter. Generally, because the fine-textured soil infiltrates water more slowly, silty loam to silty clay loam fields generate more runoff and do so more frequently than is the case for the sandy soil. The sandy field did not produce any runoff from most storms, as observable in the weir collection jugs or at the lower edge of the field during heavy rain. Although slope steepness and crop management were the same on both fields, nearly all the runoff samples were collected from the finer textured soil. With near zero surface runoff the sandy field would have lost near zero phosphorus as well. The runoff data was log-normally distributed (that is most values were very low but the were a few much higher values from intense storms. Therefore, we ran the analysis of variance on log-transformed the data (using a GLM procedure in SYSTAT 11.0). The three species mix cover crop had less runoff than others in the corn plots, but otherwise there was no significant effect of cover crops on runoff volume (Figure 15).

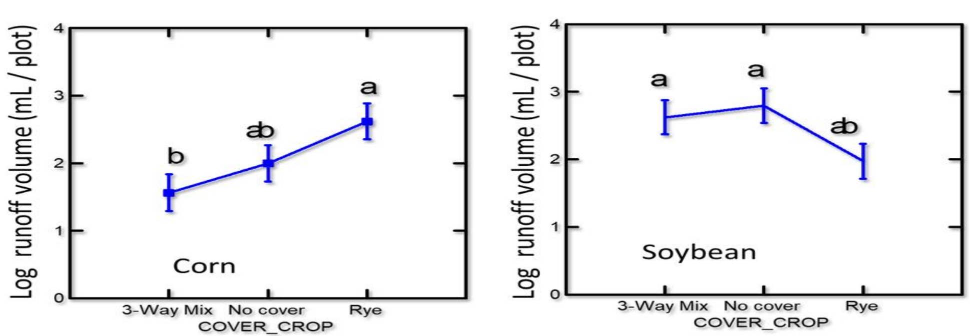

Figure 15 Volume of runoff in mL/plot across three cover crop treatments in corn and soybean plots. The three species mix cover crop had less runoff than others in the corn plots, but otherwise there was no significant effect of cover crops on runoff volume. Note the log scale runs from 1 to 10,000 mL. The measured volumes were log-transformed to achieve a normal distribution of the data for analysis.

With COVID-19 restrictions reducing our access to student labor we have not yet completed all the analyses planned for this year's runoff samples. We have filtered the samples and frozen them and for most have analyzed phosphate-P and Nitrate-N.

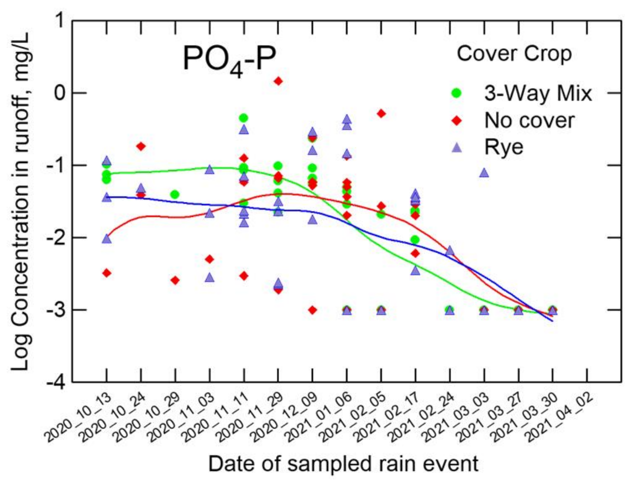

Figure 16 Orthophosphate concentration in runoff from plots treated with rye, 3-way mix or no cover treatments over time. The data were log-transformed due to non-normal distribution resulting from a high number of low concentrations and a few high concentrations. Lines are distance-weighted least squares regressions. The limit of detection was 0.001 mg/L.

Figure 16 presents the orthophosphate-P (PO_4-P) concentrations in runoff water from fine the textured soil plots with rye, 3-way mix or no cover treatments. Across all three treatments there was an overall decrease in the amount of soluble PO_4-P from November 2020 to March 2021. The data were log-transformed due to the non-normal distribution of the data resulting from a large number of low concentrations and a few high concentrations. The curves in the figure are distance-weighted least squares regression line. It is apparent from this graph and from the general linear model analysis that cover crops had no effect on PO_4-P concentration in the runoff. The concentrations of PO4-P were all less than 1.0 mg/Kg and most (but not all) were less than 0.1 mg/Kg, which is the USGS guidance concentration for eutrophication of flowing stream water.

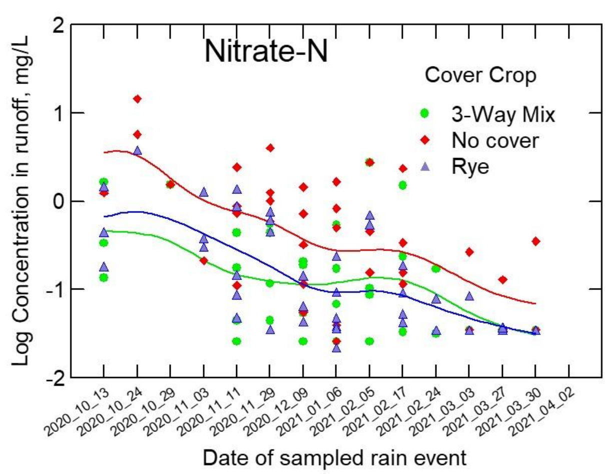

Figure 17 Nitrate-N concentration in runoff from plots treated with rye, 3-way mix or no cover treatments over time. The data were log-transformed due to non-normal distribution resulting from a high number of low concentrations and a few high concentrations. Lines are distance-weighted least squares regressions.

The nitrate-N concentrations in runoff from plots treated with rye, 3-way mix or no-cover crop between 13 October 2020 and 30 March 2021 are shown in Figure 17. Note that the nitrate-N concentrations were about 100 times as great as the phosphate-P concentrations in the same samples. The downward trend over time is even more pronounced with the nitrogen data. This trend was similar to what we found in the 2019-2020 cover crop season and suggests that the greatest nutrient losses occur with the first few storm event after harvest.

Phosphate-P concentrations in runoff across three cover crop treatments and in soybean versus corn residue plots are shown in Figure 18. The data show an interaction

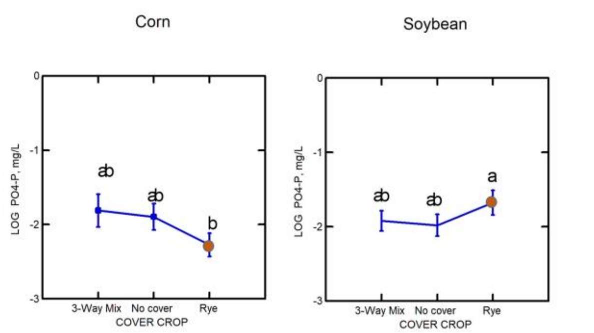

Figure 18 Phosphate-P concentrations in runoff across three cover crop treatments in soybean versus corn residue plots. The data show an interaction between the type of harvested cash crop residues present and the effect of rye cover crops on phosphate loss.

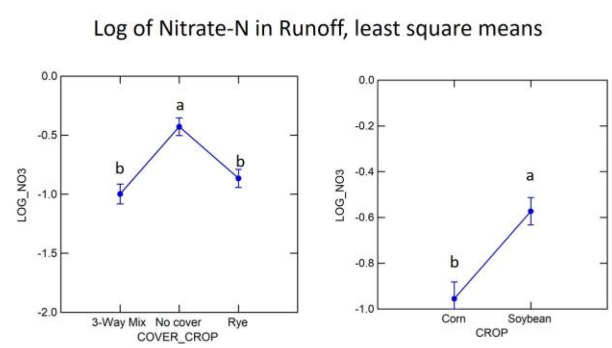

Figure 19 Nitrate-N concentrations in runoff by cover crops (left) and by crop residue type (right). The no-cover control

between the type of cash crop and the effect on orthophosphate by rye cover crops. In plots with corn residue and rye cover crop PO4-P concentrations were lower than plots with soybean residue and rye cover crop. The concentrations in the other treatments did not differ. The data was log-transformed to normalize the data distribution. The difference in PO4-P concentrations in the runoff water was very small, but this trend does agree with the general observation of greater amounts of soluble nutrients after soybean harvest compared to plots where corn was harvested.

The crop residue effect was more striking for nitrate-N (Figure 19), although the nitrate-N concentrations were all quite low. Cover crops had a significant effect, with the no-cover control plots (winter weeds only) having notably higher nitrate-N concentrations in their runoff. Also, regardless of cover crop treatment, the plots with soybean residue had higher nitrate-N concentrations in their runoff than those with corn residues.

Six soil cores were taken around each erosion weir, divided into increments from 0-2.5 cm and 2.5-15 cm, and then composted for each weir. These samples were air-dried rapidly and extracted at a ratio of 2.0 g soil in 20 mL of 0.01 molar $CaCl_2$ solution and shaken horizontally at 200 rpm for 30 minutes, then allowed to settle upright for 10 minutes and filtered. This very weak solution of a neutral Calcium salt is similar to the soil solution and is considered equivalent to water soluble. The filtrate was then analyzed on the Lachat® autoanalyzer for both nitrate-N and phosphate-P.

The trend for both nitrate-N and phosphate-P to be higher in runoff from soybean compared to corn residue plots is further supported by the soil extraction data. The results are presented in Figure 20. There were no effects of cover crop treatments, but there was more soluble orthophosphate and nitrate-N in the surface soil layer (0-2.5 cm) from plots with soybean residue than in plots with corn residue. This result suggests that the soybean crop and residue concentrated more nutrients on the soil surface than did corn, or that microbes decaying the corn residues immobilized (tied up) more of both nutrients than did the microbes decaying the soybean residue.

As with the 2019-2020 data, it is also notable that we were not able to detect any increase in phosphate-P in the 3-way mix cover crop that included cold-temperature sensitive forage radish, even after the radish was severely damaged and some plants killed by cold temperatures in January-February 2021. It is possible that once the autoclave in HJ Patterson Hall is repaired and we can perform the persulfate digestions, we may find a different pattern in the data for total soluble P (organic and inorganic forms).

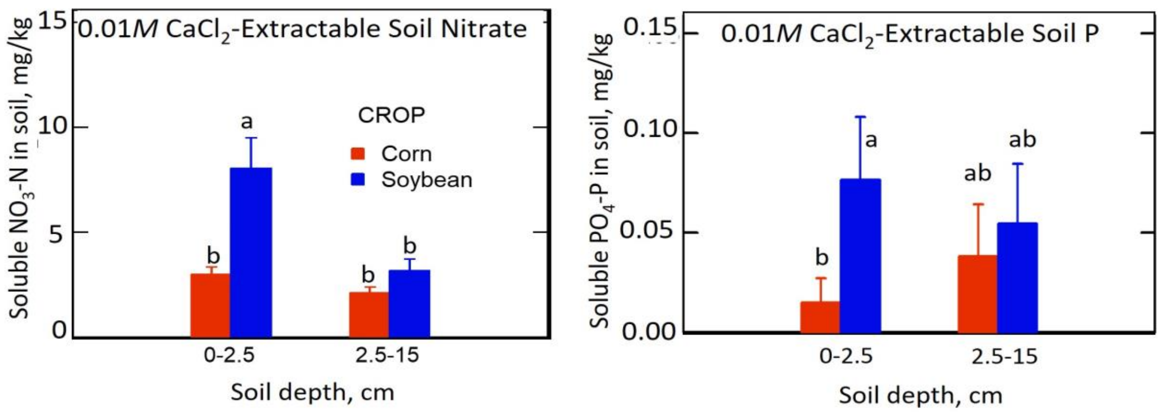

Figure 20 Water soluble nitrate-N (left) and orthophosphate-P (right) in soil samples taken in the immediate vicinity of the runoff weirs. Six soil cores were taken around each erosion weir, divided into increments from 0-2.5 cm and 2.5-15 cm, and composted for each weir. The data shown are means of all three cover crop treatments since cover crops had no significant effects. The upper 2.5 cm of soil with soybean residue was higher in both nutrients than the soil with corn residues.

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