Washington Discovery Farms® South Puget Sound Project

Evaluating Dry Manure Storage Options for Water Quality Protection Across King County, WA


Project and report produced by:

American Farmland Trust
King Conservation District
Whatcom Conservation District

(NTA 2016-0394)

June 30, 2021

This project has been funded wholly or in part by the United States Environmental Protection Agency under assistance agreement PC-01J18101 to the Washington State Department of Ecology. The contents of this document do not necessarily reflect the views and policies of the Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

Summary

American Farmland Trust, Discovery Farms® Washington, King Conservation District, and Whatcom Conservation District worked together to engage producers in a cooperative, on-the-ground research and demonstration project to assess, promote, and improve adoption of on-farm conservation practices that enhance water quality in Puget Sound.

Working on two farm sites in King County, Washington, this project measured water quality, manure, and weather data associated with four different types of manure storage: a pile on dirt, uncovered; a pile on dirt, covered with a tarp; a pile in on a concrete slab, uncovered; and a pile on a concrete slab; covered with a roof.

Between October 2020 and May 2021, the project team measured soil samples from beneath the piles on dirt, stormwater runoff from the piles on concrete, manure composition from both, and tracked meteorological events. The project analysis focused on nitrogen, nitrate+nitrite, and phosphorous with assessment of fecal coliform, salinity, and sediment parameters.

Findings from the data analysis showed that covered manure has less runoff and leaching of manure nutrients, manure on a slab has no leaching to groundwater and can contain stormwater when designed properly, manure composition is reflected in the analyte profile seen in stormwater runoff, and covered manure achieves a greater temperature to enhance the composting process and create a better end-product. Additional research is needed to fully understand the soil and water quality impacts of different manure management strategies over seasons.

Contact

For information or inquiries about this project, please contact:

Project Report:
American Farmland Trust
Addie Candib
P: (360) 726-2658
E: acandib@farmland.org

Management Practices and Outreach:
King Conservation District
Laura Redmond
P: (425) 282-1908
E: laura.redmond@kingcd.org

Research Design and Data Analysis:
Whatcom Conservation District
Washington Discovery Farms®
Nichole M. Embertson, Ph.D.
P: (360) 526-2381 x 126
E: nembertson@whatcomcd.org

Background

In 2019, American Farmland Trust (AFT) received funding from the Department of Ecology (Ecology) for its South Sound Discovery Farms® Project, a farmer-led research project, to evaluate the effectiveness of on-farm conservation practices. The project was a part of a 2016 Near-Term-Action package under the management of the Washington State Conservation Commission. The project team included AFT, King Conservation District (KCD), and Whatcom Conservation District (WCD), who also administers the Washington Discovery Farms® program. The project used on-the-ground data from two farms in King County to evaluate different treatments of dry manure storage for water quality protection (Figure 1).

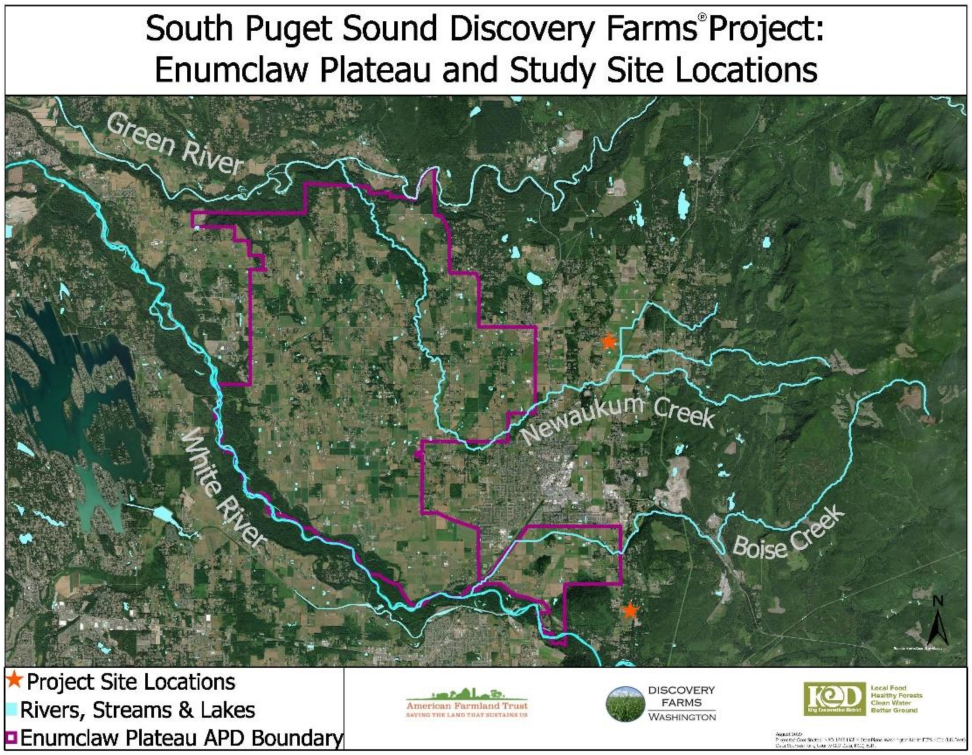


Figure 1. Map of project area in King County, WA and general project site locations.

Composting livestock manure and waste can produce a valuable resource for land managers. When applied correctly, compost can improve soil physical properties such as aggregate stability, water infiltration and water holding capacity, soil biological properties such as microbial diversity and disease suppression, and chemical properties such as nutrient cycling and cation exchange capacity. Compost can also provide an economic benefit to land managers through sales of the product and improving crop and pasture production (Brewer et al. 2013). However, if managed improperly, manure leachate and runoff can contaminate ground and surface water resources posing a risk to humans and other wildlife (Kwon et al. 2017).

Different manure storage treatments and utilization methods can affect compost quality and elevate runoff concentrations of carbon, nitrogen, phosphorus, pathogens and other pollutants (Webber et al. 2011; Richard 1996). Uncovered manure piles on bare ground can contaminate surface and ground water resources. Covering manure can prevent precipitation from coming into contact with manure and reduce leachate generation (Brewer et al. 2013). Cheng et al. (2015) found that covering piles can reduce nutrient load of leachate nitrogen and phosphorus to ground water, with a tarp being the most effective method at reducing precipitation onto the pile. Covers can also improve the quality and speed at which livestock manure composts. Pare et al. (2000) evaluated the effect of covering compost with geotextile fabric on carbon to nitrogen (C:N) ratio, leachate volume, and phytotoxicity. They concluded that covering piles resulted in compost maturing more rapidly and with better mineral retention than uncovered piles.

American Farmland Trust promotes sound farming practices and King Conservation District promotes sustainable use of natural resources through responsible stewardship. KCD's Farm Program provides services to King County cooperators through technical assistance, farm planning, education, and outreach. Manure management is one of the most commonly prescribed best management practices (BMPs) by KCD farm planners. Additionally, manure storage is one of the agricultural practices KCD's Landowner Incentive Program (LIP) invests the most public funding in. KCD prescribes a variety of treatments to manage manure, prioritizing the effectiveness of a roof and concrete pad for producing a superior finished product and protecting water quality. However, these options often present barriers to landowners due to the additional cost and labor to install these structures as well as permitting issues. Studies evaluating the effectiveness of physical coverings of manure piles, such as roofs and tarps, are limited (Patel et al. 2015). No studies were found to evaluate the effectiveness of covering manure piles in combination with impermeable padding. This study's evaluation of the effectiveness of commonly prescribed manure treatments with varying costs in protecting water quality will inform planner recommendations of manure treatment options to cooperators and potentially inform changes in cost-share policies and procedures.

Farmers' attitudes towards adopting conservation practices on their land are complex. Adopting conservation practices often come with economic and labor costs to the farmer. Many farmers care deeply about the stewardship of their land but are faced with competing pressures by communities simultaneously seeking to purchase low-cost products from environmentally friendly managed farms. The decision by a farmer to adopt a new practice can also be influenced by social pressures by other farmers, politics, family succession, the economy, and prior knowledge and experience (Ahnstrom et al. 2008). The Discovery Farms model promotes the normalization and adoption of BMPs through farmer-to-farmer outreach and learning. Additionally, this study provided a valuable opportunity to engage King County farmers, land managers and other stakeholders in discussions around the different options and benefits of adopting BMPs for manure management.

Objectives

The project aimed to measure water and manure quality data for different dry manure storage options, including with and without roofs and concrete and permeable floorings. Specifically, the project set out to:

- Install comparative solid manure storage structure treatments on two farms including slab with cover, slab without cover, permeable with cover, permeable without cover.
- Collect samples of stormwater runoff, soil leaching, manure quality, and meteorological parameters to compare the treatments.

- Assess the impacts of manure storage structures on environmental protection of surface and ground waters and landowner ease of use.
- Increase landowner understanding of dry manure storage practice effectiveness.
- Create outreach materials to assist with manure storage options and education for landowners and technical assistance providers.

Materials and Methods

Steering Committee

A steering committee was created to inform the design, outcomes, and information dissemination of the Discovery Farms project. The Steering Committee was comprised of five landowners, two of whom were also project site volunteers, with experience in livestock ownership and manure management. The first Steering Committee meeting was held in person on October 29, 2019, and was attended by Steering Committee members as well as AFT, WCD, and KCD project staff. WCD facilitated a conversation around project design to gather input from the farmers, using a localized approach. The Steering Committee members provided valuable insights and feedback on the scope of the project, which were incorporated into the design of the project.

Due to the COVID-19 pandemic, the project team decided to communicate solely via email, phone, and virtual meetings with committee members during 2020-21. The second Steering Committee meeting was held virtually on February 23, 2021. During this convening, the project materials were reviewed, and WCD presented on preliminary data findings. The Steering Committee members gave further guidance on which additional questions could benefit the community from the project and advised the team on avenues for information dissemination.

The third and final Steering Committee meeting was held on June 29, 2021. During that meeting, Steering Committee members provided reflections on the project process and outcomes, and learned about the data patterns derived from water, soil, and manure sampling to improve their practices on-farm.

Site Selection

Project partners conducted outreach to identify potential project sites. Partners narrowed potential candidates through their willingness to provide access for regular data collection, to adhere to research methods during the study, and to host educational and outreach events. Partners evaluated four potential project sites for suitability in coordination with the developing QAPP, also determining what permitting and/or code requirements needed to be adhered to and working with landowners to determine bin locations and designs that best met their goals for their respective farms. Project partners presented the potential sites and evaluations to the Steering Committee who selected two of the sites for project implementation.

The two sites selected differed in the type and number of animals present on farm. Site "A" was a mix of 6 alpaca, 65 sheep, 12 goats, 100 chickens, and 40 ducks bedded on either pine shavings and/or bedding pellets. Site "H" had two horses on site bedded on cedar shavings for the first part of the study and then pine pellets after that. To meet the minimum volume for initiating the project, Site H had mixed horse manure donated to their site at the beginning of the project and then used their own manure after that. Manure was added daily to the piles at Site A, and monthly to the piles at site H.

Both sets of landowners at the two project sites expressed enthusiasm for the project and were open to hosting events and providing access for project partners and the public to share outcomes of the project and promote education and stewardship of manure management. WCD and KCD worked with these two sets of landowners on treatment designs, implementation parameters, and outreach events and products. The treatments were installed on both sites in September 2020.

Experimental Design and Sample Collection

This study collected samples from two matched locations that resulted in the characterization and quantification of the relationship between manure storage treatments, water quality outcomes, and practice management. Complete detail of the study design and collection methods are documented in the project's Quality Assurance Project Plan (QAPP) which was approved by the Washington State Department of Ecology in October 2020.

Starting in October 2020 and ending in May 2021, the study measured environmental data from four different treatments of dry manure storage to assess the level of surface (slab treatments) or ground water (dirt treatments) protection:

1. **Slab Covered**: Manure stored in a three-sided manure bunker with concrete slab floor and sidewalls. The bunker included a roof covering over the entire storage area.
2. **Slab Uncovered**: Manure stored in a three-sided manure bunker with concrete slab floor and sidewalls. No roof.
3. **Dirt Covered**: Manure stored on a compacted soil/dirt surface. Manure covered with a tarp.
4. **Dirt Uncovered**: Manure stored on a compacted soil/dirt surface. No cover. (Control)

Figure 2. Manure storage treatments. From left to right: slab uncovered, slab covered, dirt covered, and dirt uncovered.

The two treatments with concrete slab flooring (slab covered and slab uncovered) were assessed for runoff from manure piles via collection of stormwater leachate (combination of stormwater precipitation and/or manure leachate from the piles) via 6-inch PVC pipes built into the back of the manure bunker slabs (Figure 3). Runoff from the bunkers was routed from the PVC through a flow monitoring weir and samples were collected by a refrigerated Isco auto-sampler. Samples from manure storage areas were collected when a runoff event occurred in conjunction with precipitation. Water samples were sent to a laboratory for analysis of fecal coliform (CFU/100 ml), total kjeldahl nitrogen (mg/L), nitrate+nitrite (mg/L), total phosphorous (mg/L), salinity (ppt), and/or total suspended solids (mg/L).

Figure 3. Stormwater leachate collection and monitoring setup. Image on left is the back of the bunker with PVC collection pipes, weir, and sample box with Isco shown. Image on right is the front of the bunker with two collection pipes shown per slab treatment.

The two treatments on dirt surfaces (dirt covered and dirt uncovered) were assessed for leachate losses below the piles via monthly 12 and 24-inch profile soil sampling. Soil samples were collected monthly from underneath the manure piles at depth segments of 0-12 and 12-24 inches samples and were sent to the laboratory for analysis of fecal coliform (CFU/g), total nitrogen (mg/kg), nitrate+nitrite (mg/kg), total phosphorous (Bray) (mg/kg), and/or salinity (ppt).

Manure piles from all treatments were sampled for mass balance and quality parameters via grab sample. Manure samples were collected along with soil samples and sent to the laboratory for analysis of total solids (%), total nitrogen (mg/kg), nitrate+nitrite (mg/kg), total phosphorous (mg/kg), total organic carbon (%), and/or salinity (ppt). Manure pile temperature was assessed approximately monthly using a 36-inch compost thermometer.

Meteorological parameters including ambient temperature (°F), precipitation (in), and relative humidity (%), were collected with weather stations (METER Group ATMOS-41) located near the study sites.

Information on practice management was recorded by the landowners including the frequency (date) and amount of manure addition and turning for each treatment pile, as well as the species composition of manure, and any local anomalies relevant to the project.

Data and Statistical Analysis

Stormwater leachate nitrogen and phosphorus concentrations where treatments were statistically compared at an alpha of 0.05 using paired t-tests. Statistical differences were used to verify practice recommendations, however, given the high variability of stormwater concentrations, statistical differences may be difficult to detect with this relatively small dataset. Thus, obvious trends in the data can be used to guide recommendations.

Experimental Results and Evaluation

Due to COVID-19 constraints and subsequent project delays, the project was only able to collect one full season of data from October 2020 through May 2021. Additionally, a relatively dry 2020-21 winter and spring resulted in fewer than anticipated storm events and thus fewer sample collection opportunities. Furthermore, due to the higher than anticipated cost associated with laboratory analysis of samples, fewer analytes could be regularly measured in water, soil, and manure samples. This reduced the amount of data available for many parameters. Therefore, the data analysis presented in this section only reflects those parameters for which enough data was available for meaningful analysis and conclusion.

Meteorological

Rainfall data was collected at the two sites by separate meteorological stations installed on the respective properties. When compared, the total monthly rainfall accumulations between the two stations was not significantly different. Thus, for reporting purposes, only the AgWeatherNet Enumclaw station data (Enmclw.N) is presented for brevity.

The rainfall accumulated during the monitoring period (Oct 2020 – May 2021) was compared to the 30-year average data (1991-2020) from the NOAA weather station located in Buckley, WA (USC00450945) (Figure 4). The Buckley station is located approximately 3 miles southwest of the sites.

During the monitoring period, rainfall was within 1-inch of the 30-year average for the months of October 2020 through January 2021 and for the month of May 2021. February 2021 was wetter than normal with 1.4 inches more rain than the 30-year average, while both March and April 2021 were drier than normal, with more than 2-inches less than average during each month.

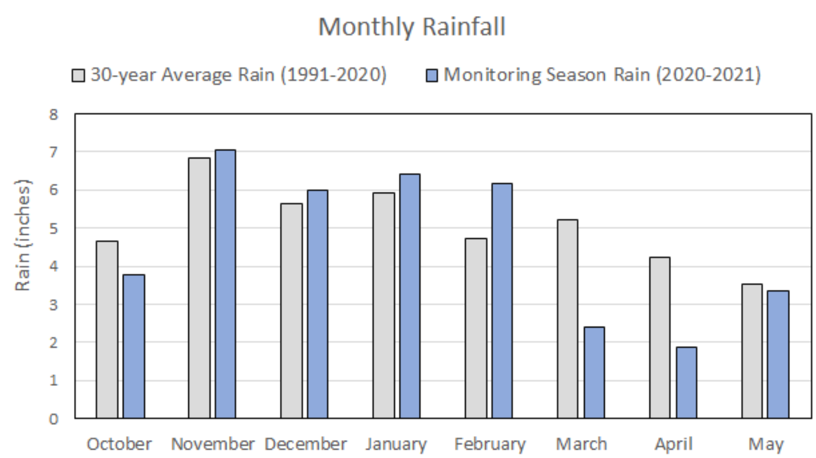


Figure 4. Monthly rainfall (inches) in Enumclaw, WA recorded at the AgWeatherNet *Enmclw.N* weather station (blue bars), and compared to 30-year averages from NOAA weather station located in Buckley, WA (USC00450945) (gray bars).

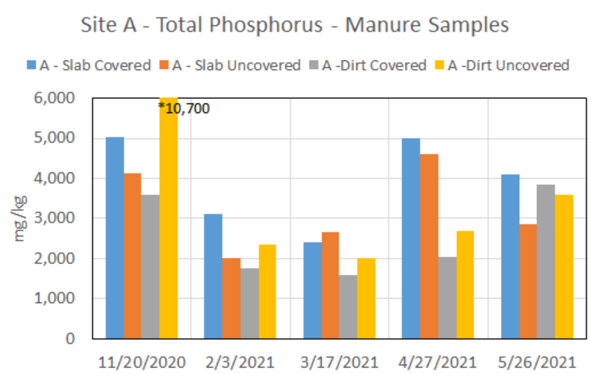
Manure

In October and November of 2020, manure was installed into each of the four treatment areas at each project site. After the initial manure installation, the piles were added to and turned regularly for the duration of the project. At Site A, the producer added manure to the piles nearly every day and had larger manure piles due to having more livestock. At Site H, the producer added manure to the piles less frequently along the order of one time per month. At each site, every time manure was added, the producer added equal volumes of manure to either both slab treatment piles or both dirt treatment piles. These practices allowed the producer to use the manure storage areas as intended, but also keep the manure pile compositions similar for comparison purposes.

Manure samples were collected from the four treatments (dirt covered, dirt uncovered, slab covered, slab uncovered) on five dates during the monitoring period and sent to the lab for analysis. Baseline samples were collected in November of 2020, and then subsequent monitoring samples were collected each month from February through May of 2021. Manure composition results are presented for total phosphorous, total kjeldahl nitrogen, nitrate+nitrite, and temperature.

Phosphorus and Nitrogen

Due to animal type and numbers, as expected, the manure composition and nutrient profiles were different between the two sites. Total phosphorus tended to be somewhat higher at Site A than Site H (Figure 5). Conversely, total kjeldahl nitrogen (TKN) tended to be slightly higher at Site H (Figure 6), and nitrate+nitrite tended to be much higher at Site H compared to Site A (Figure 7). The two sites had different amounts and types of livestock, which would account for the different manure nutrient profiles. Additionally, the maturation time of the manure at Site H could account for the higher nitrate+nitrite values, which typically occur in manure that has been in the composting process longer. These differences in manure nutrient composition were reflected in the differences in water quality runoff composition between the sites.



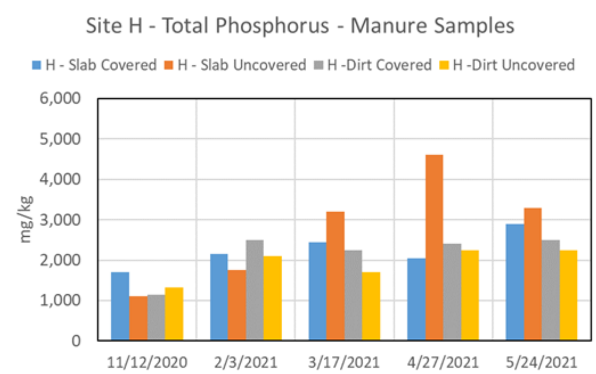
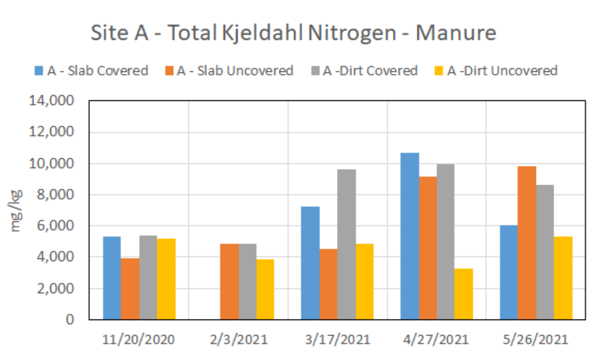


Figure 5. Total phosphorus (mg/kg) concentration in manure piles at the two sites within the four treatments during the monitoring period.



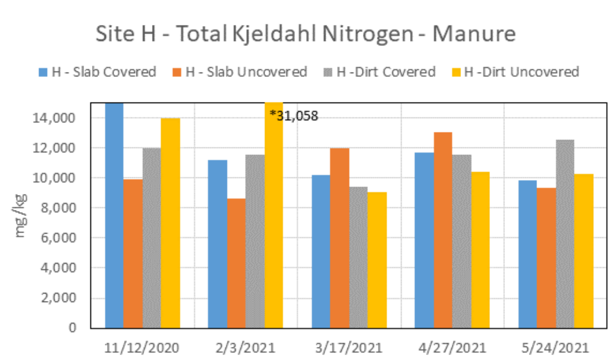


Figure 6. Total kjeldahl nitrogen (TKN) (mg/kg) in manure piles at the two sites within the four treatments during the monitoring period.

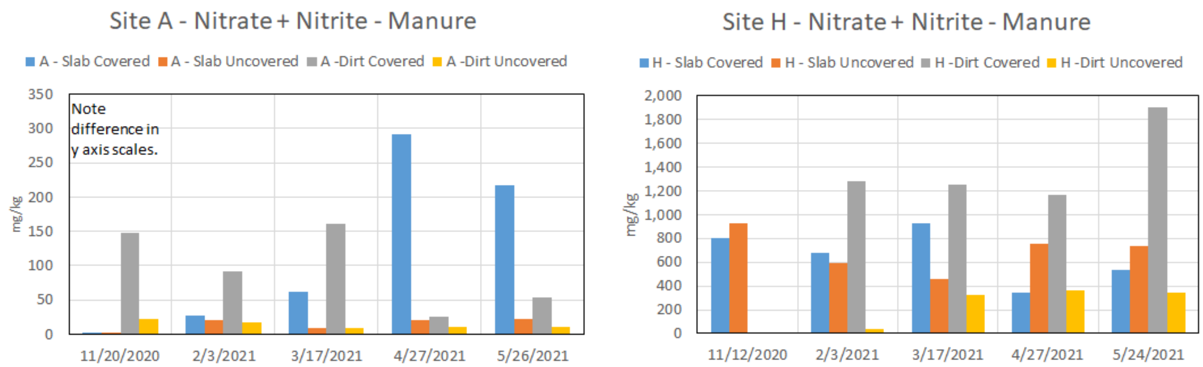


Figure 7. Nitrate+nitrite (mg/kg) in manure piles at the two sites within the four treatments during the monitoring period.

Manure Pile Temperature

Temperature measurements were taken sporadically from the manure piles from February through May 2021. At Site A, the covered treatments (slab covered and dirt covered) tended to be warmer than the uncovered piles (slab uncovered and dirt uncovered). The highest temperatures, measured at greater than 100°F, were measured at Site A in the covered slab treatment in February of 2021. At the same time, the uncovered slab manure pile was at around 60°F which indicates lower microbial activity in the uncovered manure. At Site H, the two slab treatments were warmer than the piles on compacted dirt. Maximum temperatures of greater than 100°F were detected in May of 2021 at Site H.

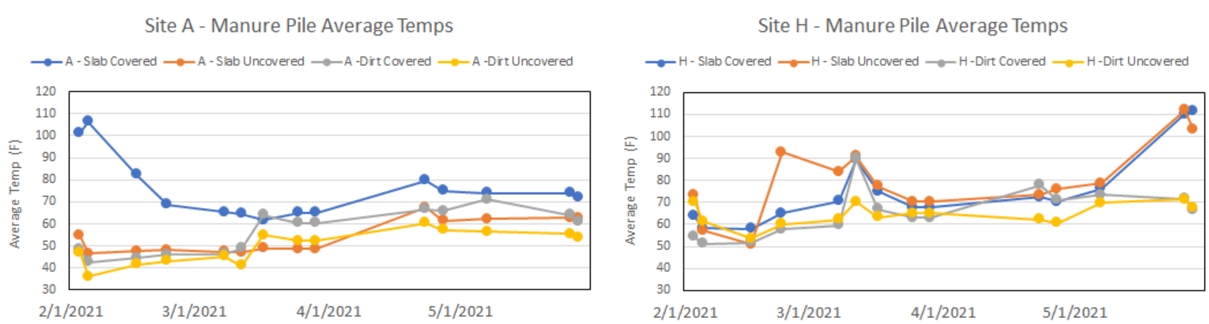


Figure 8. Average temperature (°F) of the manure piles from February 2021 – May 2021.

Stormwater Leachate

Stormwater leachate samples were collected from the concrete slab treatments during runoff events driven by rainfall (Figure 9). Samples were collected for 14 runoff events during the monitoring period (October 2020 through May 2021), and paired samples from both treatments (slab uncovered and slab covered) were collected when applicable. When rain events occurred, the flow of stormwater leachate from the uncovered bins increased as rainwater leached through the manure pile, and ran off the slab through the PVC collection system. Composite water samples were collected from the PVC pipes via an ISCO autosampler and stored on site until they were taken to the lab (Figure 3). The flow volume of runoff from the uncovered bins was measured during the events, and total volumes ranged from 2 to

137 gallons per rain event (Figure 9). Stormwater leachate volumes peaked in December and January of 2021 which correlates with the months with the highest rainfall.

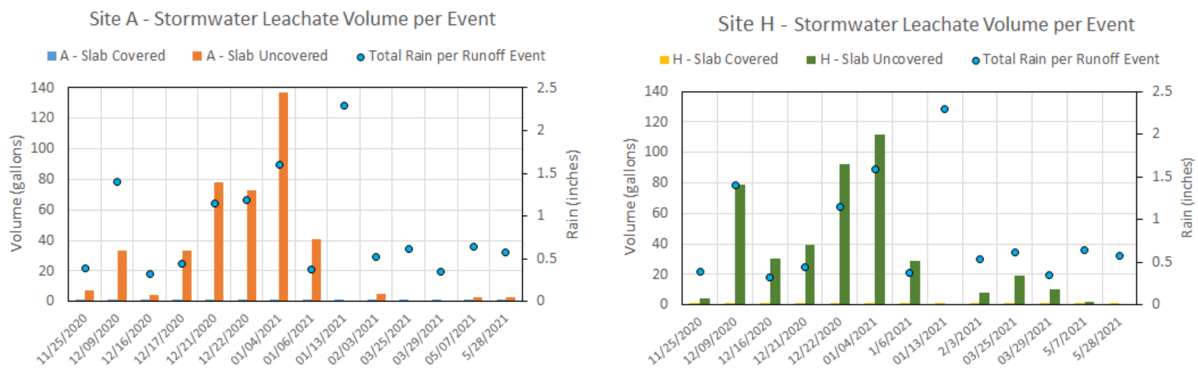


Figure 9. Stormwater leachate volume per sampling event (gal) along with total rainfall (in) per runoff event (blue points). Leachate from the covered treatment was so low it could not be measured accurately and thus does not appear on the figures.

Leachate flowing from the covered bins, however, was not able to be measured accurately because it was flowing at such low volumes for the duration of the monitoring period. It was estimated that about 5 gallons of leachate seeped from the covered manure pile per week at Site A, and less than that at Site H.

It should also be noted that leachate runoff was observed at very low flow volumes from all of the concrete slab piles (whether covered or uncovered) for most of the duration of the monitoring period. Only the manure pile on the covered slab at Site H stopped leaching completely in May of 2021. All of the other piles continued to leach for the duration of the project. The leachate was flowing at such low volumes however, that it was not possible to accurately measure the volume. The leachate was yellow to dark-brown in color from treatments indicating high amounts of organic matter from the composting manure.

Phosphorus

Total phosphorus (TP) in stormwater leachate is shown in the figure below for Site A and Site H (Figure 10). Comparing the two sites, TP was much higher in the runoff from Site A than Site H. This result was expected given the manure nutrient composition at Site A was higher. Comparing the two treatments, the uncovered treatment had significantly higher concentrations of TP than the covered treatment at Site H (p-value = 0.0035). This indicates a greater movement/loss of TP from the manure to stormwater in the uncovered pile during rain events. At Site A, the differences were not statistically significant (p-value = 0.22), with the slab uncovered treatment usually had higher concentrations. When considering the differences in flow volume, the loading from the uncovered side is estimated to be higher than from the covered treatment.

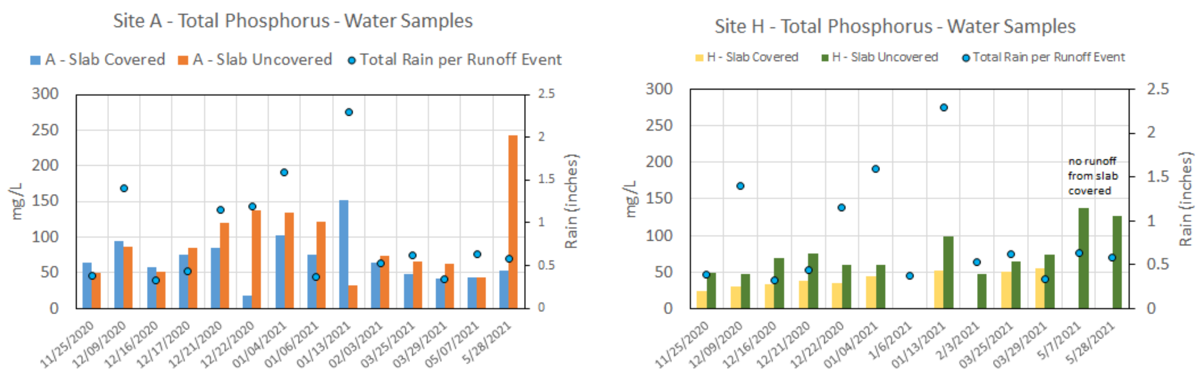


Figure 10. Total phosphorus (mg/L) concentrations in stormwater leachate at the two sites for the four treatments during the monitoring period. Rainfall (in) per runoff event is also shown on the secondary y-axis.

Nitrogen

Total kjeldahl nitrogen (TKN) in runoff is shown on the graph below along with the total rainfall accumulated during the sampling events (Figure 11). TKN was much higher at Site H than at Site A. This was unexpected given that Site H had higher TKN in its manure than Site A. Comparing treatments at Site H, the covered side clearly had higher concentrations although the results were not significantly different (p-value = 0.079). At Site A, the treatments were also not significantly different (p-value = 0.25). This result is similar to the TP results, and indicates greater movement/loss of TKN from the manure to stormwater in the uncovered piles during rain events at Site H.

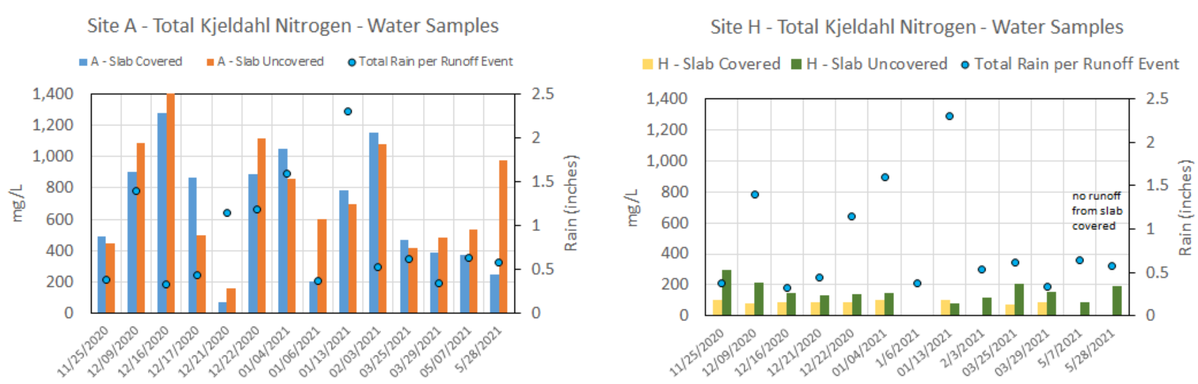
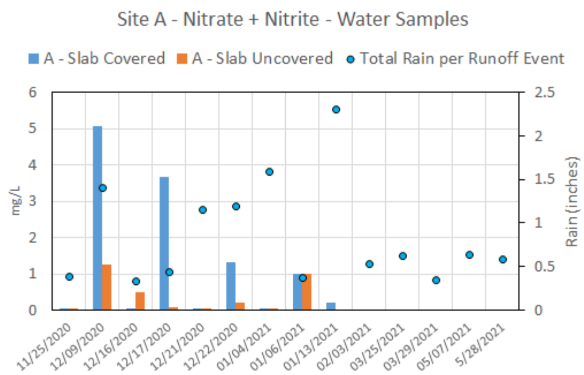


Figure 11. Total kjeldahl nitrogen (TKN) (mg/L) concentrations in stormwater leachate at the two sites for the four treatments during the monitoring period. Rainfall (in) per runoff event is also shown on the secondary y-axis.

Nitrate+nitrite in water samples was measured from November 2020 through January 2021 (Figure 12). Nitrate+nitrite concentrations were very low from Site A (which was unexpected) with the highest detected concentration of only 5 mg/L from the covered slab treatment. The low concentration of nitrate+nitrite at Site A was likely due to fresh manure being added to the piles so frequently (daily), which likely inhibited the conversion of organic nitrogen to nitrate+nitrite. Given these low and often non-detect concentrations, it is difficult to compare between treatments for this constituent at Site A. At Site H, on the other hand, the leachate water had much higher nitrate+nitrite concentrations with maximum concentrations of greater than 100 mg/L. Similar to the TKN and TP results, concentrations were consistently higher at the uncovered slab indicating increased leaching due to rainfall on the manure. However, there were no significant differences between the nitrate+nitrite concentrations (p-value = 0.12).



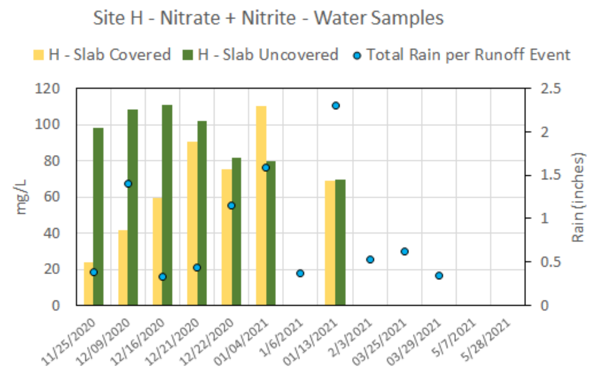


Figure 12. Nitrate+nitrite (mg/L) concentrations in stormwater leachate at the two sites in the four treatments during the monitoring period. Rainfall (in) per runoff event is also shown on the secondary y-axis.

Nutrient Mass Loading Estimates

Runoff volumes could not be measured accurately from the covered slab treatment due to the extremely low flows, so it is not possible to quantify and compare loading between the two treatments. However, it was clear from observations that the leachate flow was significantly lower at the covered treatment. We estimated that 5 gallons of leachate was produced in one week at the covered treatment, whereas a single stormwater leachate event produced between 2 to 137 gallons in 24 hours or less. Thus, in mid-winter, during the period with highest rainfall and runoff, the uncovered treatment produced >20 times more runoff volume than the covered treatment. Higher runoff volumes equate to higher loading rates of nutrients to the landscape and loss of nutrients from the manure pile. Thus, even though we cannot quantify it at this time, it is clear that the uncovered treatments produced significant higher loads than the covered treatment.

Soil

Soil samples from below the manure piles stored on the compacted dirt treatments (dirt covered and dirt uncovered) were collected six times during the monitoring period. Baseline samples were collected in October or November 2020, and then subsequent monitoring samples were collected in December 2020, and February through May 2021. Samples were collected from the 0-12-inch depth and 12-24-inch horizons for each sample event.

Phosphorus

Because of a change in laboratories, and thus a difference in comparable analytical methods, results are not shown for total phosphorus (TP) concentrations before February 2021.

TP concentrations in soil were higher at both depths at Site A than Site H (Figure 13). This correlated to a generally higher manure TP level at site A. Additionally, TP levels were greater in the 12-inch soil profile at both sites with little change in TP levels the 24-inch profile, which is expected due to the low leaching rate of phosphorous through soil. TP concentrations decreased from February 2021 through May of 2021 at Site A for each depth and treatment except the 12-inch horizon in May of 2021 when there was an increase in TP at the dirt covered treatment. This was likely correlated to a higher manure TP level also measured at that time indicating an addition of manure reflected in the top few inches of the soil. TP concentrations as Site H were much lower compared to Site A, and stayed consistent over the duration of the monitoring period. The difference in soil TP levels between the two sites is unknown. Starting manure TP levels are one factor (higher in Site A manure), but the general loss trend would have been expected to be similar if that was the only defining characteristic. Additional data is needed to make a firmer conclusion.

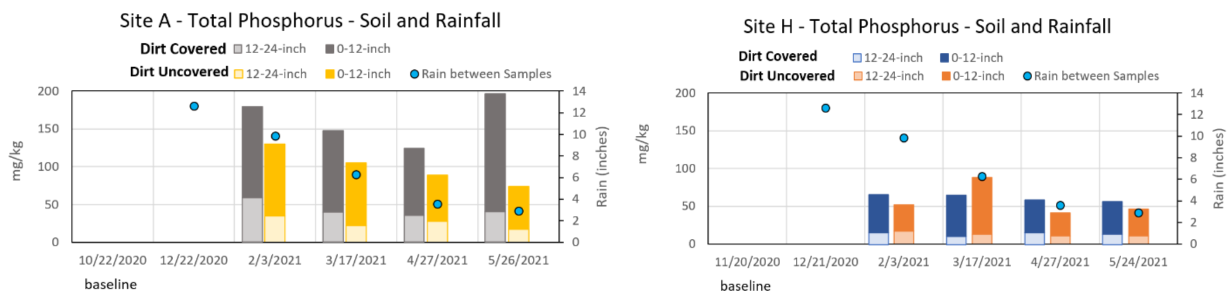


Figure 13. Total phosphorus (mg/kg) in soil samples collected from the 0-12 inch and 12-24 inch horizons. Total accumulated rainfall between events (inches) is shown on the secondary y-axis.

Nitrogen

Total Kjeldahl nitrogen (TKN) concentrations were mostly comparable in the baseline samples between the two sites (Figure 14). At Site A, TKN concentrations increased from the baseline to subsequent samples at both sample depths. Concentrations were higher in the 12-inch horizon compared to the 24-inch horizon indicating that nitrogen was moving from the manure piles to the soil, but not rapidly moving below the 12-inch depth. At Site H, TKN concentrations tended to stay consistent throughout the monitoring period and were not indicative of movement into and thru the soil. Due to an issue at the lab, 12-inch soil sample data is not available for TKN for the May 17, 2021 sample date at either site (exception is Site A, dirt uncovered).

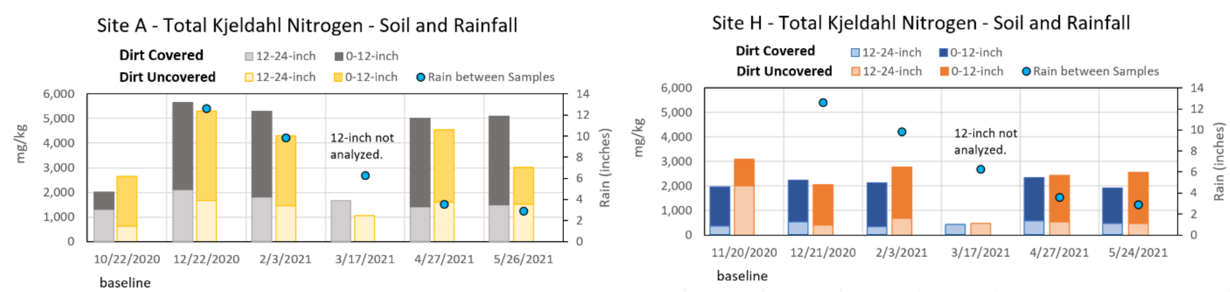


Figure 14. Total kjeldahl nitrogen (mg/kg) in soil samples collected from the 0-12 inch and 12-24 inch horizons. Rainfall between events (inches) is shown on the secondary y-axis as blue points. Note March 2021 samples were not analyzed in the 12-inch depth.

Nitrate+nitrite concentrations in soil tended to be higher in the baseline samples than in the subsequent sampling dates (Figure 15) at both sites indicating a movement or leaching of nitrate through the soil profile, most likely transported with time and/or rainwater infiltration. Nitrate values were also substantially higher at Site A than H. This is in line with the high TKN values also noted at Site A. Interestingly, the manure TKN and nitreat+nitratie values were much higher at Site H (Figure 7).

In general, the nitrate+nitrite concentration in the uncovered piles tended to decrease in both the 12 and 24-inch profiles indicating movement through the soil. In contrast, the nitrate levels in the covered pile tended to be more uniform with a slight decrease in the 12-inch profile and little to no change in the 24-inch profile. This indicated that nitrate+nitrite did not readily leach through the manure and soil under the covered piles, but did move through the manure and soil profile under the uncovered piles. While additional seasonal data is needed to produce a more robust, statistical result, the result highlights the environmental benefit of the covered piles in reducing the transport of nitrate through the soil profile to groundwater.

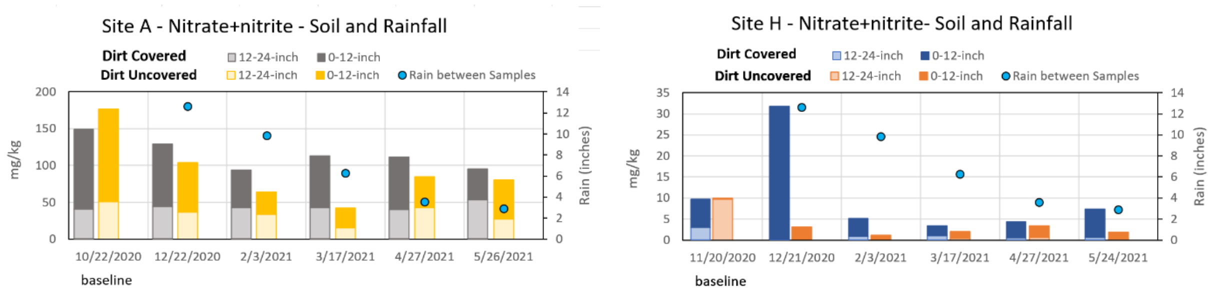


Figure 15. Nitrate+nitrite (mg/kg) concentrations in soil samples collected from the 0-12 inch and 12-24 inch horizons. Rainfall between events (inches) is shown on the secondary y-axis.

Manure Management

While some records on the manure pile management were captured, detailed measurements of manure quality and use were not part of the project objectives. However, managers from both project sites provided anecdotal observations of the differences in the manure quality between the four treatments. In general, both sites noticed that the manure piles in the cover treatments had a drier, more decomposed product as compared to the uncovered piles which were described as more of a “slop” texture. Manure from the covered treatments was characterized as easier to use, had a better quality feel, and had less offensive odor. All of these observations point to a better “composting” process in the covered manure piles. Additionally, both sites agreed that the manure stored on the concrete slab was significantly easier to handle (pile, turn, remove) than manure on dirt, and that it provided a greater confidence in environmental protection of local water resources.

Education and Outreach Outcomes

The project team hosted a virtual farm tour on November 14, 2020, which served 32 attendees, the majority of whom were farmers or landowners themselves. The tour featured one set of landowners involved with the South Sound Discovery Farms project, a short video produced by Beneath the Looking Glass LLC, and a live Q&A. During the Q&A portion, multiple farmers expressed curiosity and interest in implementing best management practices such as heavy use areas, waste storage facilities, and buffer plantings. The event showcased installation, highlighted farmers' agricultural stewardship, and promoted peer-to-peer, farmer-led learning. The virtual tour was recorded, posted to KCD’s YouTube account, and shared directly with over 8,500 cooperators through KCD’s Farm Planner’s Almanac, blog, and social media accounts, as well on AFT's website. As of June 30th, 2021 a recording of the farm tour had accrued nearly 200 views and counting. A recording of that farm tour can be found here[1].

A second outreach event occurred on June 8, 2021, reaching 24 attendees, and included a presentation about the data findings and analysis from water quality, soil quality, and manure testing from different manure storage treatments. The virtual tour was recorded, posted to KCD's YouTube account on June 23rd 2021, and shared directly through KCD's Farm Planner's Almanac, blog, and social media accounts. A recording of that presentation can be found here[2].

AFT subcontracted with Beneath the Looking Glass, LLC, an Emmy award-winning photographer and videographer in western Washington, to document the project and lead the creation of outreach materials. A short video was published for the farm tour in November 2020, and other materials, including photos and videos, were completed in June 2021. Filming for these materials occurred on-farm in March 2021. All project materials can be found here[3].

To accomplish the Funding Mechanisms deliverable associated with this project, AFT subcontracted with Portland-based nonprofit Willamette Partnership to research and write a comprehensive report, "Landscape of Agricultural-Municipal Water Partnerships with a Focus on the Pacific Northwest". The report examines five types of "agricultural-municipal partnerships," including water-quality trading programs, analyzes examples from throughout the Pacific Northwest, and presents pathways for moving these partnerships forward in Washington State. The report can be found here[4].

Due to delays from COVID-19, dissemination of the learnings from this project will take place after the end of the grant period. That said, project partners have already identified numerous opportunities to communicate the preliminary results and expand the project's potential impact. The project team submitted a proposal and was invited to present at the national Soil Water Conservation Society conference in July 2021. Also in July 2021, the team will present at the Washington Natural Resources Conservation Service State Technical Advisory Committee (NRCS STAC) meeting. The team will also present findings at a Center for Technical Development (CTD) webinar in September 2021.

Finally, the project partners have collaborated to submit funding proposals to continue this research and expand upon the preliminary findings. In May 2021, the partners submitted a full proposal to the King County Wastewater Treatment's WaterWorks grant program, and a preliminary proposal to Western Sustainable Agriculture Research and Education (SARE)'s Research and Education grant program.

Project Challenges

In early 2020, the project was on track to be completed under its original timeline of February 2021; however, the COVID-19 pandemic caused significant disruption to the project. It contributed to a lack of

[1] https://www.youtube.com/watch?v=sSbeXxRxQUQ
[2] https://www.youtube.com/watch?v=CQEotcT0z3w
[3] https://farmland.org/project/south-puget-sound-discovery-farms/
[4] https://farmlandinfo.org/publications/landcape-of-ag-muni-partnerships/

contractor availability, which presented delays and complications to installation, as well as workplace disarray and cancelled outreach opportunities. During spring of 2020, it was unclear to project partners whether installation would be feasible for the project and there were significant unknowns around what deliverables could be effectively accomplished as installation was pushed out further and further. However, with adaptability and resiliency, the project team was able to coordinate contractor selection, practice installation, monitoring equipment installation, QAPP completion, a virtual outreach tour, and outreach material development in 2020, and the project was approved for an extension by the Washington State Conservation Commission through June 2021. This extension allowed a full wet season of data to be collected, as well as attainment of other deliverables.

Initial installation of the manure treatments on the permeable dirt surfaces was not successful at either site. Both sites were long and narrow with multiple open water sources, resulting in limited safe locations available for the dirt uncovered and dirt covered treatments to be installed. Additionally, the equipment and construction of the bins at both sites caused some degree of compaction in the available areas leading to an unforeseen consequence of excessive ponding after rain events. To avoid contact with standing water, sandbags were purchased to divert ponding water during stormwater events. These were successful at one site, and the ponding decreased over time; however, at the other site, the dirt uncovered treatment had to be moved twice. This resulted in unusable data, as a baseline set followed by monthly soil data had to be collected. Thus, soil data sets are smaller than desired.

Additionally, a relatively dry 2020-21 winter and spring resulted in fewer than anticipated stormwater runoff events and thus sample collection events. Furthermore, due to the higher than anticipated cost associated with laboratory analysis of samples, fewer analytes could be regularly measured in water, soil, and manure samples. This reduced the data available and thus the analytical relevance of many parameters. Therefore, the data analysis presented in the results sections only reflects those parameters for which enough data was available for meaningful data analysis and conclusion.

Conclusion

Despite a relatively small data set, the project results support the conclusion that the covering of dry manure piles has positive environmental benefits. Covered manure piles stored on a concrete slab have significantly less stormwater infiltration and thus runoff with lower concentrations of nutrients in the leachate then uncovered manure piles on concrete slab. The covering of dry manure piles stored on dirt surfaces reduced the leaching of nutrients, particularly nitrate+nitrite, from manure piles into the soil. It also creates a better manure end-product by allowing higher heat values to be reached and creating a drier end-product. Additionally, the placement of manure on a non-permeable, concrete surface eliminated the leaching of manure nutrients below the piles. Covered manure piles, whether stored on a concrete slab or dirt, tended to be drier and have higher temperatures, which results in a better composted manure product.

The results of this study demonstrated that the manure composition and pile management also greatly affect the nutrient composition of the leachate. For instance, at Site A, there was higher TP concentrations in the manure, and therefore higher TP in the stormwater leachate from the slab runoff and higher TP in the 12-inch soil samples. Additionally, fresh manure was added to the piles at Site A more frequently, and this likely resulted in lower pile temperatures, slower composting, and lower rates of nitrogen conversion from organic forms of nitrogen to nitrate. At Site H, the piles were smaller and fresh manure was added less frequently, and thus the manure likely had higher rates of organic nitrogen conversion to nitrate. We detected evidence of this in the stormwater leachate runoff which had much higher nitrate concentrations than Site A.

At the final Steering Committee meeting for this project, members identified peer-to-peer learning to be most impactful, with special emphasis on the benefits of having in-person, on-site farm tours to demonstrate the effectiveness of the different treatments in conjunction with other farm BMPs. Members expressed that implementing BMPs can sometimes be a big undertaking for producers, and that learning about the hurdles and solutions that other producers encountered helps inform, motivate, and inspire them to apply these practices to their own operation. Members recommended incorporating more information and guidance on how to successfully compost manure into future materials and educational events and that this information could help inform producers choices to manage manure.

Due to the short duration of the project, additional funding is being pursued to extend the project and expand the data set to allow for more robust statistical analysis and conclusions. Partner agencies and organizations have expressed support and interest in continuing this research, and project Steering Committee members have also expressed interest in further participation. If continued, the future project will encompass an expanded Steering Committee, a third research site, enhanced communication between the research team and cooperators about strategies for utilizing the various manure treatments, and more real time access to data for the cooperators to help influence their day-to-day management decisions.

As a result of this project, King Conservation District has already received requests for assistance with manure storage planning and cost-share assistance. The provision of data along with conservation management practice recommendations, such as covered manure storage, is invaluable to both knowledge of environmental protection and landowner confidence in applying the practice. This project is providing unique and needed data on dry manure storage strategies to improve landowner adoption and ultimately water quality in the Puget Sound region.

References

Ahnstrom, Johan, Jenny Hockert, Hanna L. Bergea, Charles A. Francis, Peter Skelton, Lars Hallgren. 2008. Farmers and nature conservation: What is known about their attitudes, context factors and actions affecting conservation? Renewable Agriculture and Food Systems: 24(1); 38-47.

Brewer, L., N. Andrews, D. Sullivan, and W. Gehr. 2013. Agricultural Composting and Water Quality. Oregan State University Extension. EM 9053 https://catalog.extension.oregonstate.edu/em9053 Accessed [01/15/2020].

Cheng, Jianbo, Junjing Qiao, Yucheng Chen & Zhimin Yang. 2015. Nutrient loads of small-scale swine manure composting to groundwater and its prevention by covering: a case study. Environmental Science and Pollution Research. 22:15646-15655. DOI 10.1007/s11356-015-4705-2

Kwon MJ, Yun S-T, Ham B, Lee J-H, Oh J-S, Jheong W-W (2017) Impacts of leachates from livestock carcass burial and manure heap sites on groundwater geochemistry and microbial community structure. PLoS ONE 12(8): e0182579. https://doi.org/10.1371/journal.pone.0182579

Pare, Monique, Timothy C. Paulitz and Katrine A. Stewart. 2000. Composting of Crucifer Wastes Using Geotextile Covers. Compost Science and Utilization, 1:36-45 DOI:10.1080/1065657X.2000.10701748

Patel JR, Yossa I, Macarisin D, Millner P. 2015. Physical covering for control of *Escherichia coli* O157:H7 and *Salmonella* spp. in static and windrow composting processes. Applied Environmental Microbiology 81:2063–2074. doi:10.1128/AEM.04002-14.

Richard, Tom. 1996. Water Quality Protection – Cornell Composting. Cornell Waste Management Institute. Available online at the following link: http://compost.css.cornell.edu/waterqual.html Accessed [01/15/2020].

Webber, D.F., S.K. Mikelson, B.D. Whitman, T.I. Richard and H.K. Ahn. 2011. Livestock manure windrow composting runoff and infiltration characteristics from Laboratory Rainfall Simulations. Compost Science & Utilization. 19 (1): 6-14.