Final Project Report

ANALYSIS OF WATER QUALITY IMPACT OF WINDROW COMPOSTING

Laura Ward Good and Pamela Porter

College of Agricultural and Life Sciences
University of Wisconsin-Madison

Submitted to the Clean Lakes Alliance

December 2017

This report was produced by Dr. Laura Ward Good, UW-Madison Department of Soil Science, and Pamela Porter, Center for Integrated Agricultural Systems, under contract with Clean Lakes Alliance, a nonprofit organization working to improve water quality in the Yahara River Watershed through funding from the Lake Michigan Federation.

Project Summary:

This study investigates composting operations and applications on three Dane County, Wisconsin dairy farms that are composting bedded pack manures. Bedded pack manures come from livestock housing where cornstalks, straw, wood shavings, and/or sand are spread on the floor for bedding. This solid manure is typically managed separately from the manure produced by lactating dairy cows, which often goes into liquid storage. Bedded pack manure can make up 20-25% of a dairy farm's total manure production.

Composting is an ancient and cost-effective way to speed the decomposition of manure by piling it in rows and turning it regularly to aerate (NRAES 1992, USDA-NRCS 2010). A 2015 USDA Farmer Rancher SARE funded project in the Upper Yahara Watershed showed that composting bedded pack manure was a feasible practice and that it provided an alternative to winter applying the manure. For the last two years, three members of Yahara Pride Farms have been working with UW-Madison on this research project to determine whether composting can lead to reductions in phosphorus (P) runoff loads from their farms. This project was funded through a grant secured by Clean Lakes Alliance from the Fund for Lake Michigan.

Our objective was to evaluate potential runoff P losses on these farms during the manure composting process and following compost application to cropped fields and compare them to expected losses from applying the manures directly to the fields without composting. Secondary objectives were to document the agronomic benefits and costs associated with composting and to evaluate the costs per lb. of runoff P reduction.

Project Findings:

Compost is a viable way to reduce runoff P losses from livestock operations with bedded pack manure. The runoff P reductions derive from decreased erosion from stable organic matter addition, decreased P water-solubility in compost compared to bedded pack, and elimination of the need to spread during winter. Manure spread in the winter months can result in increased P loads to surface water when the snow melts. Reductions varied from farm-to-farm with field erosion and runoff rates, the amount of manure composted, and manure and compost application rates and timing.

Compost P water-solubility is 30–50% of that in the raw manure. Phosphorus water-solubility is an indicator of how much P will dissolve in runoff from a given material. Composting in outdoor windrows produces similar decreases in P water-solubility as composting under a roof.

Composting under a roof decreased the weight of the material hauled and spread on the fields on one of the study farms by approximately 70%. Sand, used on the other farms for bedding and to improve footing, increased the weight of the raw manure and the compost hauled. Producers with sand bedding cannot expect to get the same percentage weight reductions from composting that those with little or no sand in their livestock housing can expect.

On a farm where extra organic material in the form of com stalks and straw was added to increase the carbon to nitrogen (C:N) ratios and speed composting of the bedded pack, the use of compost decreased estimated farm average erosion despite this additional residue harvest.

The total estimated runoff P losses from windrows in this study were small compared to estimated runoff P reductions from applying compost vs. bedded pack to cropland.

Although composting infrastructure costs can be lower than other forms of storage, composting increases manure handling costs compared to simply spreading the raw manure. Costs per pound of P reduction with composting will vary from farm-to-farm, depending on the farm's facilities and handling equipment and the extent of the runoff P loss reduction.

Introduction

The Yahara Watershed is a 536-square-mile area which spans three counties, 87% of which is in Dane County (299,665 acres) with smaller acreages also located north in Columbia County (17,694 acres) and in Rock County to the south (26,115 acres). The lakes have an excess of phosphorus (P) which is contributing to eutrophication.

Wisconsin is one of the first states in the nation to establish numeric P water quality standards for lakes and streams. The 2010 phosphorus rule making also included an innovative regulatory compliance option for addressing P pollution called Watershed Adaptive Management (MMSD, 2017). Rather than traditional, costly engineered solutions, this law allows regulated wastewater point source to work together with nonpoint sources (agricultural producers, municipal storm water utilities etc.) on cost effective strategies that comprehensively target P reduction while achieving water quality criteria. The first major adaptive management project in the state and nationally, called Yahara WINs (Watershed Improvement Network) is being led by the Madison Metropolitan Sewerage District (MMSD), a regulated regional sewerage district located in the Yahara watershed. It calls for a 50% reduction in annual P loading. In addition, the EPA has approved a Total Maximum Daily Load (TMDL) for P and sediment in the Rock River Basin, which includes the Yahara Watershed.

Although there significant efforts to reduce the P entering the Yahara lakes from all urban and agricultural sources, controlling P loading from runoff following manure application to cropland is a priority. In addition to innovative manure digesters and nutrient concentration systems, farmers are exploring the use of manure injection, cover crops and composting systems. Animal manure application to cropland provides nutrients for crops and returns organic matter to the soil. It can also, however, lead to increased P loading to nearby surface water via runoff. This is especially true with winter applications on frozen soils.

Livestock are located throughout the county, but have the highest density in the Upper Yahara Watershed. As of 2012, there were 143,090 animal units (1,340 farms) in Dane County, 79,303 (291 farms) were located in two subwatershed north of Lake Mendota (Figure 1). Of the farms in the watershed, 84% are dairy (79,303 animal units), 14% beef and 1.8% swine.

In the Upper Yahara subwatershed, the equivalent of 106 million gallons of manure is generated on operations without storage capacity (Larson et al. 2016). This manure must be spread throughout the year, including during the winter. In the subwatershed, manure storage is correlated with farm size (Larson et al., 2016). To illustrate, 10% of the smallest farms (0-100 animal units) had manure storage, compared to 35% of medium sized farms (100-250 animal units) and 85% of larger farms (251-999 animal units). Manure on farms without storage has to be applied to cropland (typically before crops are planted or after harvest) whenever it is removed from a livestock housing facility or, if no cropland is available for spreading because crops are in the field, it has to be stockpiled until the fields are open.

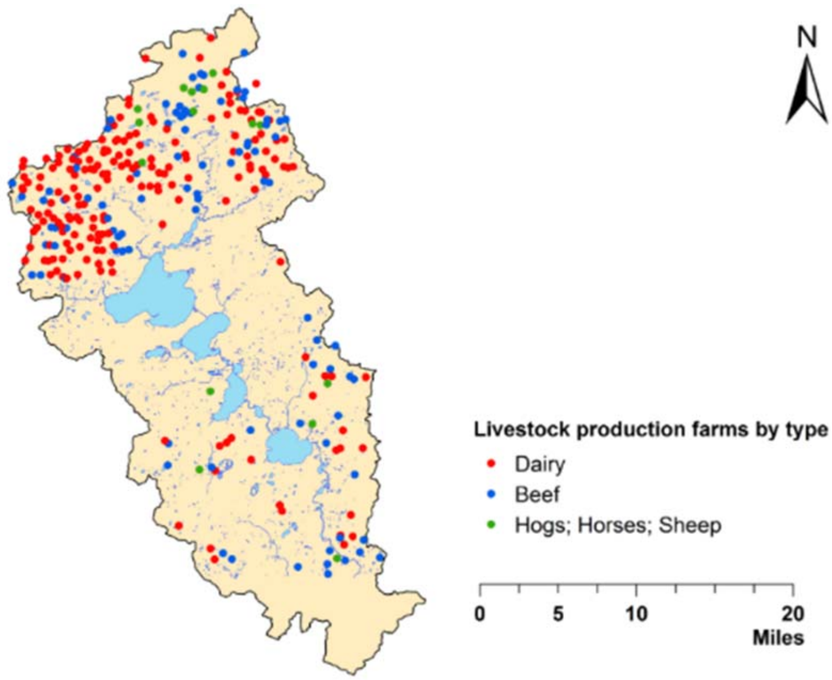

Figure 1. Distribution of Livestock Farms in the Yahara Watershed (Larson et al., 2016)

The report by Larson et al. (2016) indicated that more manure P is generated in the Upper Yahara watershed than is removed by crops. Potential solutions to addressing manure P in the Yahara watershed are to remove manure P from the watershed or redistribute it to other locations within the watershed that are P-deficient. For any larger-scale redistribution effort to be feasible, manure densification (or concentration of the nutrients in manure) to reduce the volume and hauling costs associated with transport will be required. Composting is one method of manure densification.

Windrow composting is an alternative to storage or stacking. Windrowing, or controlled decomposition by piling organic material in rows and turning regularly to aerate, is an ancient and relatively cost-effective method of processing animal manures (NRAES 1992, USDA-NRCS 2010). Composting can improve the chemical, physical and biological characteristics of soil, improving water retention and soil structure (Cooperband, 2002). It can also make manure nutrients easier to handle and transport. Manure windrows dry down and can decrease in volume and weight through the aerobic oxidation of organic materials. Ideally, the resulting composted final product is dryer, easier to spread and has a higher concentration of P and other plant nutrients. Compost also is a valuable resource with market potential, used by farmers, landscapers, nursery managers, greenhouses, engineers and road-building contractors to improve soil fertility, health and structure.

On dairy farms, heifers that are six months and younger are typically housed separately (from lactating cows) in group pens where they are fed and cared for until they reach breeding age. They are generally bedded with corn stalks, straw, wood shavings or sand. In addition to heifers, calves and steers are also often housed in buildings with bedding, even on farms where the manure from the dairy manure goes into a liquid storage pit. This solid manure, or “bedded pack,” (approximately 20-25% of a dairy farm’s total manure) is managed separately from the liquid manure produced by lactating dairy cows (often stored in concrete tanks and spread in the spring and fall). Heifer pens are typically cleaned daily or weekly and the bedded pack manure is spread directly (not stored) onto cropland.

Compared to hauling the solid bedded pack manure, composting offers farmers several advantages. Composting gives greater flexibility in the timing for land application. Manure can be windrowed rather than applied to cropland over the winter months. The final product is often drier and easier to manage, which can facilitate transporting it to fields that need P where it can replace fertilizer inputs. In addition, compared to raw manure, it is less "hot" (containing less ammonia-nitrogen) and can be spread onto alfalfa fields without damaging the growing plant tissue. This effectively gives farmers more acres (alfalfa plus corn and soybean cropland) to spread the bedded pack manure.

A 2015 USDA Farmer Rancher SARE funded project in the Upper Yahara Watershed showed promise that composting heifer bedded pack manure was a feasible practice and provided an alternative for winter-applying solid heifer manure. For the last two years, three members of Yahara Pride Farms have been working with UW Madison on this research project through grant funding secured by Clean Lakes Alliance from the Fund for Lake Michigan to determine whether composting can lead to reductions in P runoff loads from their farms. Our objective was to compare modeled runoff P losses from applications of manure from livestock housing to those from composted manure. Secondary objectives were to document the agronomic benefits and costs associated with composting and to evaluate the costs per pound of runoff P reduction.

Methods for comparing compost to raw manure applications on three farms

We collected samples of the raw (not composted) bedded pack manures and compost at beginning, middle and end stages of composting. The samples were analyzed for total P and moisture content with the routine manure nutrient analysis at the University of Wisconsin Soil and Forage Analysis Laboratory in Marshfield, Wisconsin. Samples collected in 2017 were also analyzed for ash content. Jim Richmond in Peter Vadas' lab at the US Dairy Forage Research Center in Madison analyzed the samples for water-soluble P using a 1:250 manure:water extraction selected to represent the maximum amount of P that can be lost from the manure or compost in storm event runoff (Vadas et al. 2004).

Composting allows farmers to apply manure nutrients at times and locations where they would not have been able to apply the raw manure. We interviewed the farmers to identify what fields and when they spread the compost and where they would have spread the raw manure. On two of the farms, we were able to obtain their SnapPlus nutrient management plan database for the whole farm, and for the third, we were only able to obtain it for the satellite farm where the compost was applied. SnapPlus (Good et al. 2017) is a software program that allows Wisconsin farmers to do field-by-field, year-by-year fertilizer and manure application planning and estimate erosion and runoff P losses for each field. SnapPlus calculates erosion using the Revised Universal Soil Loss Equation v. 2 (RUSLE2) and runoff P losses using the WI P Index (Good et al. 2012). See Appendix I for a description of the P Index and SnapPlus.

The SnapPlus databases include records of crops grown, tillage operations, and fertilizer and manure applications for each field. We were able to use these databases to establish past manure and compost spreading and crop management. We extended the crop rotations into the future (2017 to 2023) in the software and made two databases for comparison. In one, we entered the raw manure applications and in the other the compost applications. For the database with manure, we applied all of the manure in the season it was generated, and for compost, we applied all of the compost that would result from that manure in the year it was generated. With these databases we calculated and compared the P Index and erosion with and without composting. Details and results for each farm are below.

Figure 2. Windrow Composting Under Roof

Farm A: Year-round composting under roof

This farm composts the manure from 400 mixed age heifers year-round. In 2017, the farm completed installation of a composting building with a roof and concrete floor. The estimated annual raw manure production is 3300 tons plus 220 tons corn stalks, straw or other organic bedding material. The compost windrows are constructed by combining manure and bedding cleaned from different buildings with wetter and drier manures. Moisture of the windrows is altered depending on the condition of the starting windrow. If the windrow is too wet, additional dry organic materials are added. If too dry, liquid manure may be added to increase the moisture of the windrow. Over the two years, this farm has used various types of off-farm organic materials including sawdust and ground corncobs for bedding and mixing with the windrow. They have also used sand as part of their bedding. The nutrient analysis of the finished compost has varied somewhat over the course of the project. For our comparison, we used an analysis from the fall of 2017 that contained some ground corncobs and comparatively little sand.

Table 1. Characteristics of raw heifer bedded pack and compost used in Farm A comparison

	Tons applied annually	Total P lb/ton	P_2O_5 equivalent lb/ton*	Dry matter %	Water-soluble P % of total P
Heifer bedded pack	3500	2.9	5.3	26	35
Compost	1000	9.9	18	57	12

*Replacement value for fertilizer (80% of total P_2O_5 equivalent).

The tonnage of compost this farm spreads is approximately 30% of the tonnage of the raw heifer bedded pack (Table 1). The tonnage reduction is a result of the drop in moisture content from 26 to 57% plus loss of organic matter through decomposition. Larney and Buckley (2007) found organic matter losses of 39.8% from composting and 22.5% from stockpiling manure. While the amount of organic matter applied in the compost is reduced, the amount of P applied to the fields is about the same. In this scenario, the amount of P applied in compost is 3% less than that applied in heifer bedded pack. Although P is commonly assumed to be completely conserved in indoor composting (USDA-NRCS 2007), Larney et al. (2008) documented unexplained P losses of 5.9% during composting under roofs.

The water-solubility of the P in the compost was a third of that in the raw manure (Table 1). The P Index equations use water-soluble P in manures and compost to determine how much dissolved P is likely to run off following surface application. Reduction in P solubility from composting was noted in previous research (Larney et al 2014, Sharpley and Moyer 2000). In the current version of SnapPlus, the assumed percent solubility for both solid dairy/beef manures and compost is 40%. In our analysis, we adjusted the percent solubility of each of these amendments to reflect the measured values.

This farm has dairy cows and swine, in addition to the heifer operation. Its nutrient management plan includes all of these livestock operations and 1200 acres in 64 fields located on several satellite farms. Not all of the farm's fields get manure from the heifer operation. We identified fields where compost or solid manure had been spread in previous years and selected a subset of the farm's fields as the "farm" for the analysis. This subset included 26 fields and 427 acres. For this subset we examined the crop and tillage records and plans for future years to 2023. The planned years did not extend to 2023 for the majority of the fields in the database we received for the farm, so we assumed the current crop rotations and tillages would carry on into the future. Many of these fields had manure applications from the dairy cows or swine and we kept those applications in the future management. Crops include corn grain, corn stover, corn silage, winter wheat plus straw, alfalfa, barley plus straw, soybean, and small grain and legume silage. Many crop years had reduced tillage (no-till, strip till or vertical till). Some fields have edge-of-field grass filter areas.

With future crops and operations completed, we made two copies of the database. In one, we entered 3500 tons of the heifer bedded pack applications in each year and in the other we entered 1000 tons of compost applications in each year.

Heifer manure scenario: In SnapPlus, manure and fertilizer are applied by season. We assumed that the manure would be applied on a routine basis after buildings were cleaned and would therefore be spread equally in all months. Winter, when the ground is likely to be frozen, snow-covered or saturated from thawing, was assumed to be four months (December through March). Thus, 1100 tons were distributed in winter and 800 tons were distributed in each of the other three seasons. The rates applied were selected so as not to exceed recommended crop nitrogen guidelines (Laboski and Peters 2012, USDA-NRCS-WI 2015). Winter manure was applied to corn or other row crop fields without an over-wintering crop like wheat or alfalfa. Summer manure was applied following winter wheat harvest as those were the only fields available in the summer. In two of the years there was not enough acreage in winter wheat on this farm to accommodate the heifer manure applications so manure was assumed to be stockpiled until fall. In every year, there would likely be some stockpiling from planting in May to July wheat harvest. No manure was applied to established alfalfa to avoid damage to the alfalfa as per this farm's management. All manure was surface-applied (not incorporated by tillage).

Compost scenario: In the database with compost, we assumed that the manure could be windrowed over the winter and thus winter applications avoided. The compost was distributed equally in each of the other seasons, again not exceeding nitrogen application guidelines. Summer compost was applied to established alfalfa as per this farm's management because compost can be applied to supply P and other nutrients without damaging (burning) the alfalfa. All compost was surface-applied.

Enough corn stover and straw was harvested in both scenarios to supply the 220 tons of organic matter used in the bedding. In the compost scenario, however, an additional 100 tons of corn stover per year was harvested to account for additional organic matter used in composting. Thus our P loss estimates included the losses from soil erosion that would occur due to removal of this crop residue, a potential negative impact of composting.

No P fertilizer is used on this farm, so we did not include P fertilizer in our scenarios. Many fields have high soil test P and do not need additional P to support crop growth (Laboski and Peters 2012). There were some fields that had lower soil test P where fertilizer P was recommended. In both scenarios, crop P requirements were met by the manure or compost applications.

Farm A results: Although P Index and erosion were already comparatively low on this farm with the heifer manure, composting reduced overall estimated runoff P and sediment losses from the farm despite the increased residue removal (Table 2). Composting did not, however, reduce P losses from every field in every year. This is because manure and compost went on different crops and because some fields in the compost scenario may have had higher erosion due to increased residue removal. For example, in the first year of our scenario, the average annual P Index over the 447 acres was 2.1 with the heifer raw bedded pack manure applications, and 1.6 with the compost applications. Compost led to overall reductions, but 9 fields had no change, 8 fields had a P Index increase and 12 fields had reductions ranging from 3.2 to less than 0.1.

Table 2. Farm A reduction in P and sediment loss indicators with compost compared to raw bedded pack for 29 fields (447 acres), 2017-2023.

	Avg. rotational P Index (area-weighted)	Avg. annual P Index Load*	RUSLE2 erosion ton/acre year (area-weighted)	Avg annual Sediment Load** tons/year
Bedded pack	2.0	863	1.2	49.5
Compost	1.1	586	0.8	37.8
Reduction	0.9	277	0.4	11.7

*Annual P Index multiplied by field acres and summed for all fields and annual sums averaged, generated using the P trade report (described in Appendix I).
**This is a new calculation in SnapPlus in the Sediment Trade report, which is designed to indicate amounts of sediment that might be delivered from all of a farm's fields to the nearest surface water (Appendix I).

Averaging over 7 years of rotating crops gives a better picture of the effect of compost use on P Index values and calculated erosion for this farm than looking at just one year of losses (Table 2). The average rotational P Index for the seven-year rotation was 0.9 and the annual P load reduction as shown in the P Trade Report (described in Appendix 1) was 277 lb.

Average RUSLE2 erosion decreased by a third with compost use (Table 2). The reductions in calculated erosion with compost are attributable to the mulching effect of the additions of stable organic matter to the soil surface. Even though more organic matter was applied per acre in the bedded pack scenario, the nature of compost made it more effective in reducing modeled erosion. Surface applied organic matter additions have a mulching effect and compost, because it is more stable, is a longer-lasting mulch. In the RUSLE2 residues database, manure similar to the bedded pack manure (20-40% dry matter content) has a surface residue decomposition half-life of 20 days, while compost is expected to last more than 4 times longer with a decomposition half-life of 87 days (USDA-NRCS 2017).

Calculated runoff P reductions are partially attributable to the reduction in erosion resulting from the compost. They are also a result of compost decreased P water-solubility, the lack of winter applications, and the placement of a portion of the compost on alfalfa fields in the summer, a location that has very little runoff and erosion to transport P from the field. By running the SnapPlus P Index calculations with different solubility and RUSLE2 residue settings, we found that 61% of the reduction came from timing and placement of the compost applications compared to the manure, 38% came from the stability of the compost, and 11% came from the lowered P solubility of the compost.

We present the above results with one caveat: the P Index equations may be overestimating P losses from winter applications of the heifer pack manure and, consequently, the runoff P loss reductions with compost may be overestimated. Recent snowmelt runoff research has indicated that the P Index equations may be overestimating P release in snowmelt from solid manures but not for liquid manures (Peter Vadas, personal communication). There is not presently enough information to determine if the equations are actually overestimating runoff P from solid manures and, if they are, the extent of the over-estimation. Peter Vadas of USDA-Agricultural Research Service is leading ongoing research to understand P release from solid manures in the winter.

Farm B. Year-round out-door windrow composting

The second farm composts manure from about 200 steers and 25 cows housed on a satellite farm several miles from its home dairy farm. Corn stalks, straw and sand are used for bedding. Each week, about 90 tons of manure bedded pack are removed from the building and about 40 tons of new sand are added for bedding. No additional organic materials are added to the bedded pack when windrows are formed. This farm has been applying some of this manure after clean-out and stockpiling the rest in outdoor piles until fields become open for spreading. In the last two years, only a portion of the manure produced on this satellite farm was composted in outdoor windrows, but the farm intends to compost year-round from now on. We made the same comparison of P losses using SnapPlus software for this farm as for farm A, assuming all of the manure generated annually is applied either as bedded pack or as compost.

Ash is the material remaining after exposing an organic sample to very high heat so that all of the carbon will burn off. On this farm, both compost and bedded pack samples had dry matter ash contents ranging from 78 to 89%. For comparison, the ash content of the compost for Farm A was 34%. Such high ash contents indicate that much of the weight of the compost is from the sand bedding. Using the previously described ratio of 40 tons sand applied for 90 tons bedded pack removed, the bedded pack itself was likely to be greater than 40% sand by weight. Over the course of the project, variations in sand content in the compost and the bedded pack seemed to lead to variations in nutrient contents by weight. This is expected since the sand has little or no nutrient value compared to the organic material in the bedded pack.

Figure 3. Outdoor windrows

For our comparison, we used manure and compost analysis from samples from the fall of 2017. We lowered the dry matter percentage of the compost when we entered it into SnapPlus to represent the part of the compost that was actually organic material and not sand. Composting reduced P solubility by half (Table 3), and, as with farm A, the manure and compost solubility was adjusted in SnapPlus to reflect this difference in the P Index calculations.

Table 3. Characteristics of raw heifer bedded pack and compost used in Farm B comparison

	Tons applied annually	Total P lb/ton	P_2O_5 equivalent lb/ton*	Dry matter %	Water-soluble P % of total P
Bedded pack	4500	4.4	8.1	59	35
Compost	4150	3.9	7.1	44	17

**Replacement value for fertilizer (80% of total P_2O_5 equivalent).

In contrast to farm A, composting resulted in only an 8% reduction in the estimated annual tonnage of material applied to farm fields (Table 3). The high content of sand is partially responsible for the low tonnage reduction. Outdoor windrows of manure mixed with sawdust and sand bedding had a range of reductions that were about a third of those for manure-sawdust compost alone in experiments by Michel et. al (2004a). In addition to sand, this small tonnage reduction is because the outdoor compost contained more water (lower dry matter percentage means a higher moisture content) than the original bedded pack. Compared to windrows made under cover, outdoor windrows of finished compost can gain moisture from rain. Michel et al. (2004a) also found that rainfall on finished compost could result in moisture contents greater than the windrow starting material, as is the case with this farm's compost.

Outdoor manure composting windrows and manure stacks have been shown to lose P during the composting processes as well as nitrogen and other nutrients. Michel et al. (2004b) measured P reductions of 1 to 38% in straw-manure composts and 12 to 21% in sawdust-manure composts over 4-5 months of outdoor-composting. The researchers presumed these P losses were from runoff and leaching. Lacking a way to measure P losses in the field from manure stockpiles and compost piles on this farm, we assumed for this comparison that 10% of the original P was lost through stockpiling before application of the bedded pack or windrow construction, and an additional 10% was lost from the windrows.

According to the SnapPlus records, bedded pack manure was routinely applied to fields on this satellite farm and one several miles away. We chose these two satellite farms, with 23 fields on 294 acres, as the subset of farm fields for the bedded pack and compost comparison. One of the farms had sandy and sandy loam soils while the other's soils were silt loams. Both had steep land with 9% or greater slopes present in all of the fields. As with Farm A, we extended the existing crop rotations, tillage and manure and fertilizer applications recorded in the SnapPlus database to go through the year 2023. Crops grown included corn grain and stover, winter wheat and straw, corn silage, winter rye followed by corn silage, oat-pea forage with alfalfa seeding, and alfalfa. Tillage varied with most fields having no or minimal (one-pass) tillage in most years. Minimal P fertilizers were applied to these two farms with none recorded for 2017 or planned for the following years, so we did not include P fertilizers in the analysis. Although there were some fields that had soil test P sufficiently low that P was recommended for crop growth (Laboski and Peters 2012), in the bedded pack and compost P requirements were met by the P in the manure or compost applications.

Bedded pack scenario: For the bedded pack scenario, 1500 tons of manure were applied in the winter to corn fields, and 1000 tons were applied in each of the other seasons. No applications were made to established alfalfa. Summer applications were following winter wheat harvest, which presumes manure generated after planting was stockpiled until the harvest. Rates of application were limited to the nitrogen need for row crops. In two of the years from 2017 to 2023 there was not enough wheat acreage to apply the manure in summer and we entered that additional manure as fall applications, again assuming stockpiling.

Compost scenario: Compost was not applied in winter. Some was applied at low rates in the summer to established alfalfa and the rest was applied in approximately equal amounts in the fall and spring to row crops and seeding alfalfa. Compost application rates were again limited by the nitrogen need for row crops.

Farm B results: The use of compost cut expected average annual runoff P losses from these two satellite farms by about a third (Table 4). Overall estimated P load reductions were larger on this farm with composting compared to Farm A (426 vs 227). This is because starting losses were higher (bedded pack P Index of 6.4 vs 2.0 for farm A) due to steeper fields with more erosion and higher per acre P application rates. The reasons for runoff P reductions were the same as for Farm A: compost's stable organic matter, compost's reduced P solubility, and no winter applications, with the added reason that 10% less P was applied as compost to account for runoff and leaching losses from the windrow.

Table 4. Farm B reduction in P and sediment loss indicators with compost compared to raw bedded pack for 23 fields (294 acres), 2017-2023.

	Avg. annual P Index (area-weighted)	Avg. annual P Index Load (lb)*	RUSLE2 erosion ton/acre year (area weighted)	Avg annual Sediment Load** tons/year
Bedded pack	6.4	1394	2.8	56
Compost	4.3	968	2.2	42
Reduction	2.1	426	0.6	14

*From the P Trade Report described in Appendix I.

**This is a new calculation in SnapPlus in the Sediment Trade report, which indicates amounts of sediment that might be delivered from all of a farm's fields to the nearest surface water (Appendix I).

Compost windrow runoff P losses: Since we assumed that P was leaving the compost windrow through runoff and leaching, we attempted to quantify the runoff P losses from the windrow to ensure that they do not negate the reductions from field application of compost. We assumed that most of the losses would be in the dissolved form because Larney et al. (2014) measured P in compost windrow runoff and found it was 95% dissolved P. We estimated runoff P losses from the windrow by estimating average annual runoff volume and the concentration of dissolved P in that runoff.

To estimate the average amount of runoff annually from these windrows, we used the runoff curve number equation with a windrow runoff curve number of 81 (Tollner and Das 2004). We calculated average annual runoff from the windrows of 4.8 inches using 20-year, 24 hr. precipitation-and-snowmelt-runoff-event histograms for Dane County developed by the SnapPlus programming team. With year-round composting, we estimate that, on average, a quarter of the annual manure production would be in a windrow at any one time, with a total collective footprint estimated at 41,600 ft^2. Runoff of 4.8 inches from this estimated footprint would produce 471 ML water.

To estimate the runoff concentration, we used the relationship between compost water-soluble P (WSP) and windrow runoff total dissolved P (TDP) found by Larney et. al (2014) of TDP mg/L = 6.1+0.042 WSP mg/kg (R^2=0.68). The compost:water ratio used in the water-soluble P testing in that publication was 1:20 and ours was 1:250, so we used a conversion from Vadas et al. (2004) to get an average windrow WSP of 240 mg/kg and an average runoff TDP of 16 mg/L .

These calculations resulted in an estimate of 17 lb TDP in runoff from the windrow annually, about 0.5% of the total P in the windrow and 4% of the estimated reduction in cropland runoff P losses with composting. This suggests that to obtain the 1-38% windrow P losses previously described (Michel et al. 2004), a large amount of P would need to be lost via leaching into the soil beneath the windrow. We did not model this leaching, but it is likely that the windrow area has a high soil P concentration. The possibility of leaching makes it important to site windrows in places with low risk of leaching to groundwater. More considerations for windrow siting are outlined in Appendix II.

Farm C: Seasonal windrow composting

This farm begins windrowing manure from approximately 65 calves and 25 cows in the summer and composts until the crops are off in the fall. The farm spreads 1200 lb. of sand per month in heifer pens.

The sand is spread on the floor after the pens are cleaned. Cornstalks and/or straw are added for bedding over the sand.

Table 5. Characteristics of raw heifer bedded pack and compost from Farm C.

	Total P lb/ton	P_2O_5 equivalent lb/ton*	Dry matter %	Water-soluble P % of total P
Bedded pack**	6.9	12.5	37	38
Compost	3.4	6.3	46	18

*Replacement value for fertilizer (80% of total P_2O_5 equivalent).
** Bedded pack collected from pen without sand.

Table 5 compares the raw bedded pack to compost on this farm in the fall of 2017. In this case, the bedded pack was collected from within the pen without collecting the sand from the floor. The P concentration of the compost is lower than that of the bedded pack, even though the dry matter content of the compost is higher. That is probably due to the dry matter in the compost having a high percentage of sand. When the bedded pack is cleaned from the building, the sand goes with it. The ash content of farm C's compost (84.5%) is almost as high as that for Farm B (87.1%). The ash content of the bedded pack collected from the pen without sand was 23%. Similar to Farm B, the water-soluble proportion of total P was about half as high in the compost as in the raw manure.

In 2016, this farm took their finished compost to a 13-acre field on another farm they operate outside of the watershed. That farm has flat fields with sandy soils that have a very low runoff and erosion potential. Consequently, the P Index values on that farm were very low. Adding 15 tons per acre containing 95 lb. P_2O_5 fertilizer equivalent to chisel-plowed corn for grain did not increase the P Index of this field above 1. The reason for hauling the compost to the distant farm was not to meet P needs as soil test values there were already above the level needed to meet crop requirements. The farmer's intent was to add organic matter to the sandy soil that was lacking it. Ironically, much of the weight of the compost hauled was sand.

In order to quantify the runoff P reduction from removing the compost from the watershed, we estimated losses as if the raw manure had been applied to corn fields on the original farm at a similar P rate (7.6 ton manure/acre). We did not obtain the SnapPlus database for the farm where the compost is generated, so we chose two fields near the windrow and entered them into SnapPlus with assumed management and soil test values. One is flat (1% slope) and the other is steep (9%). Both have silt loam soils. We assumed the flat field was in corn silage, the steep field in corn for grain, the manure was fall-applied, and both fields were chisel plowed in the spring with a secondary cultivation before planting. We calculated the P Index with no manure and with bedded pack. This farm may apply their 2017 compost locally, so we also included a comparison with compost. For the compost, we lowered the dry matter percentage to represent just the organic portion so as not to overestimate compost dry matter applications for the RUSLE2 soil loss calculations.

Judging by the P Index difference between the no manure and the bedded pack shown in Table 6, removing the P from the watershed was equivalent to lowering the P Index by 2 or more on 13 acres. Compost also lowered P Index values compared to the raw manure. In this comparison, the manure and compost were applied to the same field in the same season, so the modeled benefits come from lowered P solubility and reduced erosion rather than differences in crop and season of application. Both the manure and compost reduced estimated erosion compared to the unmanured field, but the compost decreased it more (Table 6).

Table 6. P Index for corn grain fields on Farm C with no manure and with unincorporated raw bedded pack or compost applied at equivalent P rates (95 lb P_2O_5).

	No manure		**Bedded pack**		**Compost**	
	P Index	**RUSLE2 erosion T/acre/yr**	**P Index**	**RUSLE2 erosion T/acre/yr**	**P Index**	**RUSLE2 erosion T/acre/yr**
Flat field, corn silage	1.4	1.3	4.1	0.9	3.3	0.8
Steep field, corn grain	1.7	2.2	4.1	2.0	3.7	1.7

The P Index values in Table 6 are shown to one decimal place, even though they are reported in SnapPlus in whole numbers (See Appendix I), to show where there are modeled differences that would not be apparent to the general user. For example, on the steep field the P Index is 4.1 for with bedded pack and 3.7 with the compost and both would be reported as 4 in SnapPlus. This shows that under some field management scenarios, the benefits of composting may be difficult to detect.

As with farm B, we estimated the windrow runoff dissolved P losses. Using the same methodology, we calculated 1.5 lb. dissolved P in windrow runoff.

Farmer Compost Management Considerations and Benefits

Farmers we talked with explained that other farmers in the Yahara watershed appear interested in exploring the use of composting for their livestock bedding pack manure. One reason is the growing awareness that spreading pack manure on melting snow is not the best way to use the nutrients in the manure. Most farmers don't like to spread manure in the winter. It is tough to manage; it is cold and the manure tends to clump. Composting dries the manure down, saving on hauling costs, and makes the manure a better, easier product to spread. In addition, farmers are stuck in a position of having to clean out livestock barns to maintain animal health, but they don't have the time or resources to double handle the manure.

The farmers in this study have gained expertise in composting, and the quality of the compost being made by some is very high. The project has shown that P in the manure is in a less soluble state and the organic matter is more stable than raw manure.

Other advantages of composting cited by farmers include:

- Composted manure can be applied to alfalfa hay. *Raw manure can damage the alfalfa, so farmers who have alfalfa fields that require P typically use commercial fertilizer rather than manure.*

- Pathogens in manure are greatly reduced through the composting process. *If temperatures within the windrow are maintained above 131 degrees F for four hours on three consecutive days, most pathogens and viruses are killed (Bonhotal and Schwartz 2009).*
- Compost contains higher concentrations of nutrients and less moisture than manure. *This is generally true, although the farmers with outdoor windrows in this study have experienced times when compost had high moisture content due to rain. Even the compost under roof had a relatively high moisture content in late winter due to cold temperatures.*
- Compost has more flexibility for land applications and/or selling off the farm.
- Composted manure can be a source of bedding. *Farm A is currently using 25% of its compost for bedding.*
- Compost can be a saleable product and farmers are exploring four markets: sold to other farmers as a soil amendment, as a bioengineered soil sold in counties with strong storm water ordinances (Dane and Fond du Lac among them), sold as mulch, or as bedding.
- Purchased P fertilizer is expensive. Livestock farmers seem intrigued by the idea of producing their own P fertilizer and lowering their fertilizer costs. They think a compost with urea might be a particularly beneficial and workable product.
- Yield increase in alfalfa. *One farmer reported a 10% increase in alfalfa from compost spreading.*
- The capital outlay for a composting facility is less than manure storage tanks.

A convenient way to begin composting is via headland stacking. A headland stack is a pile of manure (or a windrow) that is stored on soil at the edge of a crop field until fields are ready for manure application. Often these areas of the field are lower in yield due to tractor compaction. To manage compost windrows effectively, however, and for the high temperatures needed for pathogen reduction, compost guidelines recommend that they should be turned at least weekly (NRAES 1992). This is accomplished by use of a "compost turner," a large piece of equipment that straddles the windrow. As the windrow is turned, oxygen is added and waste gases are allowed to vent, speeding decomposition. For this research project, YPF farmers rented a compost turner owned by a small company that circulates across the state. This meant that scheduling weekly turns for all three farmers was not possible, resulting in a less efficient composting process. Despite the irregular turning schedules, all three produced a compost that had lowered P solubility.

Farmers in the study said they are interested in getting others farmers to adopt composting as a practice for bedded pack manure and have received a grant to expand the practice to 8 other farms. A dairy farmer and YPF member, Jeff Endres, designed and built a unique and effective compost turner that will be used to turn the piles on these new farms. Farmers are also interested in exploring the feasibility of a farmer-owned compost facility; or perhaps a facility built in partnership with a local agricultural cooperative, where compost can be produced, sold, and redistributed to areas outside of the watershed and/or to areas where soils are low in P for crop production.

Right now the three farmers said they could use all the compost they produce and estimated the compost is worth approximately $25-30/ton in terms of nutrient value alone. One farmer reported a yield increase of about 0.5 ton/acre in alfalfa yield. With October 2017 hay prices at $120/ton, this yield increase for alfalfa was estimated at $60/acre. Applying compost to 40 acres of hay would give the farmer an additional $2400 in value compared to not applying compost. This yield bump is something they would consider in setting the price point to sell compost off farm.

The average cost right now or garden-type composts sold bulk is $40-60/ton, or $20-30 wholesale, not high enough to incentivize a dairy farmer to sell their compost. However, YPF farmers are interested in exploring higher paying compost and bioengineered soil markets in golf course and landscaping (turf, turf and shrub landscaping, planting beds) that can range from $50-150/ton (Biernbaum, 2016). Bioengineered soils, in combination with plant materials and engineered practices have been shown to increase water storage and infiltration and reduce wind erosion, surface water erosion and improve water quality compared to use of hard, non-living materials.

Cost of composting compared to P Index reduction

Research from the University of Wisconsin found windrow composting can be an economical method for managing manure compared to other manure storage/handling systems (Klemme and Holmes 1996). We estimated that composting under roof is costing Farm A about $15,960 per year more than spreading the raw manure. The cost calculations are detailed in Appendix III. By dividing these costs by the estimated average annual P Index load reduction of 277, we find a cost per P Index lb of $58. This compares favorably to the costs estimated by Larson et al. (2016) for adding manure storage, with capital costs ranging from $18 - $81 and handling costs of an additional $93 - $415 per pound P reduction delivered to Dane County surface waters (calculated with the P Index). We do not have detailed cost information for Farm B, but overall composting costs would be lower than for farm A because there is no building. On the other hand, farm costs for spreading the compost in the fields would be only slightly less than for the raw manure because composting reduced the tonnage hauled by only 8% (Table 3). In addition to the potentially lower costs, the cost per P Index lb load reduction would likely be less because the load reduction was greater. Compost use decreased the P Index load on that farm by 426 P Index lb (Table 4). Costs per pound of P reduction with composting will vary from farm-to-farm, depending on the farm's facilities and handling costs and on the amount of reduction. The amount of reduction will vary with field erosion and runoff rates, existing soil P stores, the amount of manure composted, and manure and compost application rates and timing.

Conclusions

Composting involves more handling than spreading raw manure, but gives farmers flexibility in when and where they can spread. It can dramatically reduce both the weight and volume of the original material, concentrating the manure nutrients and making it less costly to transport and spread. We found, however, that sand used for bedding added a substantial amount of weight to compost.

Composting livestock manure on three dairy farms in Dane County, rather than spreading the raw bedded pack manure, reduced the estimated runoff P load from all of the farms. The mechanisms for reduction were: compost allowed flexibility in the timing (avoiding winter spreading) and selection of lower risk fields for application, the stable organic matter in compost helped reduce erosion, and composting decreased the water-solubility of the P in the raw manure. To quantify the reductions, we looked at annual P Index values over time for all of the fields that would have had manure, and all of the fields that received compost because the same fields that would have had manure may not have received compost in any given year. The amount of P runoff reductions from composting varied from farm-to-farm and were greater on Farm B, where the initial losses with runoff manure were relatively high (6) due to more erosion and higher long-term P application rates, than on Farm A, which started with much lower average P Index values (2). Runoff from the windrow will contain high concentrations of dissolved P, but total losses are unlikely to offset the P reductions from field applications of compost compared to raw manure.

References

Biernbaum, J. 2016. Compost production and use for small and mid-sized farms. April 13, 2016. Michigan State University.

Bonhotal, J. and M. Schwarz. 2009. Environmental effects of mortality disposal. 3rd International Symposium: Management of Animal Carcasses, Tissue and Related Byproducts Connecting Research, Regulations and Response. University of California at Davis. Davis, CA. July 21-23, 2009.

Cooperband, L. 2002. Building soil organic matter with organic amendments. University of Wisconsin Center for Integrated Agricultural Systems.

Good, L.W., J. Wolter, J. Beaudoin, R. Wayne, and S. Sebrosky. 2017. SnapPlus 17.0. University of Wisconsin-Madison. Software available for download from https://snapplus.wisc.edu/.

Good, L.W., P. Vadas, J.C. Panuska, C.A. Bonilla, and W.E. Jokela. 2012. Testing the Wisconsin P index with year-round, field-scale runoff monitoring. Journal of Environmental Quality 41: 1730-1740.

Good, L.W. J. Panuska, and P.Vadas. 2010. Current calculations in the Wisconsin P Index. Available at http://wpindex.soils.wisc.edu/calculation/ .

Klemme, Rick and Brian Holmes. 1996. Windrow Composting can be feasible, cost effective. Research Brief 20. University of Wisconsin Center for Integrated Agricultural Systems.

Laboski C. A. M. and J. B. Peters. 2012. Nutrient application guidelines for field, vegetable, and fruit crops in Wisconsin. University of Wisconsin Extension. UWEX-A2809.

Larney, F.J., A. F. Olson, J. J. Miller, and B.C. Tovell. 2014. Nitrogen and P in runoff from cattle manure compost windrows of different maturities. Journal of Environmental Quality 43:671-680.

Larney, F.J and K. E. Buckley. 2007. Dry matter mass balance estimates for composted feedlot manure. Compost Science and Utilization 15 (4):222-227.

Larney, F. J., A. F. Olson, J.J. Miller, Paul R. DeMaere, F. Zvomuya, T.A. McAllister. 2008. Physical and chemical changes during composting of wood chip-bedded and straw-bedded beef cattle feedlot manure. Journal of Environmental Quality 37: 725-735.

Larson, R.A., M. Sharara, L.W. Good, P. Porter, T. Runge, V. Zavala, A. Sampat, and A. Smith. 2016. Evaluation of manure storage capital projects in the Yahara River watershed. University of Wisconsin Madison. UW-Extension Pub. BSE 001-16.

Madison Metropolitan Sewerage District (MMSD). 2017. Adaptive Management Plan, January 2017. Available at http://www.madsewer.org/Programs-Initiatives/Yahara-WINs/Resources.

Michel, F.C. Jr. H.M. Keener, J. Rigot, T. Wilkinson, and J. Pecchia. 2004a. Effects of straw, sawdust, and sand bedding on dairy manure composting. ASAE/CSAE 2004 Annual Meeting Presentation paper no. 044030.

Michel, F.C. Jr., J.A. Pecchia, J. Rigot, and H. M. Keener. 2004b. Mass and nutrient losses during the composting of dairy manure amended with sawdust or straw. Compost Science and Utilization 12(4):323-334.

Northeast Regional Agricultural Engineering Service (NRAES). 1992. On-farm composting handbook. Cooperative Extension. NRAES-54.

Sharpley, A. and B. Moyer. 2000. P forms in manure and compost and their release during simulated rainfall. Journal of Environmental Quality 29:1462–1469.

Vadas, P.A., P.J.A. Kleinman, and A.N. Sharpley. 2004. A simple method to predict dissolved P in runoff from surface-applied manures. Journal of Environmental Quality 33:749-756.

Webber, D.F., S.K. Mickelson, L.W. Wulf, T.L. Richard and H.K. Ahn. 2010. Hydrologic modeling of runoff from a livestock manure windrow composting site with a fly ash pad surface and vegetative filter strip buffers. Journal of Soil and Water Conservation 65 (4): 252-260.

Webber, D.F., S.K. Mickelson, B.D. Whitman, T.L. 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.

USDA-Natural Resources Conservation Service (NRCS). 2007. Manure chemistry – nitrogen, P, and carbon. Manure Management Information Sheet No. 7. Manure Management Technology Development Team. East National Technology Support Center.

USDA-Natural Resources Conservation Service (NRCS). 2010. Composting. National Engineering Handbook. Part 637 Environmental Engineering. Chapter 2. USDA 210-VI-NEH, Amend 40.

USDA-Natural Resources Conservation Service (NRCS). 2017. Revised Universal Soil Loss Equation, Version 2 (RUSLE2). Available at http://wpindex.soils.wisc.edu/calculation/.

USDA-Natural Resources Conservation Service-Wisconsin (NRCS-WI). 2015. Conservation Practice Standard Nutrient Management Code 590. NRCS, WI, December 2015.

Appendix I

The P Index, P Trade Report, Soil Loss Calculations and the Sediment Trade Report in SnapPlus

SnapPlus is a software program created at the UW-Madison Department of Soil Science to help farmers manage their crop nutrients (manure and fertilizer) to protect ground and surface water quality in accordance with Wisconsin's NRCS Nutrient Management Standard 590 (USDA-NRCS-WI 2015). It is available for free download at https://snapplus.wisc.edu/.

Data input to the program are livestock numbers and manure production on the farm, field names and boundaries, routine soil test information, crops and tillage for each year of the crop, and manure and fertilizer applications (nutrient analysis, rate, season, method of application). The program links to web-based GIS maps that use the field boundaries to identify soil types, slope, slope length, distance and slope to surface water, and areas with manure application restrictions. With this data, the software calculates crop nutrient needs for the predominant soil type on every field on the farm, allowing the planner to distribute manure and fertilizer to meet crop needs.

RUSLE2 Soil Loss Calculations: The 590 standard prohibits manure or fertilizer nutrients applications to fields where erosion exceeds the fields designated soil loss tolerance (T). To aid planners with this provision of the standard, SnapPlus includes the Revised Universal Soil Loss Equation v. 2. (RUSLE2, USDA-NRCS 2017) soil loss calculator. Soil loss is reported in units of tons per acre per year averaged across the crop rotation. The calculations use soil type, slope % and length, crop, yields, tillage, organic matter additions, and practices like contouring, strip cropping and in-field grass filter strips. Following NRCS conservation procedures designed to ensure that the most vulnerable parts of the field are protected, soil loss calculations use the "dominant critical soil" instead of the predominant soil in the field. The dominant critical soil is defined as the most erodible soil that makes up at least 10% of the field.

P Index: The 590 Standard includes provisions for managing manure P using the P Index. The P Index uses the data in SnapPlus to estimate runoff P delivered to surface water. Runoff P losses are estimated for particulate P (attached to eroding particles), dissolved P from the soil, and dissolved P from manure and fertilizers applied to the soil surface. The particulate P equations use the RUSLE2 erosion calculation, and the dissolved P equations use estimates of average runoff by season for a given field's soil, management, and local precipitation patterns. Soil P concentrations and amendment P rate and solubility determine the estimated concentration of P in eroded particles and dissolved in runoff. A field-to-stream P delivery ratio based on slope and distance from the field to water is used to account for some attenuation of P in flow from field to surface water. This delivery ratio errs on the side of delivery in that it assumes that the flow from the field is channelized in something like a grassed waterway, and does not include areas of deposition or infiltration. Annual and crop rotation P Indices are calculated in pounds per acre per year, but are reported in SnapPlus without units and rounded to the nearest whole number. The 590 standard prohibits manure P applications on fields with Rotational Average P Index values over 6. The WI agricultural runoff rules (NR 151) require a rotational average P Index of 6 or less, with no annual P Index greater than 12.

P Trade Report: The P Trade Report was designed to calculate P delivery load from fields to facilitate calculating reductions for practice implementation for P trading between point sources and farmers. It uses the P Index equations, but the erosion used is based on the predominant soil type in the field rather than the dominant critical (most erodible) to avoid over-stating the loads to be reduced. The P trade report shows estimated annual P loads in pounds for every field. Note that for Farm A we did not have soil maps accompanying the database, and only one soil was entered in SnapPlus for each field. Therefore the same soil was used for the P Trade Report as for the P Index.

Sediment Trade Report*:* The Sediment Trade Report was also designed to facilitate water quality trading. It is an estimate of the sediment load delivered to surface water from fields. It uses the RUSLE2 erosion calculations and assumes that only the smaller eroded (silt and clay) particles are delivered to water. It also uses a field-to-stream delivery ratio with the same assumptions used in the delivery ratio used for the P Index and P Trade Report. The report shows estimated annual sediment loads by field in tons.

References

USDA-Natural Resources Conservation Service (NRCS). 2017. Revised Universal Soil Loss Equation, Version 2 (RUSLE2). Available at http://wpindex.soils.wisc.edu/calculation/.

USDA-Natural Resources Conservation Service-Wisconsin (NRCS-WI). 2015. Conservation Practice Standard Nutrient Management Code 590. NRCS, WI, December 2015.

Appendix II. Siting

Nutrients and pathogens can be transported from outdoor windrows to surface water through runoff and to groundwater through leaching. For this reason, windrows need careful siting. The table below shows the manure stack siting guidelines from Wisconsin NRCS Waste Storage Facility Conservation Practice Standard 313 from 2014. It gives an idea of the conditions to look for when siting compost windrows. Farms in sandy soil areas (Hydrologic soil group A), areas with runoff prone soils (Hydrologic soil group D), shallow soils, high water tables, and/or steep topography may have difficulty locating suitable composting sites.

Table 10 – Temporary, Unconfined Stacks of Manure and Derivatives Outside the Animal Production Area

1. Waste Consistencies Note 1		
	> 32% Solids	16% to 32% Solids Note 2
2. Size & Stacking Period		
Stacking Period	8 months	8 months
Maximum Volume/Stack	≤ 40,000 cu ft.	≤ 15,000 cu ft.
Maximum Number of Stacks/40 acres Note 3	–	2
Frequency of Stacking Site Use	1 year out of 2	1 year out of 3
3. *Hydrologic Soil Groups*		
	B or C	B or C
4. Subsurface Separation Distance		
Subsurface Saturation	≥ 3 ft.	≥ 3 ft.
Bedrock	≥ 3 ft.	≥ 5 ft.
5. Surface Separation Distance		
Wells Note 4	≥ 250 ft.	≥ 250 ft.
Lakes	≥ 1,000 ft.	≥ 1,000 ft.
Sinkholes, or other Karst Features	≥ 1,000 ft.	≥ 1,000 ft.
Quarries	≥ 1,000 ft.	≥ 1,000 ft.
Streams	≥ 300 ft.	≥ 500 ft.
Wetlands and Surface Inlets	≥ 300 ft.	≥ 500 ft.
Areas of Concentrated Flow	≥ 100 ft.	≥ 300 ft.
Land Slope Down Gradient of Stack	≤ 6%	≤ 3%
Floodplain	≥ 100 ft.	≥ 300 ft.
Tile lines	≥ 40 ft.	≥ 40 ft.

Note 1 Refer to AWMFH, Figure 9-1 for consistency values and Chapter 4 for % solids, for specific livestock types.

Note 2 16% to 32% solids represents waste at near saturation conditions where additions of free water from runoff, rain, or snowmelt can result in liquid flow conditions.

Note 3 The separation distance between stacks shall be at least 100 feet.

Note 4 Community water system wells may require larger separation distances (see NR 812).

Appendix III. Estimating Composting vs Manure Costs for Composting under Roof

Below are estimated costs (labor and machinery) for producing, hauling and spreading one windrow of compost (Table 1) versus the equivalent bedded pack manure (Table 2). Costs were estimated by calculating the labor and machinery costs for each step needed to prepare one 6' x 14' x 150' windrow from 6 weeks of bedded pack manure productions on farm A. The total costs were $4,877 for the compost and $3,043 for spreading the manure without composting. This amounts to a $15,960 annual cost for composting ($42,430 per year for composting - $26,470 for spreading raw bedded pack).

Costs to produce, haul and spread one compost windrow (details in Table 1)

1. Process corn stalks into bales

Assume 12 700 lb corn stalk bales/week x 6 weeks = 72 bales. 72 x 700 lb = 50,400 lb/2000 = 25.2 tons. Assume $20/ton to shred, chop, bale and haul square bales to farm.

Subtotal cost = 25.2 tons x $20/ton = $504

2. Mix and shape one windrow =

Machine costs:

a. Clean, scrape alleys - 10.25 hours (15 minutes/day x 42 days) x$75/hour machine costs= $788

b. Load bedded pack manure into 2 dump trailers - 1 x 3.5 hours x $75/hr machine costs = $263

c. Transport bedded pack to compost facility and unload – 2 x 3.5 hours x $55/hr machine = $385

d. Add corn stalks and shape into windrow – 1 x 3.5 hours x 55/hour machine = $193

e. Labor for all of the above - 24.5 hours x 15/hr = $368

Subtotal cost = $1,995

3. Finishing Compost: (Turning and building depreciation costs)

a. Farmer is charged $200/hour to turn windrow. Turn pile weekly for 12 weeks. Takes 0.5 hour to turn windrow. $200 x 0.5 hrs x 12 = $1200

b. Straight line depreciation for new compost facility; $100,000 x 5% = 5000 *11 (6 wks/52 wks) = $550. Assume the depreciation costs attributed to one windrow is $550; $100,000 building is depreciated at 5% per year over 20 years; and that a windrow is made every 6 weeks.[1]

[1] Cite: IRS Table 7.3: https://www.irs.gov/publications/p225/ch07.html#en_US_2016_publink1000218229

$100,000 x 5% = $5000

6 weeks/52 weeks = 11%

$5000 x 11% = $550

Subtotal cost: $1,200 + $550 = $1,750

4. Field spreading compost

Loading finished compost at barn onto grain truck. Assume it takes 1 person 3 hours to load compost onto a grain truck; takes 2.24 hours to reload compost onto Tebe compost spreader and spread compost.

$60/hour machine costs end loader x 3 hours = $180

1 person x $15/hr x 3 hours = $45

1 x 2.24 hours x 200/hour machine costs = $448

Subtotal cost = $678

Total costs for making, hauling and spreading 6 weeks of bedded pack = $4,877

Compost volume calculations

Beginning windrow: 7 x 14 x 150 = 12,600 cubic feet (ft3)/27 = 467 cubic yards

Finished windrow: Volume reduced 20% by mixing[2] and 40%[3] from shrinkage from composting.

Assume the initial windrow of 467 cubic yards reduces in size by 60% over the 12 weeks of composting. An initial 20% reduction in volume at the beginning in mixing and shaping the windrow; 40% reduction in shrinkage through active composting.

467 - 20% = 374 cubic yards; 374 cubic yards - 40% = 224 cubic yard

Total costs to produce, haul and spread compost = $4,877/224 cubic yards = $21.77 per cubic yard.

Total costs to produce compost for sale from farm (no spreading costs) = $18.97 per cubic yard

[2,3] Tellus Institute, Boston Massachusetts http://www.calrecycle.ca.gov/LGCentral/Library/DSG/IOrganic.htm

Table 1. Estimated cost for processing 6 weeks of bedding pack or making one windrow (6 x 14 x 150 feet)							
Note: Starting volume 467 cu yards; Final finished volume 224 cu yards.	**Equipment/process**	**Cost/hr**	**Time**	**#**	**Units**	**Cost/unit**	**Total cost**
		$	hr				$
Process corn stalks into bales							
Square bale corn stalks to use for bedding	shred, chop and bale into 700 lb square bales			25.2	ton	20	$504
Adds additional corn stalks from round bales as needed (if add free stall manure)							
Subtotal							**$504**
Initial Windrow Preparation: Clean barn and construct windows (clean shed and make 150' x 7' x 14' indrow (every 6 wks)							
Clean scrape alleys barn: push manure to pit	skid steer with rubber tire scraper	75	10.5	1			$788
Load bedding pack manure into dump trailer with a skid steer; Dump bedding pack manure nextdoor at the compost facility; Mix and add corn stalks, form into windrows	skid steer to load	75	3.5	1			$263
Two tractors with dump trailers transport bedding pack to compost facility	tractor + dump trailer, tandem axle	55	3.5	2			$385
Add corn stalks and shape into piles, windrow 7' x 14'	John Deere 310 G tractor loader	55	3.5	1			$193
	Subtotal hours x $15/hr labor	15	24.5				$368
Subtotal							**$1,995**
Finishing compost							
Pile turning (power and size of equipment)	Turner (rented)	200	0.5	12	turns		$1,200
Compost facility depreciation	$100,000 cost at 5% depreciation per anum						$550
Subtotal							**$1,750**
Field spreading of compost: Hauling to field							
loading compost at barn onto grain truck	end loader	60	3	1			$180
reload compost onto Tebe compost spreader		200	2.24	1			$448
	Subtotal hours x $15 labor	15	5.24				$79
Subtotal							**$628**
TOTAL COSTS To PRODUCE, HAUL and SPREAD compost							**$4,877**
TOTAL COSTS per cubic yard to PRODUCE, HAUL and SPREAD compost							**$21.77**
TOTAL COSTS per cubic yard to PRODUCE compost (for sale from farm)							**$18.97**

Table 2. Estimating costs for processing 467 cu yards of bedding pack							
	Equipment/process	Cost/hr	Time	#	Units	Cost/unit	Total cost
		$	hr			$	$
Process corn stalks into bales							
Square bale corn stalks to use for bedding	shred, chop and bale into 700 lb square bales			25.2	ton	20	504
Subtotal							**$504**
Clean barn, load manure, haul to field and spread							
Clean scrape alleys barn: push manure to pit	skid steer with rubber	75	10.5	1			$788
Load bedding pack manure onto a slinger spreader	skid steer to load	75	3.5	1			$0.00
Haul and spread manure (within 1 mi, 2 loads per hr)	tractor (250 hp Fent 930 Tractor) + 3500 gallon spreader (Kuhn Knight side discharge slinger spreader)	100	13.4	1			$1,340.00
Labor	$15 hr. labor	15	27.4	1			$411.00
Subtotal							**$2,539**
TOTAL COSTS Manure							**$3,043**
TOTAL COSTS per cubic yard to PRODUCE, HAUL and SPREAD manure							**$6.51**