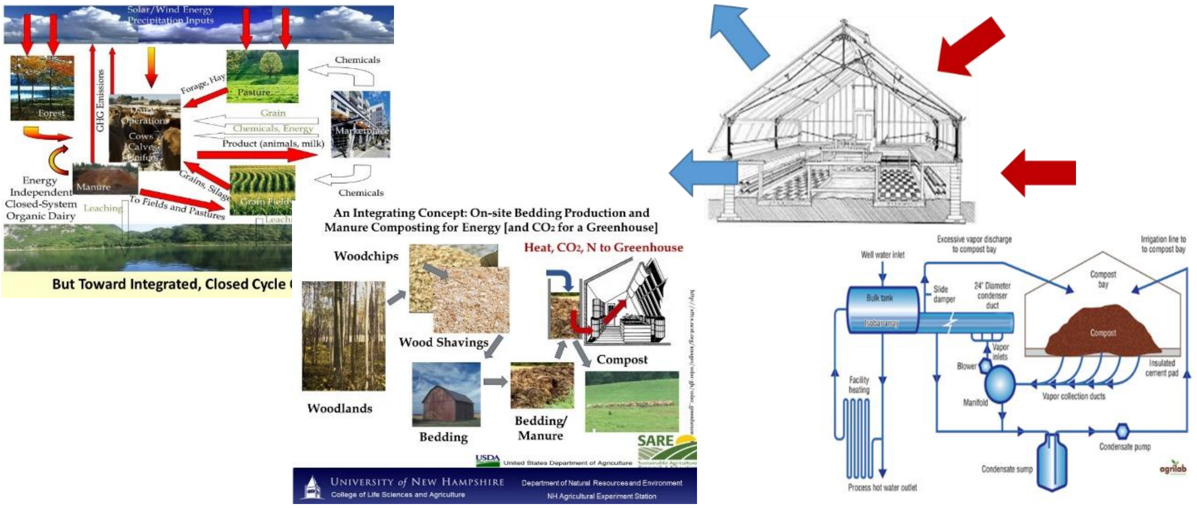
The Agroecosystem Project at the Organic Dairy Research Farm, University of New Hampshire
Summary of Results and Proposals for Applications



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Prologue: Origin of the Agroecosystem Project at the University of New Hampshire Organic Dairy Research Farm – John Aber

Introduction

"You should apply for this grant." This declaration from Tom Kelly, Director of the Sustainability Institute at the University of New Hampshire (UNH), was one of several key events that led to the research program summarized here. The year was 2007, and I had just come out of 4 years in central administration at UNH. Returning to the faculty, I had not intended to apply for any more research grants.

Tom had a different idea. The opportunity he was promoting was a new call for proposals from the USDA program in Sustainable Agriculture Research and Education (SARE). The call focused on studying agricultural systems as ecosystems, or agroecosystems. With decades of experience studying forest ecosystems, Tom figured it would be "easy" for me to apply the same concepts to agriculture. An intriguing and creative idea – not the first from Tom.

A second key event was the establishment, in 2006, of the first Organic Dairy Research Farm (ODRF) at a land grant institution. With inspiration from senior faculty member Chuck Schwab, University of Maine Extension Professor Richard Kersbergen and, again, Tom Kelly, UNH, through the NH Agricultural Experiment Station (NHAES), had converted the ~300 acre Burley-Demeritt Farm and Dudley Lot 7 miles from the main campus to an organic dairy. Investments by NHAES in this new facility were crucial to getting it up and running. As a unique facility at a unique Farm, UNH highlighted this new venture, and the birth of its first calf [76].

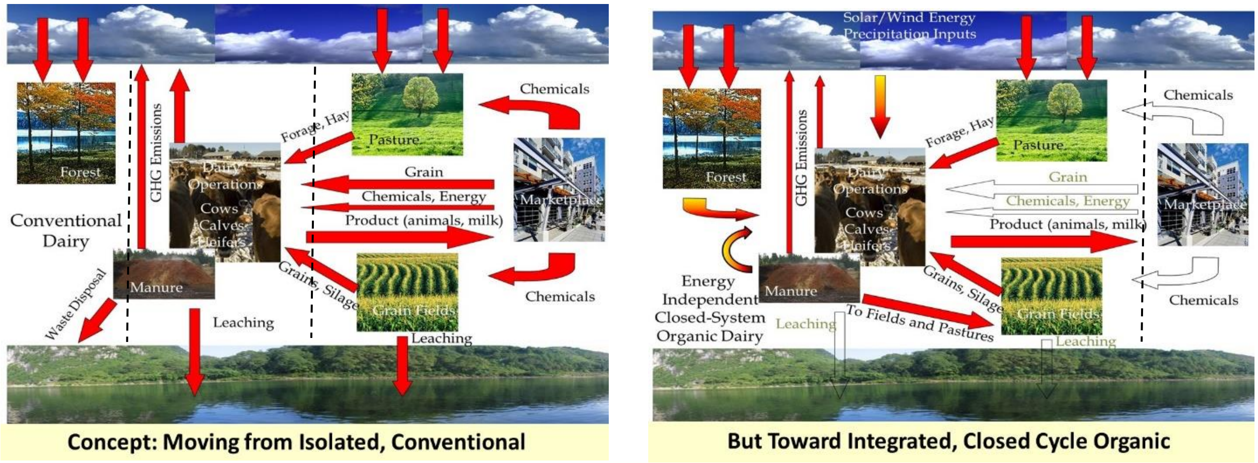
The establishment of the ODRF led to a cascade of other events that made the research reported here possible. One early opportunity was created by the paucity of research on organic dairy operations at major land grants across the country. Because of this, leaders from the 4 largest organic milk producers in the country, Stonyfield, Organic Valley, Aurora and Horizon, were drawn to the farm, providing both financial assistance and input on the needs of the industry.

Through interactions with personnel from these four producers, the lead investigators on this project had the opportunity to meet with industry reps, and from this to determine the ways in which new information might help sustain the dairy farmers providing milk to the processors, and also reduce the environmental footprint of farm operations. Our focus on bedding, energy and environmental impacts resulted in large part from these meetings.

These events together - the SARE call, the establishment of the ODRF, and interactions with industry experts - created the opportunity to pull colleagues together to look at this whole-farm system as an ecosystem. With Bill McDowell, Matt Davis, Charles Schwab and Kevin Brussel the proposal went in, and was accepted.

Structure of the Project and the First Proposal

Starting with the goal of increasing the sustainability of organic dairy operations in the Northeast, and having experience with the concept of nutrient and energy cycles, we began to consider ways of closing those cycles at the ODRF by retaining as much of the organic matter, carbon and nitrogen capital on-site as possible. The central concept of the proposal as submitted is summarized in Figure P.1.



Concept: Moving from Isolated, Conventional

But Toward Integrated, Closed Cycle Organic

Figure P.1 – The initial concept for the UNH/SARE Agroecosystem Project. The goal was to move from an isolated dairy with major commodity inputs from the marketplace and pollution outputs to the environment (boundaries noted with dashed lines on diagram to the left) to a system with increasingly closed cycles, including links to woodlands on the site and composting of organic wastes (note the single dashed line on the diagram to the right).

As the ideas for this proposal were being developed, we became aware of an innovative method for composting farm wastes that minimizes environmental impacts, speeds the composting process, and captures "waste" heat for heating farm facilities. A visit to one of the first of these innovative systems at Diamond Hill Custom Heifers in Enosburg Falls, Vermont, provided the inspiration for including this new technology in our SARE proposal. At the facility, we met Brian Jerose of AgriLab Technologies®, also in Vermont, who had designed and guided the installation of that system. The process is called Aerated Static Pile/Heat Recovery Composting (ASP/HRC), and out of this visit developed a long-standing collaboration between UNH and AgriLab covering the design of the physical system at UNH and the control and data acquisition systems as well. A description of the ASP/HRC facility built at the ODRF is included in Chapter 3, and information on operations and heat generation and capture in Chapters 4 and 9.

Another relatively new technology that contributed to the final structure of the proposal was a commercial-scale wood shaving machine, essentially an oversized wood planer on a trailer, that could turn whole logs into thin shavings suitable for livestock animal bedding material. Given the preference for wood products for barn bedding among organic dairy operations in New England (as later supported by results of a survey of regional dairy farmers, Chapter 2), and given the prevalence of low quality softwoods on many New England dairy farms, including the ODRF, the prospect of closing the carbon cycle on the farm and reducing bedding costs by converting the softwood resource to bedding became part of our proposal. With support from the NHAES, a wood shaving machine was purchased for the ODRF and this project.

Another very major event in the development of this project, and of the ODRF, was the emergence of an anonymous donor who was fascinated by both the Farm and the Project, and supported almost all of the cost of building the composting facility described in chapter 3. Some of our initial efforts on composting for energy capture, as reported in Chapter 1, were interesting, but not at a scale relevant to commercial operations. This new facility, as the only one of its kind at the only ODRF in the country, provided a unique opportunity of incredible value to the project. At the request of the donor, the facility was generously named for an alternative energy pioneer, Joshua Nelson. The naming event was highlighted by UNH in a press release in 2014 [121].

As these disparate pieces came together, it became possible to describe a research project built on the concept expressed in Figure P.1 that included a number of tangible goals and testable ideas. At an operational and process level, these included internalizing bedding production and composting of wastes (Figure P.2).

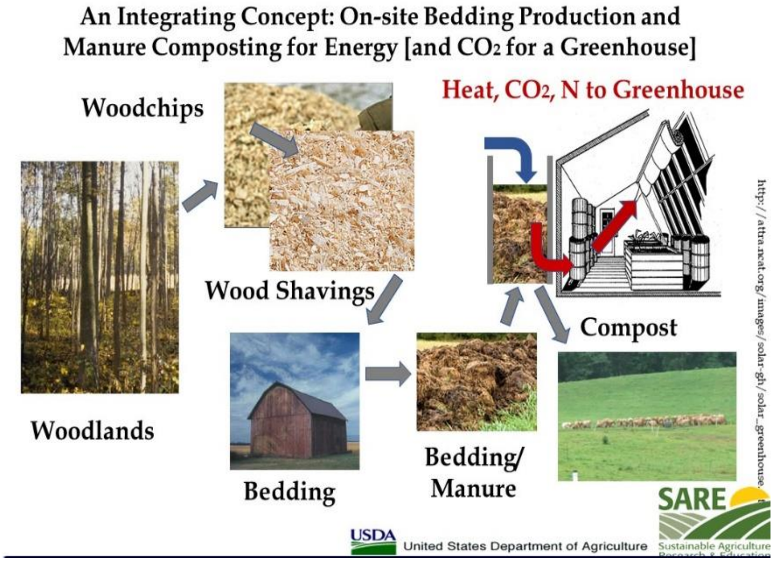


Figure P.2 – Graphic presentation of the steps in an integrated system for internalizing energy, carbon and nitrogen cycles at the UNH Organic Dairy Research Farm. See text for explanation.

Briefly, we envisioned a system whereby low-quality softwoods from the extensive woodlot at the ODRF were harvested and converted to bedding using the recently acquired wood shaving machine. The shavings would be used as bedding, with the resulting manure bedding mixture composted in the newly constructed ASP/HRC composting system, with the heat generated by the compost captured and used on the farm. Chapter 2 includes references to the results of the bedding work, which has been published in professional and stakeholder outlets. Chapters 3 and 4 describe the building and operation of the ASP/HRC facility, including the amount of energy generated per day.

To address, at least partially, the environmental impacts of farm operations, and especially the composting process, Chapters 5 and 6 present information on emissions of gases from in the compost vapor, and the use of a simple biofilter to trap ammonia. Chapter 7 extends the environmental analysis to include impacts on water quality using data from a set of groundwater wells and a small creek on the farm property. Chapter 8 brings operational farm data together to construct a nitrogen budget for the property and assess the potential for loss to the environment.

A final conceptual step described in the proposal, but not physically tested, was using the heat and gases generated by the composting facility to enhance production and extend the season in an adjacent greenhouse (Figure P.2). In Chapter 9 we test this final concept by modeling a linkage between an ASP/HRC composting facility and a greenhouse system, using UNH as a case study. In the Epilogue we propose how that physical linkage might be accomplished, again at UNH.

Another Source of Inspiration – Coming Full Circle

There was one additional, historic source of inspiration for this work, and one that comes full circle with recent sources of support for the ODRF. In the 1970s, John and Nancy Jack Todd, along with others, established the New Alchemy Institute, and constructed the first Ark (Figure P.3). Reflecting many of the values of the time about self-sufficiency and minimizing environmental footprints, including concepts we now include under the aegis of Sustainable Agriculture, The Ark was conceived as a self-contained food production/waste management system that recycled wastes as fertilizer, produced food and drew energy from the sun. The resemblance between The Ark and the system envisioned in Figure P.2 is not coincidental. I was a post-doc at the Marine Biological Laboratory in Woods Hole, Massachusetts in the early '70s, and was aware of, and drew inspiration from New Alchemy that continued into this USDA-SARE project.

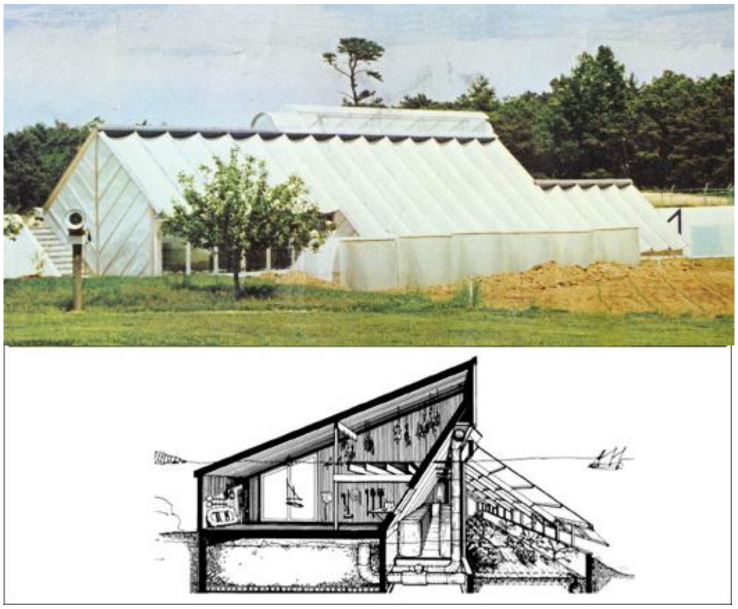


Figure P.3 – Image and conceptual diagram of the original New Alchemy Ark on Cape Cod in Massachusetts [6].

Among the early contributors to the work of New Alchemy were Gary Hirshberg and Bruce Fulford. Both prepared reports on alternative energy and agriculture systems [35, 45, 46], and when our USDA-SARE project began, the only reference on compost-heated greenhouses in the USDA database was a report by Gary Hirshberg out of New Alchemy (a useful set of references can be found in [26]). To close this historical circle, Bruce Fulford now operates City Soil, a composting operation in Boston, has been a long-time advocate for composting, and also served as a member of the Ph.D. thesis committee for Matt Smith at UNH. Gary Hirshberg went on to become a founder and CEO of Stonyfield Yogurt. Both he and Stonyfield were strong initial supporters of the Organic Dairy Research Farm at UNH, providing both financial and technical support. At the ceremony announcing the establishment of the ODRF, Gary Hirshberg said, "This could not come at a better time, as the organic dairy market in general and New England in particular are in need of more organic farmers. We believe organic dairy farming has the promise of saving New Hampshire and New England family farmers." [75]

Acknowledgements

Serendipity played an important role in being able to bring the agroecosystem concept to life at the UNH Organic Dairy Research Farm, but the fortunate confluence of events was helped along at each step by many good people who supported and advanced the work.

One of the most rewarding parts of working with the SARE program on this project was the wonderfully creative and innovative approach to agricultural research taken by the Board of the Program, and those managing the program, especially Vern Grubinger, Director of the Program, David Holm, who was our primary program manager throughout the life of the grant, and Kathleen Newkirk who joined with David on annual site visits and provided important feedback from her experiences working with both forest and agricultural systems. Presentations to the Board and managers were always open events with wonderful give and take of ideas. Everyone involved on the USDA side seemed to assume that innovative approaches were to be expected. The questions were often about "what is next" based on the most recent results, and always with an eye to implementation for the benefit of farmers.

Another important component leading to the success of our research program, to the extent evidenced by this report and previous papers, was the extended timeline of the grant. Recognizing that ecosystem-level research takes time, the SARE Board and Management defined the grant to be funded as a series of three, 3-year increments, assuming good progress toward proposed goals in each 3-year period. Completing the multiple goals of the proposal, and especially working through the logistics of construction and testing of major facilities, made the extended time frame essential.

The list of people at UNH who contributed to this project is almost too long to enumerate (Table P.1). While it could be argued that all of these folks were just doing their jobs, conflicting priorities and resource scarcity at universities always require that choices be made. Each person in the table helped to make this project possible.

While physical and administrative resources at a Land Grant University are essential to carrying out the kind of project reported here, perhaps the most valuable resource is the pool of energy and enthusiasm and ability represented by students. Some of the stories about student involvement are presented in Chapter 1, and all those involved in the work are included in Table P.1.

Table P.1 List of Participants in and Supporters of the UNH Agroecosystem Project

Lead Investigators
John Aber, Bill McDowell, Matt Davis, Charles Schwab, Kevin Brussel

Graduate Students
Ph.D.: Matthew Smith, Allison Leach,
Masters: Ashley Green, Catherine Dunlap, Michelle Galvin, Charles Simms, Jennifer Campbell, Shan Zuidema

Undergraduate Students
Honors and Capstone Projects: Nichole Williamson, Dena Hoffman, Gabriel Perkins, Amy Lamb
Presenters at the Undergraduate Research Conference: Margaret Phillips, Brian Godbois, Makenzie Benander, Paul Pellissier, Bella Oleksy, Jacki Amante, Bryan Vangel, Alyssa Reid, Joshua Cain, Spencer Tate, Elizabeth Harvey, Andrew Morehouse, Rena Caron
Lab and Field Assistants: Patrick Wheeler, Sarah Ehrmentraut, Pia Marciano, Zach Charewicz, Katerina Messologitis, Emily Dutton, Andrew Moriarty, Pat Cota, Helen Clark, Cathleen Turner, Joshua Trott

Collaborators
Agrilab Technology – Brian Jerose, Jason McCune-Sanders
USDA-ARS Tim Griffen (now at Tufts University), Sarah Goslee, Kathy Soder
University of Maine Extension – Richard Kersbergen

SARE Grant Administrator and Reviewers
Vern Grubinger, David Holm, Kathleen Newkirk

UNH Administration – College of Life Sciences and Agriculture
Jon Wraith, Dean of the College and Director of the NH Agriculture Experiment Station
Anita Klein, Associate Dean

Operations at the Organic Dairy Research Farm
Ryan Courtright, Farm Manager
Isagani Kimball, Lead Farm Worker
Tom Oxford, NHAES Farm Manger

Of special note are the many contributions made by Matthew Smith. Matt spent a total of 4 years designing, redesigning, rebuilding, debugging and operating both the wood shaving machine and the composting facility, and was indefatigable in that effort. Most of what is reported here would not have been possible without him.

External collaborators also offered support and crucial initial information. Foremost among these was our long-standing collaboration with Brian Jerose and Jason McCune-Sanders of AgriLab Technologies in Enosburg Falls, VT who designed the heat exchange system for the facility, and the software to manage aeration times and record data. The value of the high-resolution data on performance of the composting system is demonstrated in chapter 4. Colleagues at the USDA Agricultural Research Service (ARS) offices in Maine and Pennsylvania, especially Tim Griffin (now at Tufts University), Sarah Goslee and Kathy Soder, carried out an initial, very detailed analysis of soil and pasture conditions at the Farm.

Purpose and Structure of This Report

Beyond capturing the history of the project, this report will present a summary of the major research efforts completed, and will conclude with a review of findings with the highest potential for economic value, and a specific proposal for implementation of a compost-greenhouse connection (Epilogue). As the project progressed, goals and emphasis changed a bit, but generally held true to the outlines in Figures P.1 and P.2. The full text of all three 3-year proposals, as well as much additional information summarized in this report, can be found on the projects website [1].

This report is not intended to be in the format of a peer-reviewed publication. As presented in Chapter 2, many of the central findings have already appeared in both academic and professional outlets. Results summarized in Chapters 4-6 are elaborated in two Ph.D. dissertations by Matthew Smith and Allison Leach [87, 53] produced at the University of New Hampshire. It is our intention that the results contained here will be accessible to practitioners and the public, so the presentation will be more narrative than scientific, the units are English rather than metric, and the discussions of methods and statistics, for example, are truncated.

Chapter 1 reviews the role of early student engagement in the project, and presents some results that put the project into the larger context of the operations of the ODRF. Also included is a detailed discussion of an early student honors thesis that provided preliminary data on composting with heat recovery.

Chapter 2 presents a description of the current state of the ODRF, and reviews results from previously published research. Summaries and references are included for a survey of dairy farmers in New England, operations of the wood shaving machine, and initial results on heat generation and capture in the UNH ASP/HRC facility. As full results are already available in the open literature, this chapter will highlight only the most important and operations-relevant findings.

Chapter 3 reviews composting as an agricultural waste management strategy as well as details about the size and operation of the composting system constructed at the ODRF.

Chapter 4 presents detailed measurements not previously published on energy generation and capture for the ASP/HRC system at the UNH ODRF, and presents methods for extrapolating all available data to total annual values for the full facility.

Chapter 5 begins to deal with the by-products of the composting process. In particular, data are presented on the trace gas emissions in the exhaust from the facility during full operation.

Chapter 6 presents results of a study on the performance of simple organic biofilters in terms of removing ammonia from the exhaust streams measured in chapter 5.

Chapter 7 extends the analysis of environmental impacts to include water quality, focusing on nitrogen concentrations in samples from groundwater wells located across the farm property, and surface water in a small creek draining from the farm pastures.

Chapter 8 takes a broader view of potential nitrogen issues by developing a complete nitrogen budget for the farm and estimating two operational characteristics applied to farms around the world: nitrogen use efficiency and nitrogen surplus.

Chapter 9 begins by estimating the amount of compostable material generated by UNH and the Durham community, then uses three methods to calculate the amount of heat energy that could be generated from this material, and compares this with measured heat demands from greenhouses at the UNH agricultural research farms. The goal is to assess the potential for linking ASP/HRC systems with greenhouses to reduce heating costs, enhance production and extend the useful growing season.

In the Epilogue we highlight two results from the study that we feel offer viable economic opportunities. The first is to reduce bedding costs for farmers and generate income for operators by creating either private or cooperative enterprises to produce bedding from low quality, on-farm softwood resources. The second is to extend high tunnel greenhouse production beyond the normal growing season using heat generated by ASP/HRC systems. Four potential applications of this concept using existing or proposed high tunnels on the UNH campus are presented.

Chapter 1: Initial Steps and Preliminary Investigations – John Aber

There is one important component to any project at a research university that is key to the success of the endeavor – the students who become involved. The excellent work by both undergraduates and graduate students on major parts of this project are reported in some detail, with those students as co-authors, in chapters 2 through 8, but some important preliminary information, and also some inspiration for the lead investigators, came from undergraduates initially drawn to the goals of the project.

Just as the project was getting underway, the opportunity was offered to first-year students in Environmental Science to do field work at the Organic Dairy Research Farm (ODRF) that would be of relevance to the grant. Several jumped at the chance to get involved in real research projects. The team (Figure 1.1) surveyed the wood resource at the ODRF, both standing biomass and annual increment, and determined the sustainable yield from the approximately 170 acres of woodlot. The biomass and energy content of that wood was compared with farm energy consumption and bedding purchases, and it was determined that those woods could be managed sustainably to provide the Farm's bedding requirement indefinitely.

Table 1.1 Harvestable wood compared with demand for bedding at the Organic Dairy Research Farm at UNH - full presentation at: https://mypages.unh.edu/sites/default/files/agroecosystem/files/energy_use_and_product_-_aber_presentation.pdf

Wood Production
10.1 tons/acre.yr   152 tons/farm.yr
Converts to
840 "cords" of bedding per year
Bedding Demand
135 "cords" per year

Figure 1.1 First-year Environmental Science student team that measured the wood resource at the ODRF:
Brian Godbois, Makenzie Benander, Paul Pellissier, Bella Oleksy, Jacki Amante, Bryan Vangel, Alyssa Reid.

Projects in another class developed proposals for solar, wind, and geothermal energy for the farm, in the context of the energy budget of the Farm, with results presented at the UNH Undergraduate Research Conference. Graduate students working with principle investigators on the project developed data sets and models on hydrology of the Farm, including movement of some key chemicals, and a full report on the water use footprint of the Farm operation. Reports and presentations can be found at: https://mypages.unh.edu/agroecosystem/hydrology-and-water-balance
(https://mypages.unh.edu/sites/default/files/agroecosystem/files/materials_and_element_cycling_-_campbell_davis_presentation.pdf
https://mypages.unh.edu/sites/default/files/agroecosystem/files/materials_and_element_cycling_-_davis_report.pdf

Two honors undergraduate students pursued thesis work at the farm that offered initial information relevant to major efforts on nitrogen cycling and energy generation by aerated static pile composting. While these efforts were later refined substantially, as seen in the following chapters, the educational value of SARE support was clear, and the results from this early work provided guidance for later and more detailed studies.

Gabe Perkins produced a first rough estimate of the nitrogen cycle and total nitrogen balance of the Farm (Figure 1.2). Using data from purchases and sales of grain, milk and other commodities, as well as inputs from precipitation, this first study estimated a net nitrogen surplus (inputs – outputs) at about 62 lbs per acre (69 kg/hectare) per year. A much more complete analysis by Allison Leach in her dissertation [53] resulted in a similar conclusion; that imports of grain resulted in nitrogen inputs to the Farm that were substantially greater than losses through the export of milk (see Chapter 8).

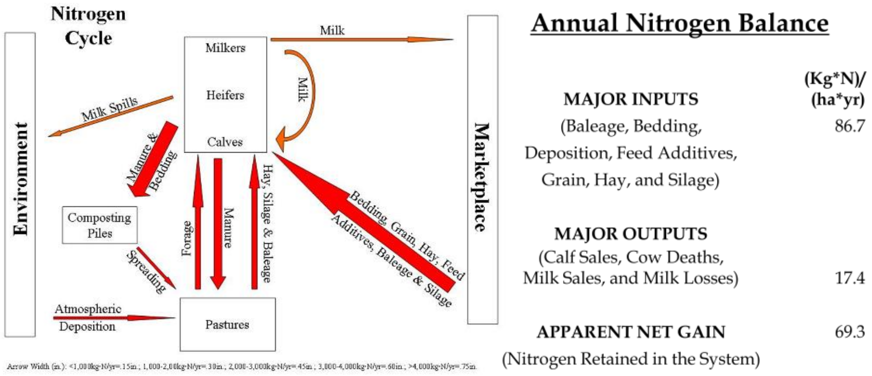


Figure 1.2 A first estimate of the nitrogen cycle and balance of the UNH Organic Dairy Research Farm (Perkins 2010).

Before the construction of the commercial-grade aerated composting facility described in chapters 3 and 4, senior honors student Amy Lamb tested low-cost methods for aerating compost piles to speed decomposition and also to generate heat [51].

Manure stockpiled before spreading can be an important source of both water and air pollution. At the establishment of the ODRF, manure/bedding wastes were held for up to 2 years in unmixed, non-aerated piles. Water quality around these piles was low, based on both visual criteria (Figure 1.3) and measurements of nitrate in groundwater wells adjacent to the piles (Chapter 7). For her thesis, Lamb took three different approaches to questions of heat and trace gas generation in manure/compost systems. The first was to measure the temperature and gas concentration profiles in the non-aerated manure piles stored at the Farm (Figure 1.3). The second and third involved measurements from aerated static piles at two different scales. For all three, gas concentrations were measured with a GFM-400 a landfill gas monitor produced by Gas Data and temperatures using manual, analog probes [51].

Figure 1.3 Images of stockpiled manure at the ODRF prior to the construction of the new composting facility. Impacts on local water quality are clear. Measurements of gas composition within the pile showed high levels of methane [51].

For the non-aerated pile at the ODRF, ten locations were sampled at one, two and four-foot depths for carbon dioxide, oxygen, methane, and other gases, as well as temperature. Not surprisingly, methane concentrations were high in this pile, and increased with depth. There was an inverse relationship between the concentrations of oxygen and methane in these preliminary measurements (Figure 1.4). LEL is the lower explosive limit, which for methane is 5%.

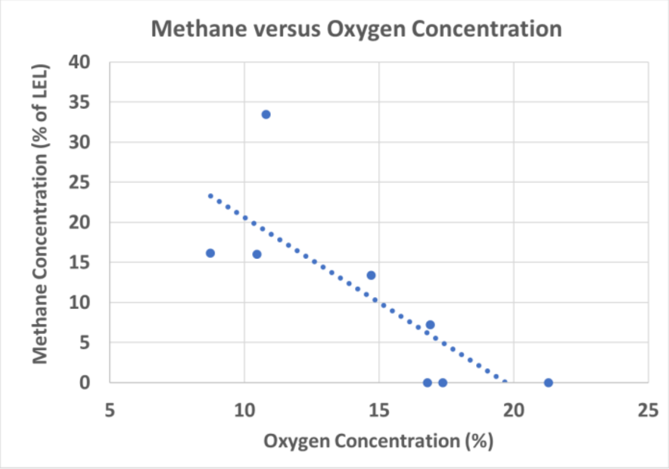


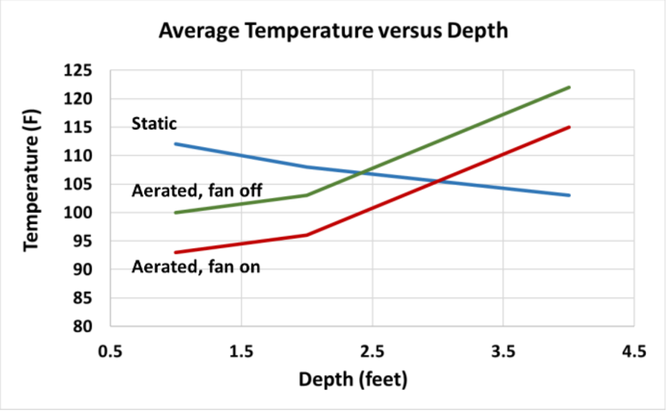
Figure 1.4 Changes in measured concentrations of methane and oxygen with depth in non-aerated manure piles at the ODRF [51].

For comparison with these commercial-scale static piles, a similar procedure was applied to material in an Aerated Static Pile/Heat Recovery Composting (ASP/HRC) system at the Diamond Hill Custom Heifer operation in Enosburg Falls, Vermont. This is the location of the first installation of an ASP/HRC system in the northeast (again, see full discussion of ASP/HRC systems in chapter 3). Sampling was carried out over the course of a 14 hour period and included times with the aeration fan on, and times with the fan off for up to 4 hours.

An important result from this comparison of sites is that methane concentrations were below detection limits at all times and all depths in the aerated pile even during one trial when the fan had been off for 4 hours. The 4 hour, fan-off period, longer than any that would occur during normal operations, was not sufficient to induce methane production.

There was also a difference in temperature profiles (Figure 1.5). Temperature peaked at the bottom of the aerated pile, with highest values at the top of the static pile. One explanation for this difference could be that colder air entering the aerated pile continues to warm as it passes down through the pile, and reaches a maximum temperature just before exiting the pile and entering the heat exchanger. For the static pile, higher temperatures at the top reflect higher concentrations of oxygen, and hence higher rates of decomposition, with heat being conducted down through the pile to areas of lower rates.

Figure 1.5 Changes in temperature measured a different depths in a large static pile at the ODRF, and a commercial-scale Aerated Static Pile/Heat Recovery Compost system at Diamond Hill Heifer operation in Enosburg Falls, Vermont [51]. Aerated pile had slightly higher tempeatures following 4 hours with the fan off.



In the initial absence of the commercial-scale composting facility built at the ODRF, Lamb tested a much simpler approach to aerating static piles, and generating usable heat as well. Replicate piles roughly 10 feet square were established (Figure 1.6). In one trial, perforated leach field pipes were laid, covered in wood chips, and then with a mixture of dairy manure and spent animal bedding. The pipes were then connected to a fan driven by a solar panel which could be used to draw air down through the piles. In a second trial, the pipes were set vertically in the pile to facilitate passive aeration, with no fan connection. A third trial was a control pile without pipes. Piles were initially about 6 feet high, and the same methods were used to measure temperature and gas concentrations as for the large static and static aerated piles described above (Figure 1.6).

Figure 1.6 Establishment of areas for measurement of temperature and gas concentrations in small compost piles, and sampling method used on all piles.

All three trials, including the horizontal pipes with the fan off, initially reached temperatures near or above 140°F at the 1 foot depth through passive aeration (Table 1.2). Temperatures were similar or higher down through the pile underlain with horizontal pipes, while the vertical pipe and control piles were lower at the 4 foot depth.

Table 1.2 Temperature by depth in aerated and control piles after 7 days incubation

	Pipe Location		
Depth	Horizontal	Vertical	Control
1 foot	147	139	138
2 feet	156	146	150
4 feet	149	112	122

For these small piles, aeration actually had a negative effect on temperature (Figues 1.7), at least at the rates of aeration used in this trial, due to the volume of cooler ambient air drawn into the pile. Aeration times and rates would have to be moderated to maintain a high temperature, and to allow capture of heated vapor from the pile (See Chapters 4 and 9). As with the Vermont sampling, methane concentrations were below detection limits at all times both within the piles and in vapor exhaust created with the fan on.

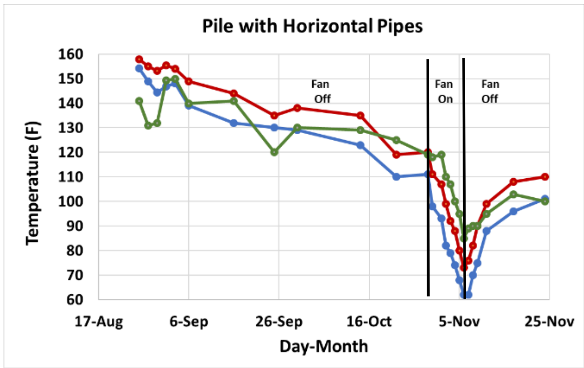


Figure 1.7 Changes in pile temperature over time for small, aerated pile with horizontal leach field pipes under the composting material. Aeration was passive during periods with Fan Off, and active during the short period with the Fan On. [51].

From this work, Lamb concluded that smaller piles may still be suitable for achieving the goal of more rapid aerobic decomposition and the elimination of methane emissions from farm wastes, but larger piles, or slower aeration rates, might be required to sustain usable heat generation (see Chapters 4 and 9).

A final conclusion to be drawn from this work, relevant to our analysis of the potential value of ASP/HRC systems in the University of New Hampshire context (Chapter 9 and Epilog) is that it is possible to develop and operate simple and inexpensive alternatives to the very high end, research-grade facility described in Chapters 3 and 4.

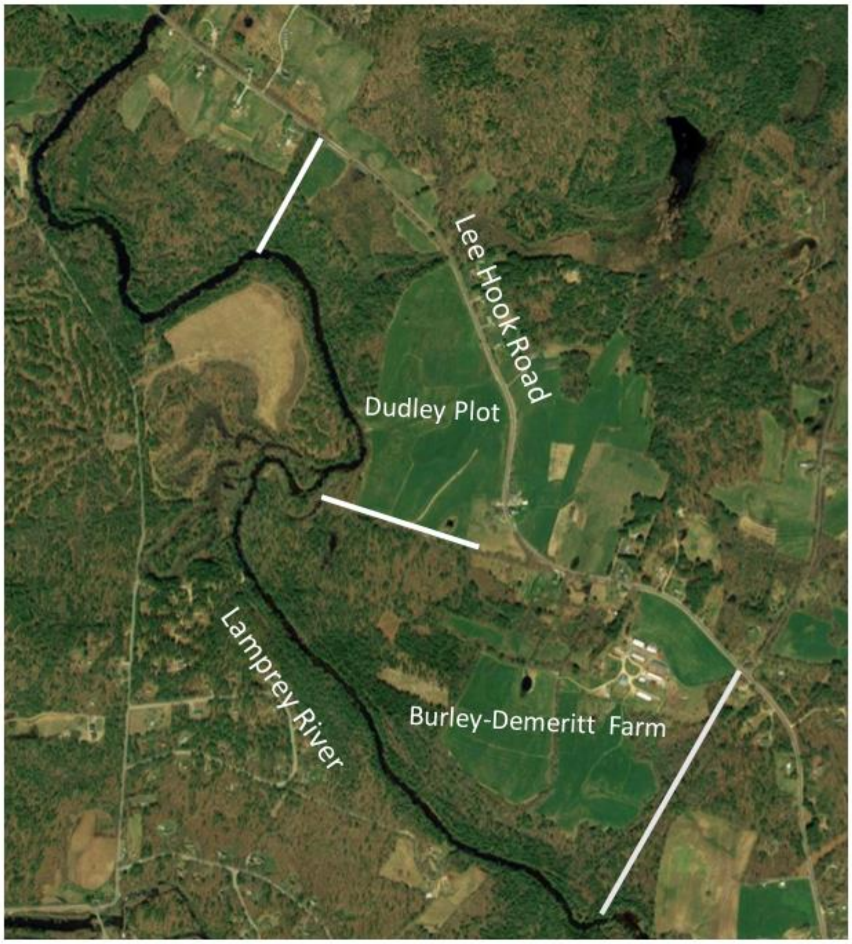
Chapter 2: Current Status of the UNH Organic Dairy Research Farm and a Summary of Previously Published Research – Matthew Smith and John Aber

Current Status of The Organic Dairy Research Farm – and a Valuable Year 0 Assessment

The research presented in this publication would not have been possible without the pre-existence of the Organic Dairy Research Farm (ODRF). Chapter 1 presents some early descriptions and early measurements made possible by this unique resource, which remains the only Organic Dairy Research Farm that is part of and located near the main campus of a Land Grant University. What is this farm like, how does it operate, and how representative is it of New England dairies?

The ODRF encompasses two adjacent properties, the Burley-Demeritt Farm and the Dudley Lot. These Farms are bounded by Lee Hook Road and the Lamprey River (with small private inholdings) in the town of Lee, NH (Figure 2.1). Farming on both properties dates back to the 1700s, with current land use divided between pastures and managed woodlots. The total area for both is about 300 acres, of which about 170 are in woods, and about 110 are in pasture and forage production. The remaining area includes barns, roads and laneways. Of the wooded acres, 17 are classed as wetlands with limited accessibility for harvest [112].

Figure 2.1 Aerial view of the UNH Organic Dairy Research Farm in Lee, NH



The Farm is managed and operated as much like a small-scale New England organic dairy farm as possible, while still allowing for feeding trials and other experiments. The ODRF generally milks 40-50 registered Jersey cows and houses an additional 40-50 dry cows, heifers and calves. All stock are grazed on certified organic pastures from early May until early November supplying the bulk of the animals forage needs. To supplement pasture in the summer, milkers are also fed baleage (an ensiled forage product harvested from the farm fields) and nutritional concentrates twice daily, post milking, to meet additional energy and dry matter intake requirements.

Cows are housed for the winter in a 32’x 144’ open bedded back barn with a 70’x144’ exercise yard, facilitating overall cow comfort. A calf barn is used to house young stock, complete with southern exposure, natural ventilation and individual calf pens. Dry cows and heifers are housed in a 20’x40’ three sided bedded-pack structure facing south. The majority of the structures on the farm including the milk house and milking parlor are converted farm structures.

The bedded pack barn uses wood shavings for bedding, and is emptied 2-3 times per year. Removed materials become feedstock for the composting facility described in detail in Chapter 3. The yard is scraped daily and manure is stockpiled until transferred to the composting facility.

The Farm is run as a research facility, and while meticulous financial records are kept, the Farm is not managed to maximize financial return. This approach affects feeding regimes and the handling of waste streams.

In the Prologue, we discussed the importance of early connections with the four major producers of organic milk in the country, and how that led to the goals of our agroecosystem project. There were other early cooperators as well who were drawn to the unique characteristics of the Organic Dairy Research Farm (ODRF). Among these were researchers at the USDA Agricultural Research Service offices in Maine and Pennsylvania, including Tim Griffin, Sarah Goslee and Kathy Soder. They established an intensive sampling grid (Figure 2.2), and applied nationally standardized methods to complete detailed measurements and maps of soil and pasture conditions. These valuable products offer an important “before” analysis of initial conditions at the time of establishment of the ODRF and the initiation of the agroecosystem project.

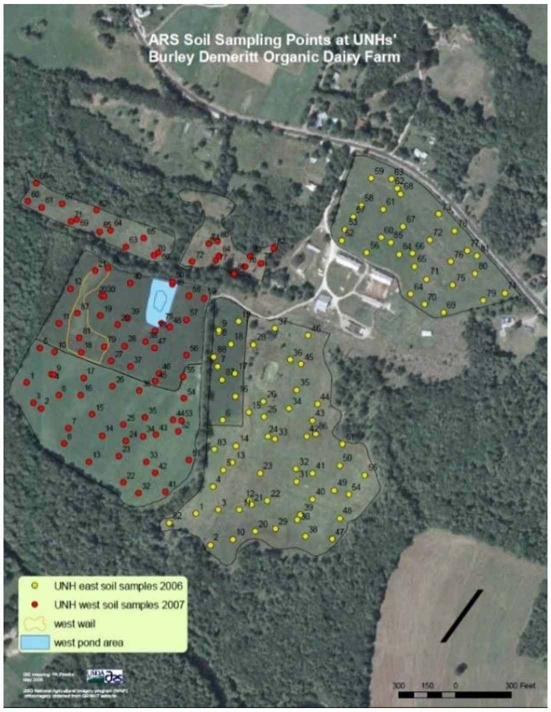


Figure 1.8. Grid of locations used by USDA-ARS researchers to measure soil and pasture conditions at the UNH ODRF in 2008.

Previously Published Research

Many of our research results relating to the assessment of bedding needs of New England dairy farmers, the production of bedding from low quality softwoods, and the construction, operation and energy generation and capture of the ASP/HRC system at the UNH Organic Dairy Research Farm (ODRF) have been published in both peer-reviewed and practitioner-oriented outlets. Rather than repeat those presentations here, we will list the papers and outlets, and summarize the major findings that relate to the core goals of the proposal.

These publications are grouped under three broad topics: 1) A survey of characteristics and bedding preferences of both organic and conventional dairy farmers in New England, 2) Testing and economic analysis of the value of the shaving machine for producing bedding, and 3) Design, construction, operation and heat generation of the ASP/HRC system at the UNH ODRF.

Survey of New England Dairy Farms

- Simms, L., M. Smith, J. Alvez, J. Colby, and J. Aber. 2015. Alternatives for rising bedding costs in New England dairies. Dairy Briefs Vol. 62 (Winter). University of New Hampshire Cooperative Extension, Durham, NH.

- Smith, M.M, C.L. Simms and J.D. Aber. 2017. Animal bedding cost and somatic cell count across New England dairy farms: Relationship with bedding material, housing type, herd size, and management system. The Professional Animal Scientist 33:616-626

Major points in these two papers of relevance to this project include: 1) that the UNH ODRF is near the median among New England dairy farms in terms of acreage, herd size, amount of pasture, and amount of woodlands, 2) Wood-based materials are preferred for bedding among organic and conventional dairy farmers, although price and availability often dictate the use of a wide range of other materials, and 3) many organic dairy farmers expressed an interest in the possibility of being part of a cooperative effort to produce bedding with a wood shaving machine.

Operation and Economic Analysis of a Wood Shaving Machine for the Production of Bedding

- Smith, M.M., J.D. Aber and T. Howard. 2017. Economic viability of producing animal bedding from low quality and small diameter trees using a wood shaving machine. The Professional Animal Scientist 33:771-779

- Smith, M.M, C.J. Park, C. Andam and J.D. Aber. 2018. Utilization of low grade wood for use as animal bedding: A case study of eastern hemlock. Journal of Forestry 116:520-528

Results of extensive trials with the operation of the particular model of wood shaving machine purchased for this project suggest that the size, cost and operating time requirements are too great to be supported by a single, average-sized New England dairy farm. However, the options of a regional cooperative or a single-purpose private enterprise, or other organizational structure that could keep the machine running for a majority of a year, could prove profitable and sustainable.

The second paper here tested the value of eastern hemlock shavings as a bedding material, and found it to be as effective at reducing microbial activity as eastern white pine shavings, and have a lower cost for the wood resource. However, the moisture absorption capacity of eastern hemlock was significantly lower than that of eastern white pine, indicating a tradeoff between the two species for use as bedding.

Design, Construction, Operation and Performance of an Aerated Static Pile/Heat Recovery Composting System

- Smith, M. and J. Aber. 2014. Heat recovery from Compost. BioCycle 55:26-28

This paper introduced the concept of Aerated Static Pile/Heat Recovery Composting to the professional composting/waste management community, and included the first published images of the UNH ASP/HRC facility.

- Smith, M. M., and J.D. Aber. 2014. Heat recovery from compost: A guide to building an aerated static pile heat recovery composting facility. Durham, NH: University of New Hampshire Cooperative Extension; Research Report. 81 p.

- Smith, M. and J.D. Aber. 2017 Heat Recovery from Compost: A Step-by-Step Guide on Building an Aerated Static Pile Heat Recovery Compost Facility. University of New Hampshire Cooperative Extension, Durham, NH. 72pp.

These two publications present in great detail the specifications used to build the UNH ASP/HRC facility.

- Smith, M., J.D. Aber and R. Rynk. 2017. Heat recovery from composting – a comprehensive review of system design, recovery rate and utilization. Compost Science and Utilization 25 (sup1) S11-S22.

This systematic review describes the methods used historically and currently for capturing the heat generated by aerobic composting. It has become one of the most frequently accessed articles this journal has ever published.

- Smith M.M and J.D. Aber. 2015. Heat extraction & utilization from composting as an alternative to anaerobic digestion for reducing energy costs at dairy farms. UNH Dairy Report 2015: New Hampshire Agricultural Experiment Station and University of New Hampshire Cooperative Extension; 2015 pp. 33-35.

- Smith, M. and J. Aber. 2017. Recover energy from composting to heat water on farms. Progressive Dairyman 19:61-63 and Progressive Dairyman Canada. 3:63-65.

These two present the concept and potential value of capturing heat from compost to a general practitioner audience.

- Smith, M.M and J.D. Aber. 2018. Energy Recovery from Commercial-Scale Composting as a Novel Waste Management Strategy. Applied Energy 211:194-199

This paper is the first to present data on the rate of actual heat capture at the UNH ASP/HRC facility. A major point from this paper is that the actual rate of capture and retention in a system that uses a heat exchanger/water tank storage method is highly dependent on the temperature of the water in the storage tank (see more discussion of this in chapters 3 and 4). This means that, to maximize heat capture, the composting system needs to be connected to another system that exhibits a relatively constant requirement for the heat produced.

A second point is that, working at maximum efficiency, the system can generate and capture as much as 900 BTU/min from each of 4 sets of paired bays in the system, during periods of active aeration. See Chapters 4 and 9 for extension of these calculations to full operation for a year.

Chapter 3: The Aerated Static Pile/Heat Recovery Compost System at the University of New Hampshire – John Aber and Matthew Smith

Introduction

Definitions of sustainability might include the intelligent use of integrated systems of production, waste reduction, and recycling that provide for societies needs while reducing environmental impacts. Sustainable ventures need to succeed in three domains simultaneously: economic, environmental and social. Agriculture is critical for feeding a growing world population, but is also an important component of the overall impact of human activity on the global ecosystem. Waste products produced by agriculture augment both climate change and reduction in water quality. Proposed solutions to the problem of minimizing agriculture's impact also need to succeed in all three domains, meaning that financial benefit and social acceptance are required for a proposed method for reducing environmental impacts to gain acceptance.

Dairy operations are the largest component of the food production system in New England. Unlike consumption of meat, pulses and grains, a significant fraction of dairy products consumed in the region is produced here as well, even though the overall number of dairy farms continues to decline [115]. In keeping with the goals of this Agroecosystem study funded by USDA-SARE and the NHAES (see Prologue), we worked on developing and testing new technologies and processes that could increase the financial and environmental sustainability of organic diaries in the region (see summary in Chapter 2). A centerpiece of this research has been developing a unique set of information on a relatively new method for composting organic farm wastes, and generating usable heat as well.

In this chapter we review composting as a waste management practice, and describe in detail the Aerated Static Pile/Heat Recovery Composting (ASP/HRC) system at the University of New Hampshire (UNH) Organic Dairy Research Farm (ODRF). The Farm is operated as a research unit of the New Hampshire Agricultural Experiment Station (NHAES).

Composting as a Waste Management Practice

As limitations on disposal of organic wastes in landfills increase in the U.S. and Europe [8, 24, 42], composting is receiving increased attention as an alternative waste treatment method. In particular, Aerated Static Pile (ASP) composting is emerging as a viable method for reducing labor and space requirements for processing a wide variety of materials.

Composting is the process by which organic materials are broken down by microorganisms into a stable, pathogen-free, humus-like product [24, 43]. Composting requires a carbon source (e.g., plant litter, crop residue, wood chips), a nitrogen source (e.g., animal manure, human waste, food waste), and microorganisms that then decompose the feedstocks [81]. Compost can be a preferred soil amendment because it provides nutrients in an organic, slow-release form, while also enhancing soil structure and organic matter content, improving water retention capacity and reducing rates of nutrient losses [78, 79, 80]. Land application of compost has also been shown to promote carbon storage [20].

Composting is an aerobic process, where oxygen is provided to feedstocks passively, mechanically, or through forced aeration [82]. One of the primary byproducts of this process is heat. This is not to be confused with anaerobic digestion, which processes feedstocks in an oxygen-limited, anaerobic environment, where one of the primary byproducts is methane (CH_4).

The composting process encompasses three unique stages which each have distinct microbial communities and physical characteristics [20, 3.9, 3.10, 105]. The three stages are an initial mesophilic stage, a thermophilic stage, and a second mesophilic or maturation phase. The composting process is controlled by oxygen availability, the material's moisture content, particle size and bulk density, and the ratio of carbon to nitrogen, as well as temperature, pH, and the microorganisms present [24, 70, 81].

There are a number of composting methods utilized by both farmers and commercial composters. The following is a brief summary of the more common on-farm composting methods, which are described by Rynk et al. [82]. An updated version of this technical guide is due out in the summer of 2020.

Static pile, passive composting systems involve stockpiling wastes and allowing the materials to decay slowly over time, without being turned or managed in any way. While this represents the lowest cost option, it also requires the longest time to reach a finished product. This type of composting system, especially if outdoors and uncovered, also has the greatest risk for odors and environmental pollution, including leaching of nutrients to groundwater and the production and release of methane (CH_4), a powerful greenhouse gas (See Chapter 1).

Conventional methods for increasing aeration and speeding the decomposition process include the use of windrowed piles in which materials are held for up to 1-2 years and turned frequently to assure mixing and complete aeration. This method is slow and labor intensive and is most frequently used by backyard gardeners and other small-scale operations. In the U.S., commercial systems processing food wastes are required to maintain windrow temperatures > 130^{o}F for 15 days straight with 5 turns of the pile for the final product to be saleable. While more material can be processed more rapidly than with passive systems, the extra machinery and labor increase the cost of the operation, and heat recovery, if attempted, is more difficult and less efficient.

Passively-aerated composting systems involve placing mixed feedstocks over a collection of perforated pipes (usually 4 inch diameter drainage pipe 4 feet apart). As the feedstocks begin to compost and the microorganisms generate heat, that heat raises due to convection, which pulls fresh air into the bottom of the pile through the pipes (see Chapter 1). While more efficient than passive systems, the primary drawback is adding and removing the composting feedstocks without damaging the exposed pipes.

Aerated Static Pile Composting Systems with Heat Recovery

In contrast to the previously mentioned composting processes, the ASP approach does not require turning during the active composting phase, reducing labor and fuel costs. Organic wastes are loaded once onto a concrete floor in which perforated pipes have been embedded. The pipes are connected to a manifold system and fan that either draws air down through the decomposing feedstocks (negative aeration), or forces air up through the material (positive aeration) (Figure 3.1, see detailed discussion of the UNH system in the next section). In negative airflow applications, the process creates a contained airflow of heated vapor that can be directed through a heat exchanger and/or biofilter to reduce odor and other pollutants. Capital costs for an ASP composting can be higher than for simpler conventional systems, but as the piles do not need to be turned, labor costs are lower and the amount of space required for the composting facility is smaller due to much faster time to produce finished compost.

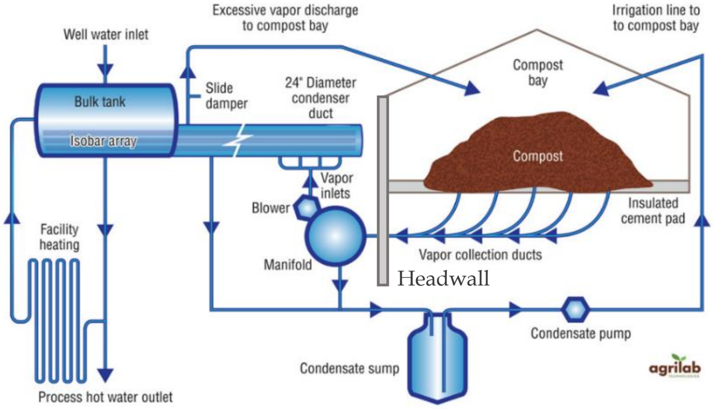


Figure 3.1 Conceptual diagram of an Aerated Static Pile/Heat Recovery Compost (ASP/HRC) System [88].

ASP composting was first described in 1975 [21, 30] and used initially for processing of sewage sludge. Economic analyses of this method suggest its value for wastewater sludge processing [120] and the concept has been expanded to paper sludge and vegetable waste from greenhouse production and other food system materials [14, 38, 104], including animal wastes [122]. Detailed research on the method has included analyses of microbial communities over time [58]. Models of the process have been developed and reviewed [58, 57, 59]. Reviewed models focus primarily on energy balance within the material itself, with the scope of validation limited to forced aeration systems [52].

In addition to a contained and faster composting process, the vapor captured in an ASP system represents a potentially harvestable source of heat energy [89]. Heat generated by microbial activity during decomposition can be captured and used for other purposes, such as heating buildings and greenhouses. Heat in the vapor can be used directly or routed through a heat exchange system and stored as hot water [89, 104, see also Chapters 4 and 9]. Methods for recovering heat from ASP vapor streams (an ASP/HRC system) have emerged in the last several years and have been implemented so far only in a small number of facilities [3.25]. Reviews of heat capture systems have appeared only recently [3.25] and few models of commercial-scale systems have been reported. As a new technology, few estimates of usable energy generation and capture are available for commercial scale ASP/HRC systems [3.25, 92].

Aerated Static Pile (ASP) composting, then, offers the potential for faster processing of organic wastes, reducing organic waste disposal in landfills, and also generating a saleable soil amendment. When combined with a heat recovery System (ASP/HRC), the benefits also include usable heat energy and the potential to offset greenhouse gas emissions. In the context of an integrated food system, ASP/CHR systems can help minimize the environmental impacts of agricultural production and can be applied at a range of scales.

The Aerated Static Pile Heat Recovery Composting System (ASP/HRCS) at the University of New Hampshire

In 2013, the New Hampshire Agricultural Experiment station (NHAES) constructed the first ASP/HRC facility at a research university at the Burley-Demeritt Farm in Lee, NH, USA, the setting for the University of New Hampshire's Organic Dairy Research Farm [89, 90]. The farm is part of the University of New Hampshire and is managed and operated by the NHAES.

The facility was designed in conjunction with Agrilab Technologies ®, using concepts developed from their first ASP/HRC system designed for a heifer operation in Vermont, USA [104]. Funding for construction of the facility was provided by an anonymous donor, and the building was later dedicated to, and named for, alternative energy pioneer Joshua Nelson, at the donor's request (See Prologue).

Figure 3.2 Joshua Nelson Energy Recovery Compost Facility located at the University of New Hampshire Burley-Demeritt Organic Dairy Research Farm in Lee, New Hampshire, USA. The images show A) the exterior doors to the facility where compost feedstock is loaded, B) piles of composting material in the facility, and C) the back of the facility where the gas exhaust from the facility is piped, allowing for heat recovery and measurements.

The Joshua Nelson Energy Recovery Composting Research Facility is a pole barn structure that is about 100' wide, 50' deep and 25' tall (Figure 3.2a). It has 4 pairs of replicate bays (8 bays total) into which feedstocks are loaded (Figure 3.2b, Figure 3.3). These replicate bays allow experimental trials with different feedstock mixes, aeration times and irrigation treatments. Each of the 8 bays are aerated by two pipes embedded in the concrete floor, for a total of 16 pipes. These aeration pipes are connected to a 1 HP fan which pulls ambient air through the piles for microbial oxygenation. A programmable logic controller (PLC) operates gate valves which control the timing of aeration for each bay. The heated compost vapor that is pulled from the composting feedstocks is sent through a concrete headwall, into a manifold of PVC pipes and through a heat exchanger system developed by Agrilab Technologies ® [90], which stores heat in a 295 gallon hot water tank (Figure 3.1). The fan and valves are the only mechanical parts of the system which require only dollars per day in electricity to operate.

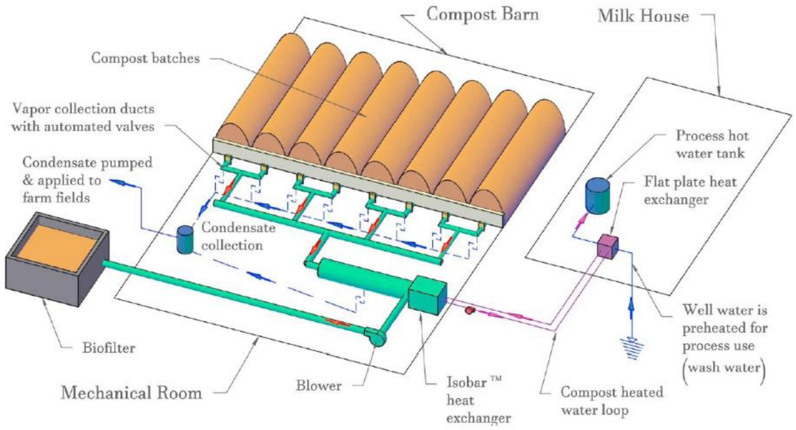


Figure 3.3 Conceptual diagram of the UNH ASP/HRC system (Smith and Aber 2018). This aerial view of the facility's eight bays shows the direction of air flow from the piles to the heat exchanger. Exhaust from the facility is directed to a biofilter (see Chapter 6).

After passing through the heat exchanger, the cooled compost vapor is sent through a biofilter to scrub ammonia (NH_3) and odor (see Chapter 6). Temperature sensors located in each pipe exiting the compost chamber through the headwall allow continuous monitoring of vapor drawn from each bay (Figure 3.3). Additional sensors are located in the inlet and outlet pipes on the heat exchanger, inside the water tank, and in the exhaust pipe leaving the building. Two additional sensors record air temperature in the room in which the pipes and heat exchange system are located, and within an insulated section of that room in which the pipes leading from the headwall to the heat exchanger are shielded. Two final sensors provide data on rate of air flow through the system (ft^3/minute) and relative humidity of the vapor stream, which was near saturation throughout the system at all times. Data are collected from all sensors at one minute intervals by a Web Energy Logger. Both the control system and the data logging system were developed and installed by AgriLab Technologies ®. In Chapters 4 and 9 we present data on temperature and airflow measured at each point in the system.

The ASP/HRC composting facility processes dairy and equine manure, spent animal bedding (pine wood shavings), and waste feed hay. The four pairs of bays are loaded and unloaded at different times so that materials of different mixtures, ages and stages of decay are present at any one time. This variation widens the range of conditions under which data were collected and so enhances the generality of results.

A complete description of facility design and cost can be found in [89, 90]. A descriptive video is available at: https://www.youtube.com/watch?v=YNTX5vqN2Fs&feature=youtu.be

Chapter 4: Estimating Potential Total Energy Gain from a Multi-bay Aerated Static Pile Composting System with Heat Recovery – John Aber, Matthew Smith, and Allison Leach

Introduction

In an earlier paper [92], we reported results from short-term experiments on heat generation and capture from the UNH ASP/HRC system. The data for that paper resulted from experiments in which the heat storage water tank was emptied and refilled with ground water at ~ 50°F. Compost vapor ranging up to 150°F was then drawn through the system, and the rate of temperature increase in the stored water used to calculate heat capture. As the 3-4 hour experiments continued, the temperature of the water in the tank increased, narrowing the difference in temperature between the compost vapor and tank water (see Figure 4.1).

In addition to establishing the range of possible energy capture rates from a single set of bays, the paper stressed the importance of the temperature difference between the heat source and heat sink in determining the rate of energy capture from the system. This is not surprising in that any heat transfer process is a function of the temperature differential between source and sink.

One important management principle to be drawn from this is that to maximize energy capture from this ASP/HRC system, the storage component should be tied to a relatively constant demand for the generated heat. In other words, a relatively constant drain of heat from the water tank would be optimal. In Chapter 9 we will discuss another option – using the heat directly in a greenhouse application, without the heat exchanger/storage tank component.

The goal of this chapter is to estimate the total amount of heat energy that can be captured from the UNH ASP/HRC system over a full operating year. To do this, we need to put the data on short-term energy capture [92] into the context of commercial operating conditions, including the fraction of time that a given pile is aerated per day, and changes in pile temperature over time.

Under the farm operational conditions at the UNH ODRF, it is not possible to run enough controlled experiments to test all possible combinations of pile temperature, aeration time and material condition. Instead, we have produced a simple, excel-based model that captures the behavior of the different parts of the system. Here we test that model against measurements from the system, and then use the model to predict potential total annual heat capture.

A Simple Model of the UNH ASP/HRC System

As a simple physical system, the UNH facility can be described with a simple spreadsheet-based model that describes heat transfers as a function of empirically derived transfer coefficients applied to the measured gradient in temperature across any boundary. The model developed is available on request of the first author.

Comparisons among predicted and measured temperatures across the UNH system suggest that the model accurately captures the dynamics of that system (Figure 4.1). In addition to supporting the general accuracy of this simple model, three points can be made that are relevant to system management and potential total heat yield.

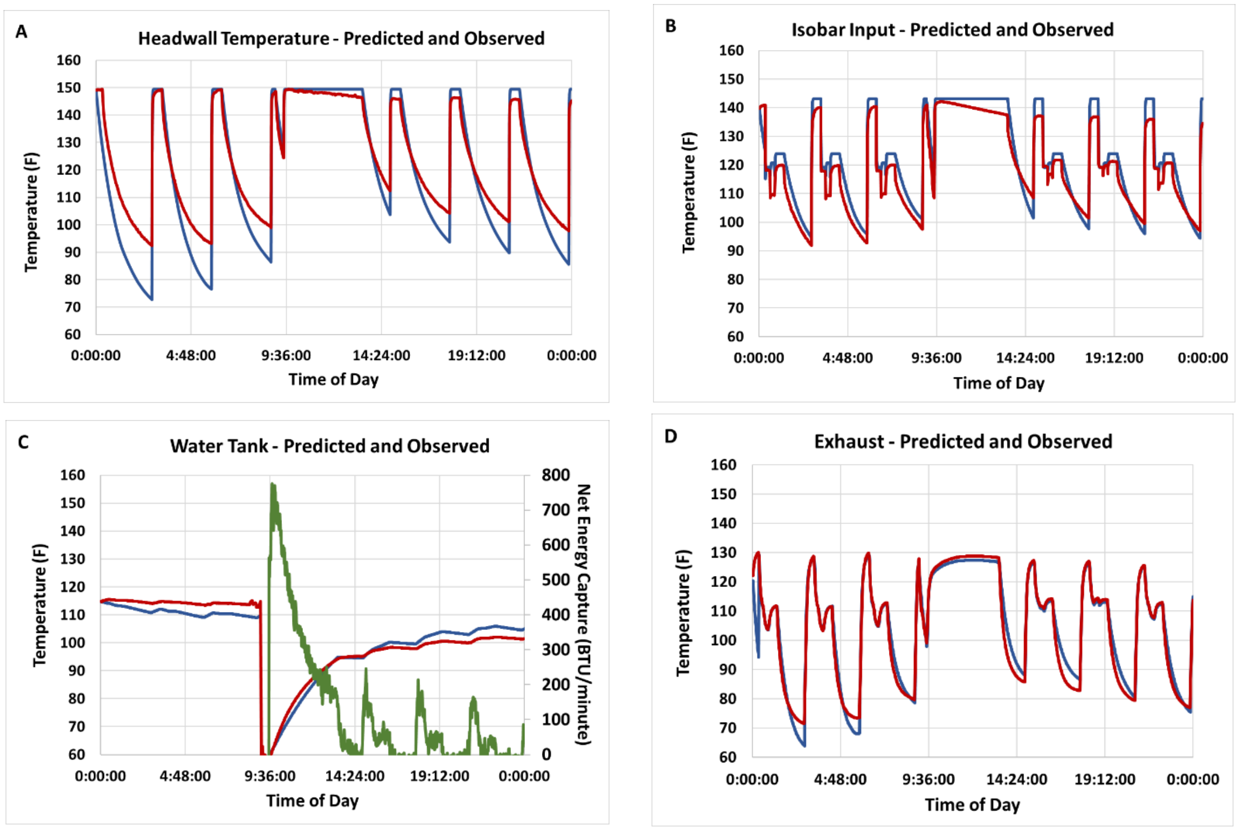


Figure 4.1 Model performance in terms of predicted (blue lines) versus observed (red lines) at 4 locations in the ASP/HRC system: A) At the headwall as the vapor exits the compost pile, B) As the vapor enters the isobar heat exchanger, C) Temperature of the water in the water tank – green line is energy capture (right axis), D) As the vapor exits the system as exhaust.

First, Figure 4.1c shows both an accurate prediction of tank water temperature over time, and also re-emphasizes the importance of the gradient in temperature between vapor stream and tank water in terms of rate of energy capture. During this trial, as the initially cool water is warmed by the vapor and approaches vapor temperature (Figure 4.1c), the rate of energy capture declines (green line).

Second, both figure 4.1a and b show a systematic difference between predicted and observed in terms of vapor temperature that develops during the ~ 4 hour trial during which air was drawn continuously down through the pile (see Smith and Aber [92] for a complete description of these experiments). This difference persists for the remainder of the data set, suggesting that the long aeration period reduced measured pile temperature, and that this reduction was not immediately reversed.

Finally, Figure 4.1d presents data on how exhaust temperatures vary over both the regular management cycle, and the 4-hour experiment. What this shows is that the exhaust gas will often still be at high temperatures, either at the beginning of an aeration cycle, or when the temperature of the water in the tank is elevated.

In 2016, the long aeration time experiments were carried out repeatedly using vapor from a single set of bays. While this provided the wide range of pile tempeatures required for developing the relationships captured in Figure 4.1 and Table 4.1 below, changes in pile temperature also show the impact of these multiple, long aeration times (Figure 4.2). The normal pattern of rapid assymptotic increase in pile and vapor temperatures, followed by a slow decrease over a multi-week composting cycle, is disrupted during and following each extended aeration event. Especially noticeable is the decrease following four consecutive days of extended aeration (days 136-139, May 16-19). Return to previous or expected temperatures was delayed for several days.

It is important to note that data from a previous analysis of shorter but variable aeration times more representative of normal composting operations [92] showed no significant effect of aeration length per cycle on vapor temperature.

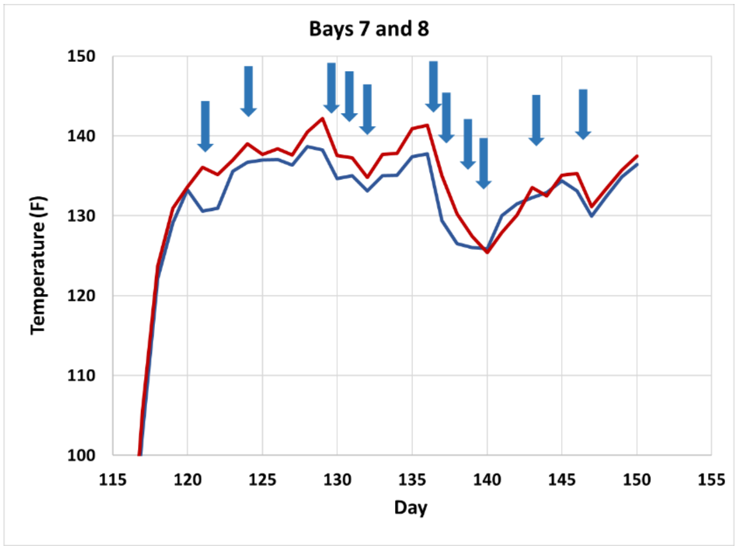


Figure 4.2. Headwall temperatures for Bays 7 and 8 for a 35-day period in May/June 2016. Arrows indicate days with long (3-4 hour) aeration trials.

To the extent that the comparisons in Figure 4.1 demonstrate the ability of the model to emulate the function of the UNH ASP/HRC system accurately, we can use the model to predict the total potential energy capture from this system over periods from a day to a year.

For the predictions that follow, we used a pattern of aerating for 40 minutes every 4 hours, for a total of 4 hours per day, with pile, tank and room (ambient) temperatures specified within the ranges measured at the facility. Results (Table 4.1) emphasize the importance of three variables. As expected, water tank and pile temperatures, and the difference between the two, were the primary factors controlling energy capture. Surprisingly, the ambient temperature in the area holding the water tank was also important. The model, which includes data on changes in tank temperature when aeration is not occurring, contains a factor for energy loss to the surroundings. Even though the tank was well insulated, energy loss into the room holding the tank, which was not heated, was significant during periods of cold weather. Negative values for heat capture result from energy loss from the tank to the operating room during periods where capture from the vapor stream is minimal.

System Temperatures (F)		Ambient Temperature (F)		
Tank	Pile	60	70	80
		BTUs (1000s)		
90	150	27.5	57.1	72.0
	140	13.1	42.6	57.5
	130	-1.4	28.2	43.1
	120	-15.8	13.7	28.6
	110	-30.3	-0.7	14.1
	100	-44.7	-15.2	-0.3
70	150	86.3	115.8	130.7
	140	71.8	101.4	116.3
	130	57.4	86.9	101.8
	120	42.9	72.5	87.3
	110	28.5	58.0	72.9
	100	14.0	43.6	58.4
50	150	159.7	174.6	189.5
	140	145.2	160.1	175.0
	130	130.8	145.7	160.5
	120	116.3	131.2	146.1
	110	101.9	116.8	131.6
	100	87.4	102.3	117.2

Table 4.1 Predicted rates of energy capture for a 24 hour period from a single pair of bays at the UNH ASP/HRC facility (1000s of BTUs per day) as a function of temperature differential between vapor and water tank, and ambient temperature in the facilities operations room.

Two Long-Term Data Sets for Annual Extrapolations

To produce reasonable estimates of potential total energy capture for a full year from this facility, we need to specify aeration schedules and changes in pile temperature over the full composting cycle. In commercial operations, aeration times are generally reduced as composting materials decay. Aeration times can be higher during the initial, thermophilic phase of the composting process, and can be greater for heat removal purposes than needed to meet microbial demand for oxygen [82]. As the composting process continues, and the easily digestible feedstocks are consumed by the microbes, temperature starts to decline and so does the need for aeration.

Figure 4.3 presents two example data sets collected as part of this study. The first trial captures standard (or actually ideal) initial conditions and rates of heat generation over time. Pile and vapor temperatures rise quickly to 150^{o}F and decline slowly over the 150+ day composting period. Material for the second trial was saturated with water at the beginning, and never achieved the maximum temperatures of the first trial, but temperatures also declined more slowly, and aeration times were longer. During both trials, changes in the amount of aeration time was modified to simulate management practices in commercial operations.

Another point derived from Figure 4.3a is that substantial amounts of heat energy can be generated over long composting cycles. Note that the vapor temperature in this trial remained above 100^{o}F even after nearly 6 months of decomposition. While commercial composting operations tend to emphasize throughput rates, and so rarely hold material longer than 3-4 weeks, a system managed for maximum heat generation may be optimized with longer composting cycles.

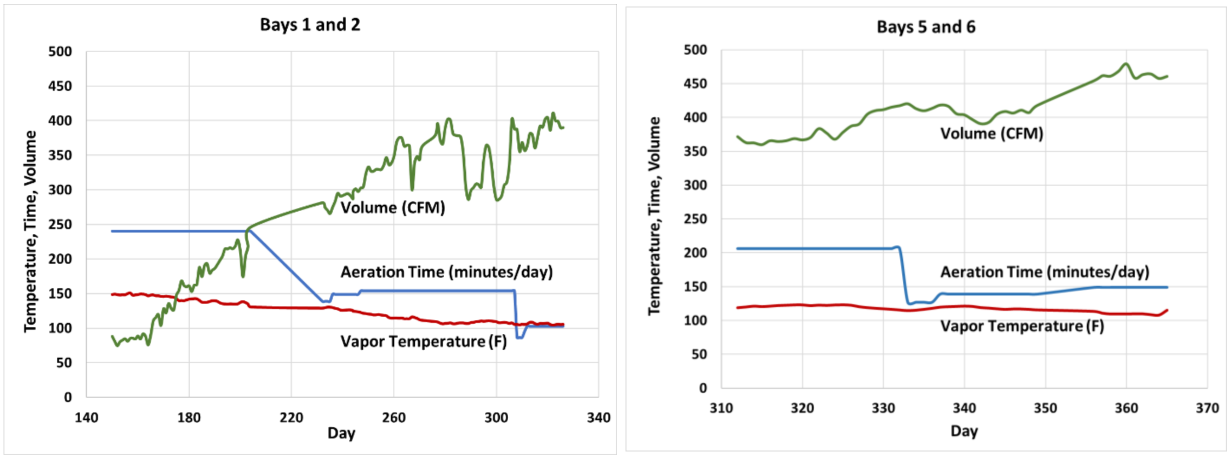


Figure 4.3. Data for vapor temperature, airflow volume and aeration time for two composting trials. Volume is related to hours of aeration and average airflow rate during aeration, but was also measured directly.

It is possible to run the model of heat generation and capture (Figure 4.1) for a very large number of combinations of changes in pile and water temperatures and aeration times over different lengths of composting cycles, the range of which is captured in Figure 4.3. However, the major drivers of energy capture are presented in Table 4.1 and can be extrapolated directly to different management scenarios. Enumerating all possible combinations in a large table might not enhance the clarity or value of the information provided. For example, estimating actual heat capture using the data presented in Figure 4.3 would require specification of changes in the temperature of water in the storage tank as well, requiring in turn a description of the use of the capture heat.

A final point is that these numbers are for a single pair of bays. There are four pairs of bays in the facility, so potential energy capture estimated from the values in table 4.1 should be multiplied by 4 when assessing the capacity of the full system, assuming there is enough material to keep the facility operating throughout the year.

Conclusions

From the values in Table 4.1, and understanding that these numbers are for one set of bays out of four in the facility, it is clear that the range of predicted total energy capture from the UNH ASP/HRC system at full operation could range from essentially 0 (high tank temperature with low pile and ambient temperatures) to nearly 800,000 BTU per day (pile at 150^{o}F, tank at 50^{o}F, ambient at 80^{o}F).

The effectiveness of this type of system as a source of heat energy is then very clearly linked to management practices and the nature of the heat sink to which the captured energy is applied. In Chapter 9 we will present several different methods of estimating total annual energy capture using a range of techniques and assumptions, and explore the potential for one particular application: using compost heat to extend the growing season in a high tunnel or greenhouse.

Chapter 5: Compost Gas Exhaust from an Aerated Static Pile Heat Recovery Composting System - Allison Leach, Nicole Williamson, Matthew Smith, and John Aber

Introduction

Chapter 4 presents the potential for generation and capture of heat energy from an Aerated Static Pile/Heat Recovery Composting (ASP/HRC) system. The decomposition process also generates gases such as carbon dioxide (CO_2), ammonia (NH_3), methane (CH_4), and nitrous oxide (N_2O) [7, 34, 2, 101, 83] that can contribute to climate change or local air pollution [103, 99]. In particular, the carbon dioxide and ammonia concentrations in compost gas can be much higher than ambient levels. [7, 4, 68].

The ratio of the two main carbon gases (carbon dioxide and methane) emitted during decomposition of farm wastes will vary depending on the concentration of oxygen in the pile [3, 48, 97, see also Chapter 1]. This ratio will affect the impact of the process on the climate system, as methane is ~25 times more effective than carbon dioxide in retaining long-wave, infrared, or “heat” radiation [106].

Most studies on compost gas exhaust concentrations cited above have occurred at the lab scale and have relied on expensive lab testing equipment. Lab-scale results may not accurately reflect conditions in commercial-scale facilities. We could not find any studies in the literature exploring gas concentrations at ASP facilities with heat recovery.

The goal of the research reported here was to develop a sampling procedure for measuring exhaust emissions from composting facilities using inexpensive and portable gas sampling technologies suitable for use in a commercial-scale facility, and to use these methods to characterize the concentrations of carbon dioxide, ammonia, methane and oxygen in the exhaust stream from the UNH ASP/HRC system.

Methods

We began this study by comparing available methods for measuring elevated concentrations of carbon dioxide, ammonia, methane and oxygen in the high temperature, high humidity environment of the vapor streams from the ASP/HRC facility. As a result of these method tests [53], colorimetric gas detection tubes were selected as the preferred method, and were used to measure carbon dioxide and ammonia (RAE Systems, and Drager Systems). Detection tubes were selected because of their wide concentration range (RAE Systems: 25-1000 ppm ammonia, Drager: 1000-5000 ppm ammonia, RAE Systems: 0.25-20% carbon dioxide) and accuracy at high temperature and humidity [77, 27]. Gas detection tubes are also relatively inexpensive and can be used by commercial compost facility operators.

A gas detector (RKI Eagle Portable Gas Detector) was used for methane measurements because quantitative gas detection tubes for methane are not available. Methane concentrations are measured on a scale of 0-100% of the lower explosive limit (LEL, or 0-5% by volume). Oxygen measurements from the gas analyzer were used to monitor aeration before an oxygen sensor was installed in the facility. Oxygen was measured in the gas detector using an electrochemical gas sensor with a measurement range of 0-40%. The oxygen measurements from the gas detector were corrected using a comparison between the gas detector and facility sensor oxygen measurements [See 53], for additional details on sampling methodology).

Gas sampling was conducted for four complete compost trials, each of which had two paired bays with the same feedstock material (Table 5.1). These individual bays are not true replicates because there is not a divider between bays. Although the pipes drawing air through the two paired bays are 4 feet apart, aeration in one bay can also pull some air through the adjacent, paired bay. However for this study, each of the individual bays will be reported separately.

Start date	Bays	Total number of days	Days Sampled	Number of sampling events	Compost Trial Condition
September 2015	1 & 2	83	4 days	32	Blocked air flow
October 2015	3 & 4	53	6 days	23	Delayed microbial activity
August 2016	3 & 4	61	22 days	39	Standard conditions
November 2016	7 & 8	40	14 days	23	Low temperature

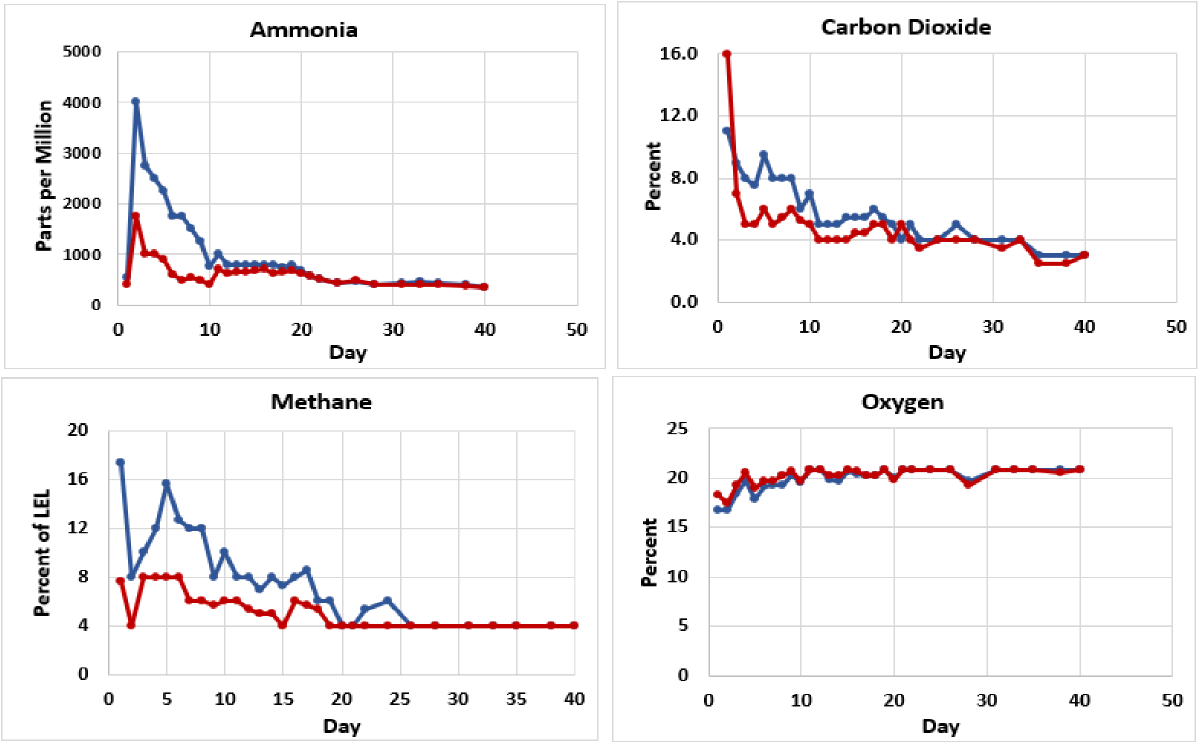
Table 5.1. Descriptive information for four compost sampling periods.

As evident in the final column in Table 5.1, pile conditions varied widely across the four composting trials, with the August 2016 trial representing standard or ideal conditions, and the other three showing variations in composting rates and gas emissions. Given this variation, we present here the August 2016 data set as most relevant to well-managed, professional operations. The results of the other three trials are presented in Leach [53].

Results and Discussion

Changes in pile temperature and gas concentration are presented in Figure 5.1. On the first day of sampling, just after the feedstock was put in place, temperatures and ammonia concentrations are near minimums, while both carbon dioxide and methane are at their highest levels. This suggests that the material was anaerobic prior to loading, due to outside storage. After just one day of aeration, the ammonia concentrations quickly peaked to maximum readings: over 4000 parts per million for bay 3 and near 2000 parts per million for bay 4. At the same time, carbon dioxide and methane concentrations both started to decline. Pile temperatures followed a similar pattern, peaking in the first week, and declining over time.

Combining data from both bay 3 and bay 4 reveals a strong relationship between pile temperature and concentrations of carbon dioxide and ammonia (Figure 5.2). Data from day 1 and 2 of the trial are not presented as they represent initial pile conditions rather than the result of processes after loading. This relationship is to be expected as higher temperatures reflect higher rates of microbial processing, which will also result in higher rates of release of carbon and nitrogen from the feedstock.



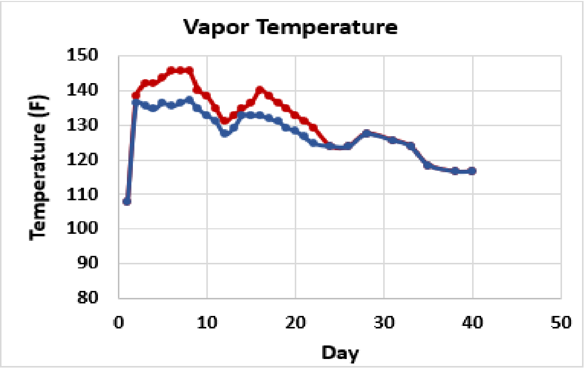


Figure 5.1 Trends in vapor temperature and gas concentrations over a full composting trial beginning in August 2016 for two composting piles: Bay 3 (Blue line) and Bay 4 (Red line).

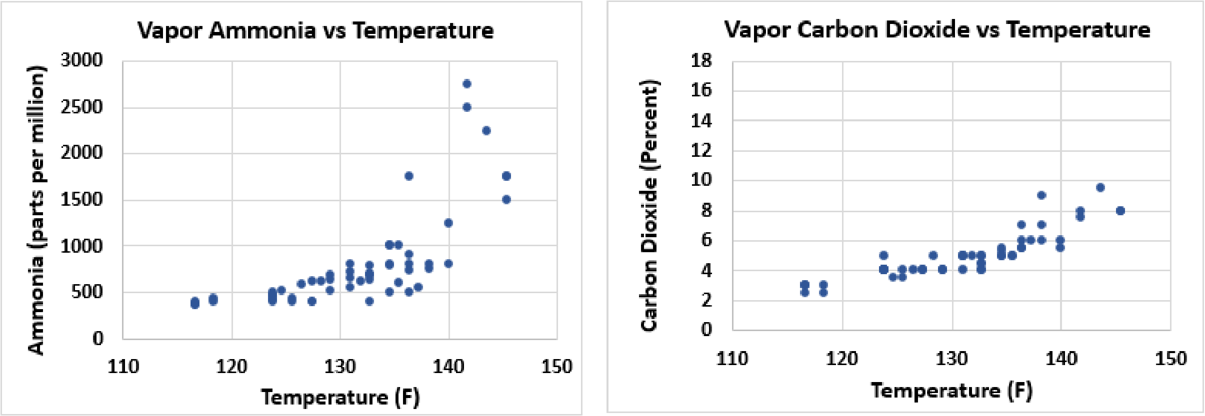
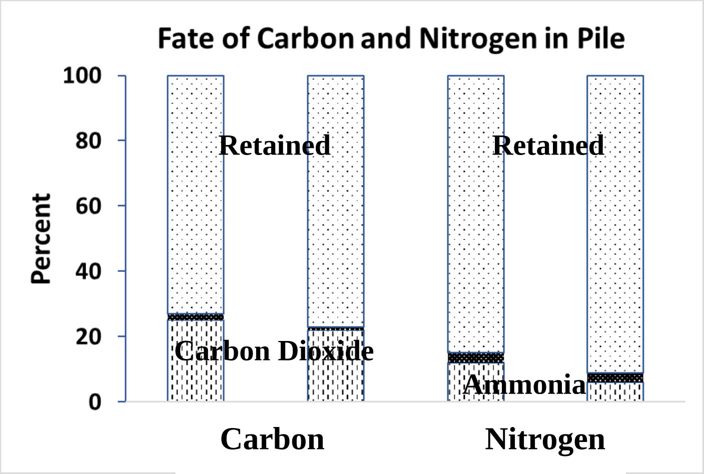


Figure 5.2. Relationships between vapor temperature and concentrations of ammonia and carbon dioxide. Outliers from day 1 and 2 of trial removed.

In the introduction we highlighted the potential importance of the partitioning of carbon losses between carbon dioxide and methane. By combining measured gaseous losses with estimates of initial pile content as well as measures of leaching losses that occur thought condensation that occurs as the vapor is cooled in the heat exchanger [53, 87], we can report the fractions of initial carbon and nitrogen lost and retained for the August 2016 trial (Figure 5.3).

For carbon, losses were primarily through emission of carbon dioxide (22-25%), with 73-77% retained in the organic matter within the pile. The remaining 1-2% was emitted as methane or leached in condensate (in Figure 5.3, black bars between retained and carbon dioxide). For nitrogen, emissions of ammonia accounted for 6-12%, with 85-91% retained. Losses in condensate accounted for about 3% of initial feedstock (black bars in Figure 5.3). Greater emissions for carbon than for nitrogen are consistent with the expected decrease in the carbon:nitrogen ratio in the feedstock as decomposition proceeds.

Figure 5.3. Fate of initial carbon and nitrogen in feedstock for August 2016 trial. See text for explanation



The ratio of carbon emitted as carbon dioxide versus carbon emitted at methane (~20:1) is much higher than ratios measured in static piles at the ODRF and agrees with undetectable levels of methane at the Diamond Hill Farm ASP/HRC facility (Figures 1.3, 1.4). Similar differences in this ratio between aerated and static piles have been noted in the literature [3, 48, 97]

Conclusions

Two major conclusions can be drawn from this first set of measurement on gas emissions from a commercial-scale ASP/HRC facility.

The first is that ammonia concentrations in exhaust gases are several orders of magnitude higher than atmospheric concentrations and can pose environmental challenges. During full operation, ammonia odors were clearly detectable in the exhaust prior to the initiation of the biofilter work reported in the next chapter.

The second is the potential for reducing the climate impacts of manure management on farms by replacing static non-aerated composting piles, which generate high methane emissions, with next generation composting systems that capture heat and reduce overall greenhouse gas emissions.

Chapter 6: Designing and Testing a Biofilter for Ammonia Removal at a Commercial-Scale Composting Facility – Nicole Williamson, Allison Leach, Matthew Smith, and John Aber

Introduction

Composting provides an environmentally friendly alternative to landfill disposal for processing organic waste material. Aerated static pile composting is a method of composting that pulls air through the compost to promote microbial activity, generating usable heat energy while also minimizing surface and groundwater contamination (see Chapters 1, 4 and 5). While limiting some environmental impacts, this process still produces exhaust vapors with pollutants like ammonia that can impair local air quality [e.g. 74]. One response to the problem of ammonia emissions could be the installation of a biofilter. Biofilters use biological process to remove unwanted elements from waste streams.

For example, passing ammonia-rich gases, like those described in Chapter 5, through a carbon-rich, microbially active substrate could reduce ammonia emissions from the facility through microbial immobilization of the ammonia resource [71, 65]. Materials frequently used for biofilter removal of ammonia include wood chips with or without finished compost added [see reviews by 119, 72, 15]. Such biofilters are cost efficient and easily installed.

The use of biofilters is a well-established method for reducing emissions of odors and toxins from composting and wastewater treatment systems, having been employed as early as 1953 in a sewage treatment plant in Long Beach, CA [65]. Key characteristics of such systems include the type of material used in the filter, the structure, porosity, moisture content and temperature of the material pack, and the frequency and rate of aeration [82]. Mathsen [60] and Nanda et al [65] provide general reviews on each of these topics. Mature compost, wood chips, straw, hay and similar materials are most commonly used in farm settings. Unique combinations [e.g. 47] reflect local availabilities. We focus here on the effects of biofilters on ammonia (NH_3) as this is the primary constituent having a negative effect on odors and air quality.

Janni et. Al [49] tested a portable effluent air characterization method at 6 different sites using a range of biofiltering approaches. Inlet carbon dioxide (CO_2) concentrations ranged from 618-3085ppm, and ammonia (NH_3) concentrations from 4.7-37.6ppm. No changes in carbon dioxide concentration were measured, and ammonia removal efficiencies ranged from 60-90%. Removal increased with moisture content in these systems, but so did nitrous oxide (N_2O) production. Rate of airflow increased with measured pressure drop across the material. Mathsen [60] emphasizes that slower air movement and lower pressure drops are important for maintaining relatively equal rates of airflow throughout the entire filter.

Chen et al [13] report consistent ammonia removal rates of 95% over 210 days at inlet concentrations of up to 110ppm. Lower efficiencies occurred above 110ppm, and after 200 days. Ling and Chen [56], as part of a larger study, report 95% removal of ammonia by a compost/activated charcoal mixture with inlet concentrations from 20-500ppm and with retention times in the biofilter of about 30 seconds. Pagans et al [71] found 95% removal using mature compost as the medium and inlet concentrations up to 2000ppm.

Nicolai et al [67] compared the retention efficiency for ammonia in biofilters using a mixture of compost and wood chips ranging from 10% to 90% and over three levels of moisture content. They found that efficiencies were relatively constant with compost content above 20% of the total, and moisture contents above 40%. They recommended at 30:70 mix of compost:wood chips to optimize aeration, contact with biofilter material, and potential for biological activity.

Most of the references cited above test biofilters in lab-scale settings with low concentrations and do not consider commercial-scale facilities and higher gas concentrations. Here we address the construction, sampling methods, and ammonia removal efficiency of two different organic biofilters. The biofilters are located at the UNH ASP/HRC facility Organic Dairy Research Farm in Lee NH.

Methods

Ammonia removal efficiency of the biofilters tested as part of this study was determined by comparing the concentration of this gas in the exhaust stream from the ASP/HRC facility (see Chapter 5 for methods) against concentrations following passage through the biofilter. To measure emissions from the biofilter, we needed to design and construct an enclosure that would isolate those emissions from ambient air. To achieve this isolation, we used a system of pipes and valves to capture exhaust gases and direct them to the biofilter, placing biofilter materials over this piping system, and then building an enclosure over the biofilter to isolate emissions from ambient air (Figure 6.1).

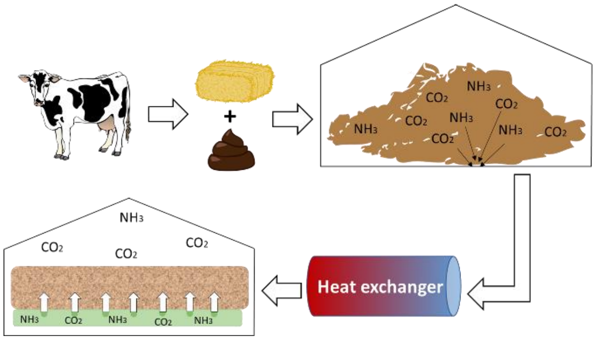
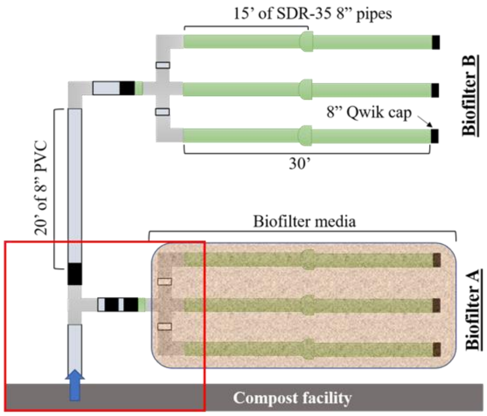


Figure 6.1 Conceptual diagram of the linked composting/biofilter system at the UNH ODRF

The pipe system for the biofilter was laid out as a pair of filter areas, each with a three pipe system for distributing exhaust from the composting facility to the biofilter (Figure 6.2). Each leg of this system was 30 feet long. Pipes were standard 8 inch diameter leach field pipes purchased from a local dealer. This pipe system was laid on the ground and valves were included at each of the black square locations to direct airflow. Biofilter material was laid over the pipes and mounded to a depth of approximately 3 feet.



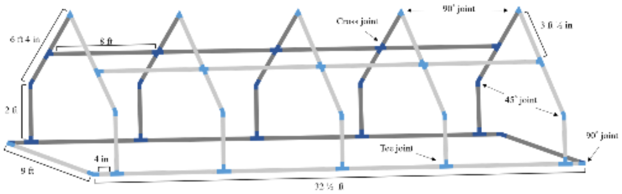


Figure 6.2 – Left, aerial schematic of layout of biofilter pipe system. Above, design of PVC frame to hold plastic cover allowing enclosure of biofilter for gas sampling.

The frame for the enclosure constructed to isolate and measure gases passing through the filter material was constructed of PVC tubing in a peaked house design (Figure 6.2). For sampling, this frame was overlain with plastic sheeting anchored to the ground with boards weighted down with sandbags and stones. Sampling described below was designed to detect any dilution of gases that occurred during sampling periods by leakage around this cover.

The initial concentration of ammonia and carbon dioxide within the enclosure would be the ambient concentration in the atmosphere. As this initial air is displaced by flow-through from the exhaust stream and biofilter, the concentration within the enclosure approaches that of the gases leaving the biofilter material. A set of methods experiments with gas sampling over time following placement of the enclosing plastic film demonstrated that, at normal fan speeds in the facility, concentrations within the enclosure reached an asymptote within 10 minutes. For all results reported below, this 10 minute acclimation time was used.

For all sampling trials, concentrations of ammonia and carbon dioxide were measured at the exit port of the composting facility, and within the enclosure, after acclimation. As previous studies had suggested that concentrations of carbon dioxide did not change significantly by passage through a biofilter [e.g. 49], we used comparison of facility exhaust and enclosure concentrations of this gas as an indicator of leakage or dilution by ambient air from outside the enclosure.

Gas concentrations were measured using the protocol and colorimetric gas detection tube methods described in Chapter 5.

Results and Discussion

Comparison of measured carbon dioxide concentrations in the facility exhaust and in the biofilter enclosure confirmed that those concentrations were similar, supporting the finding in previous papers that this gas did not change during passage through the filter. This also supports the assumption that the gas concentrations within the enclosure were not affected by leakage or dilution by the ambient atmosphere.

For all trials, the initial efficiency of ammonia removal was very high. Over a standard 21 day composting cycle trial with a range of ammonia inlet concentrations, ammonia removal efficiency averaged 70-100% (Figure 6.3a). Efficiency increased significantly with increasing inlet concentration across all trials and biofilter types (Figure 6.3b). The efficiency of the wood chip only filter declined over the three year time period that it was in place, dropping to an average below 50% in year 3 (Figure 6.3c). There were no significant differences between removal efficiencies for the wood chip only and wood chip plus compost filters.

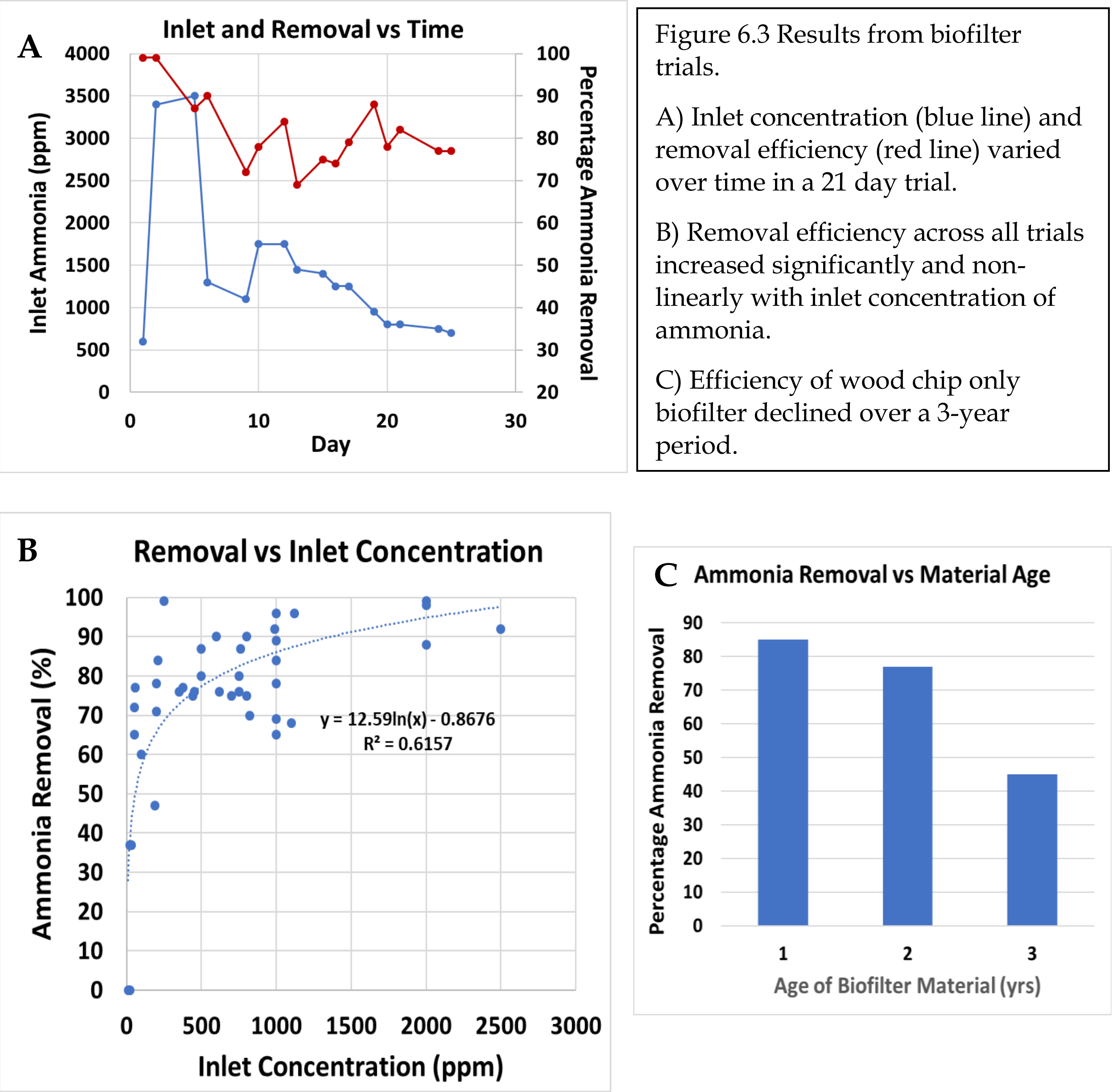


Figure 6.3 Results from biofilter trials.

A) Inlet concentration (blue line) and removal efficiency (red line) varied over time in a 21 day trial.

B) Removal efficiency across all trials increased significantly and non-linearly with inlet concentration of ammonia.

C) Efficiency of wood chip only biofilter declined over a 3-year period.

Conclusions

Our results substantiate that simple biofilters can generally be effective at removing 70-100% of ammonia from the exhaust gas stream of an ASP/HRC system like the one at the UNH ODRF. Efficiencies are a function of inlet concentrations, and decline with the age of the biofilter materials, dropping below 50% in the third year of operation. There were no significant differences between wood chip biofilters with and without compost included.

Chapter 7: Waste Management Practices and Water Quality at the UNH Organic Dairy Research Farm – William H. McDowell, Michelle D. Shattuck, J. Matthew Davis and John Aber

Introduction

In addition to the air quality issues addressed in the last two chapters, agricultural practices are also known to affect water quality as part of what has been described as the Nitrogen Cascade [36]. In particular, accumulation of excess nitrogen in areas of concentrated animal agriculture, especially in barn and containment areas, or where animal manures are stored, can increase concentrations of ammonium and nitrate in water leaching through these wastes [e.g. 98]. One potential advantage of ASP/HRC systems in this regard is that manure/bedding wastes are stored under cover within the facility, protected from rain and snow. In the case of the UNH Organic Dairy Research Farm (ODRF), other changes in waste management described below occurred at the same time as the establishment of organic dairy practices. These changes provide the opportunity to examine the response of water quality across the farm.

Two changes are highlighted here. The first is a shift from the storage of barn wastes (manure and bedding) in an exposed, uncovered and anerobic site (Chapter 1), to the aerated and covered environment within the ASP/HRC structure (Chapter 3). This change occurred when the facility was completed in 2013. The second is the elimination of miniature swine from the animal husbandry operations at the ODRF in 2009. The swine were raised in a single enclosed facility from which wet manure was washed daily into an open storage lagoon.

At the beginning of the agroecosystem project, we proposed to measure and monitor nitrogen levels in groundwater at different locations across the Burley-Demeritt farm. This work used groundwater wells that were installed in 2008 with support from the US EPA through the Connecticut River Airshed Watershed Consortium and the NH Water Resources Research Center. With additional support from the SARE grant for our Agroecosystem Study, research has been completed describing ground and surface water flows [11, 37, 28, 63, 5]. Pairing this understanding with measurements over time of nitrogen concentrations in the groundwater wells and surface waters on the farm provides insight into changes in nitrogen dynamics related to changes in waste management practices during the first 10 years since the establishment of the Organic Dairy Research Farm.

The purpose of this chapter is to present data on water flows and nitrogen concentrations across the ODRF and to highlight changes in water quality downflow from the outdoor manure storage and waste lagoon locations following the elimination of the miniature swine operation, and the relocation of the dairy waste storage to the composting facility. We also present data from wells adjacent to the barn and yard area where temporary storage of manure/bedding materials before loading into the ASP/HRC facility has continued. Farm operations are beginning to eliminate this intermediate, outside storage, moving wastes directly from the barn to the composting facility.

Methods

Groundwater dynamics were determined using a combination of physical properties and hydrologic measurements [11, 12]. Satellite imagery (LIDAR – a laser-based reflectance technique) was used to map changes in elevation across the farm in high resolution (Figure 7.1). Surficial geologic materials present at the farm were mapped and combined with coarse-scale USGS maps of soil type augmented with additional test bores across the farm to generate a soils data layer.

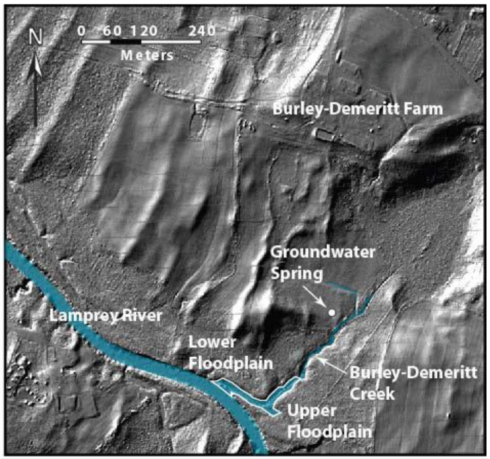


Figure 7.1. Elevational map of the ODRF with simulated side lighting to emphasize relief (Galvin 2010).

Groundwater sampling wells were installed at different points across the farm. Three were located just downflow from the swine waste lagoon, and two were located near the area where manure and bedding materials from the dairy operation were stockpiled outdoors before the construction of the covered ASP/HRC facility (see Chapter 1). Additional groundwater wells were located along the elevational gradient evident in Figure 7.1 to produce the distribution of sampling sites shown in Figure 7.2, which also includes a surface water sampling station in Burley-Demeritt Creek (BDC in Figure 7.2).

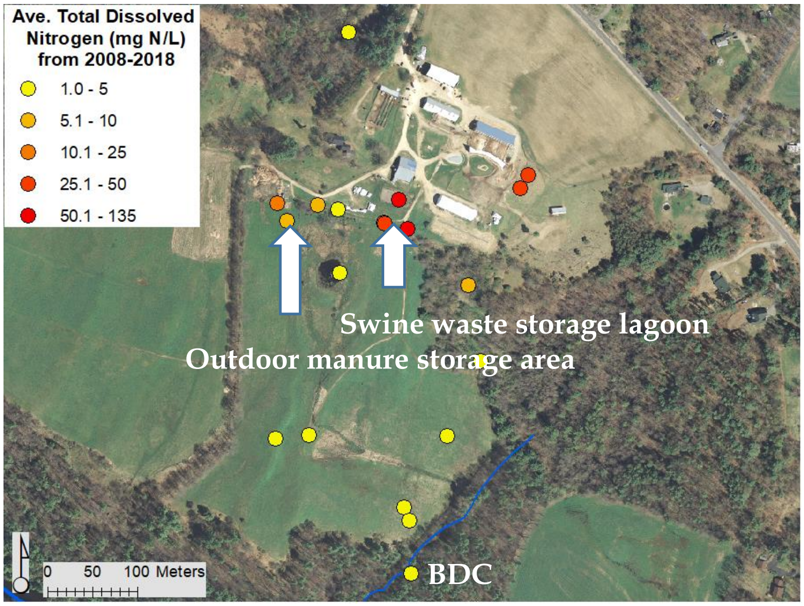


Figure 7.2. Location of groundwater sampling wells with measured ranges of total dissolved nitrogen values.

Single well (slug) tests were conducted on a number of wells to estimate the hydraulic conductivity of the different geologic materials. These data served as input to an industry-standard groundwater hydrology model (MODFLOW) that was then used to predict rate and direction of groundwater flows across the farm [11].

Water samples were collected from this set of sites at roughly monthly intervals through 2014, and less frequently thereafter. Total dissolved nitrogen in samples was determined with a high temperature carbon analyzer with nitrogen module [62], nitrate was determined by ion chromatography [116] and ammonium was determined using the automated colorimetric method [107].

Results and Discussion

Data derived from this set of studies have been used in several presentations on the impacts of agricultural watersheds on groundwater and streamwater quality [e.g. 21, 123]. Here we present only the subset of this rich dataset that relates to changes in water quality after ceasing to use the lagoon for swine barn wastes, and initiating operation of the composting facility and storing barn wastes mostly under cover.

Figure 7.2 shows the location of the sampling locations, as well as mean concentrations of total dissolved nitrogen in the early years of the agroecosystem study. The locations of both the swine waste lagoon and the manure stockpiling operation are shown. The two red dots at the upper right are adjacent to the barn and pad area where cows are housed when not on pasture. This area receives runoff and daily scrapings from the pad area. Total nitrogen concentrations remain high in this area, although the form of nitrogen present has changed (see Figure 7.5 below).

The high level of nitrogen in groundwater adjacent to the lagoon and manure/bedding storage point sources is greatly reduced by the time the water reaches the creek draining the farm (BDC), and the adjacent Lamprey River (Figure 7.2). Samples from the Lamprey taken above and below the farm show no evidence of an impact of the ODRF on river water quality [21]. Based on our chemical data and likely flow paths, it appears that passage of groundwater through both pastures and a naturally vegetated wetland prior to entering the creek may play an important role in minimizing the impact of this contaminated groundwater on total N export from the site. Both biological processing (denitrification) and physical dilution may play a role here. Results from the groundwater flow model suggest that dilution may be particularly important in driving nitrate concentrations (Figure 7.2 and 7.3).

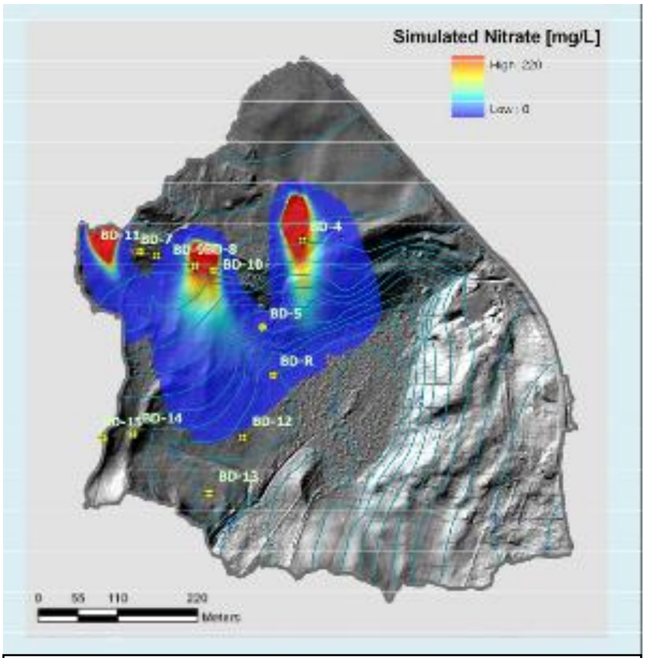


Figure 7.3 Modeled dilution of dissolved nitrogen concentrations measured at farm “hot spots” described in Figure 7.2 and accompanying text, by groundwater flow [12].

The impact of alterations in waste generation and management practices is apparent in changes over time in nitrogen concentrations in samples from wells adjacent to the manure/bedding storage area and swine waste lagoon (Figure 7.4). At both locations, reduction in nitrogen concentrations began immediately following the elimination of the waste source (2013 for bedding and manure, and 2009 for the swine operations).

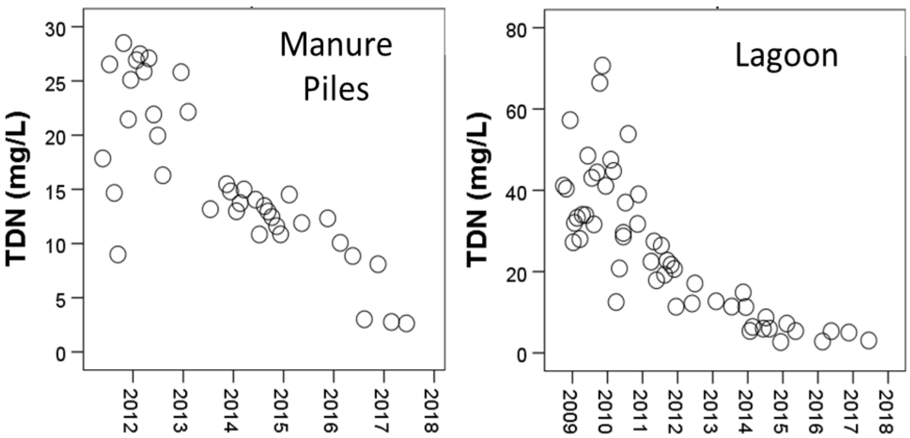


Figure 7.4. Measured changes in total dissolved nitrogen concentrations in groundwater adjacent to two animal waste storage location following removal of those waste streams. See text for explanation [61].

While total nitrogen concentrations measured in the wells adjacent to the barn and pad remain high, the form of nitrogen present has shifted (Figure 7.5), with a marked decrease in nitrate, but a simultaneous increase in dissolved organic nitrogen (DON).

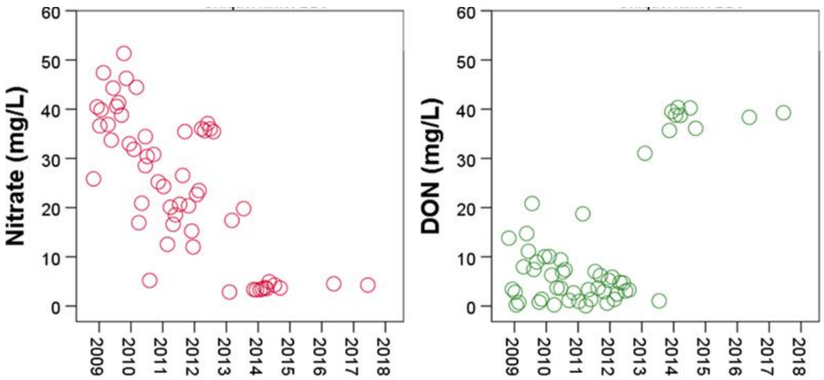


Figure 7.5. Measured changes in nitrate and dissolved organic nitrogen in wells adjacent to the barn and pad at the ODRF [61].

Results also show that while nitrate levels are low on average in wells closest to the Lamprey River and in the creek draining from the farm to the river (Figure 7.2), concentrations in the creek are influenced by flow rate (Figure 7.6), with highest concentrations seen during periods of low flow.

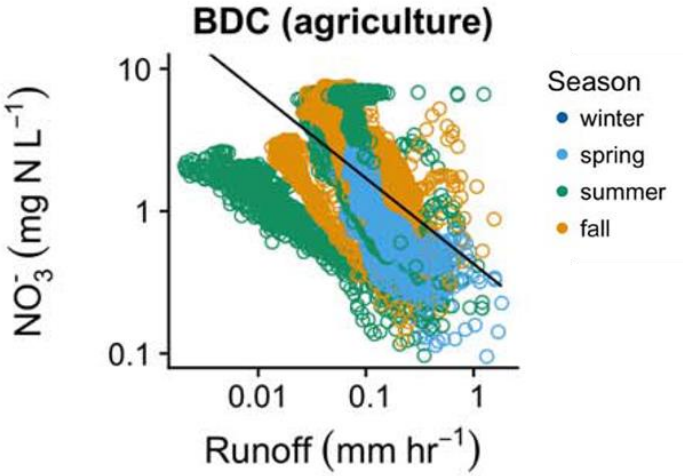


Figure 7.6. Nitrate concentrations in the Burley-Demeritt Creek (BDC) draining the ODRF as a function of season and runoff (flow normalized by area, reprinted from [50]).

Conclusions

This partial presentation of results from extensive studies measuring and modeling ground and surface water dynamics and nitrogen concentrations demonstrates the additional benefit of a covered composting system, such as the ASP/HRC system at the UNH Organic Dairy Research Farm, in reducing nitrogen runoff into groundwater. The data also suggest that high concentrations of nitrogen generated by high density stock or waste areas can be diluted or processed in soils, wetlands and streams in adjacent, low-density areas such as those that occur in pasture-based systems with unmanaged land use buffers.

Chapter 8: Nitrogen Cycling, Surplus and Use Efficiency at the Organic Dairy Research Farm - Impacts of Composting - Allison Leach and John Aber

Introduction

Agricultural production is a major component of human impacts on the cycling of nitrogen at local to global scales, and reactive forms of nitrogen created through the production of fertilizers or combustion of fossil fuels can have “cascading” effects [36], affecting environmental quality during passage from atmosphere through soils to surface and ground waters. At the farm level, management of agricultural wastes, and especially animal manures, are a major factor in a farm’s overall environmental impact [e.g. 39].

Our work at the UNH ODRF suggests that conventional approaches to manure management using static piles stored outside can enhance nitrogen leaching to groundwater as well as increased emissions of methane to the atmosphere (Chapters 1, 5 and 7). Composting, especially using the aerated static pile (ASP) method presented in Chapters 3-6, offers the potential to reduce both pollution vectors. Many of these improvements are related to housing the decomposing feedstock under cover in a building and controlling the decomposition process through continuous aeration.

An additional aspect of the long-term consequences of composting in terms of reducing nitrogen (N) pollution might best be assessed using a farm N budget and a range of compost export scenarios [118, 69, 10, 44, 25]. Specifically, exporting compost as an additional saleable product could remove excess nitrogen introduced in feeds, reducing the potential for emissions of waste N to waters or the atmosphere. In this chapter we present data on the nitrogen budget of the UNH ODRF and explore the impact of retaining or exporting produced compost on farm operations in terms of net nitrogen surplus (excess of external inputs over export in product) and nitrogen use efficiency (the percentage of nitrogen inputs exported in products).

Farm nitrogen budgets and performance indicators

A complete farm N budget includes all transfers of nitrogen across the farm boundaries (inputs and outputs), as well as transfers among major parts of a farm (e.g. Figure 8.2). Farm N inputs can include fertilizer, feed, livestock, bedding, and biological nitrogen fixation (BNF) by legumes like clover in pastures. The farm N outputs are the farm products such as milk and sold cattle. In this chapter we also consider the impact of including the sale of compost as an additional product. Other N loss pathways, including leaching to surface or subsurface water or emissions to the atmosphere, can also be measured or estimated. The farm N budget approach has been used extensively in the technical literature to compare productivity and efficiency of different operations [118, 69, 55 22, 23, 25]. Two performance indicators are used most frequently: Nitrogen surplus and nitrogen use efficiency.

Nitrogen surplus is just the difference between N inputs and outputs, or the amount of nitrogen crossing the physical farm boundaries (Figure 8.2, 8.3). By convention, the amount of nitrogen added to a pasture-based dairy system through biological nitrogen fixation, primarily by legumes such as clover or alfalfa, is also included as an input. The fate of the N surplus is not always clear depending on the level of detail in the budget calculations. Potential fates for the N surplus include storage on the property (with soil storage being the most likely reservoir in pasture systems) or loss to the environment (leaching to water or emissions to the atmosphere).

Nitrogen Use Efficiency (we will use NUE for this) is the percent of N invested into farm production (inputs) that makes it into the intended products (e.g., crops, milk, animals sold, and in this case, compost).

Methods

The ODRF averages about 80-100 head of registered Jersey cows (Figure 8.1) including 40-50 milkers and the rest heifers, dry cows and calves. The farm property spans about 300 acres, including about 170 acres in woodlands and 110 acres in pastures and forage production (see description in Chapter 2). The farm is a USDA certified organic dairy operation. Lactating cows are on pasture from early May to early November, following USDA organic guidelines. Milkers' diet is augmented with a mixture of imported organic feed grains plus forage and baleage, most of which is produced on-site. The farm property has an open bedded pack barn for the cattle, storage barns, a step-up milking parlor, and the composting facility described in earlier chapters.

Figure 8.1 Jerseys grazing at the University of New Hampshire Burley-Demeritt Organic Dairy Research Farm

Agricultural wastes generated at the ODRF are processed at the Joshua Nelson Energy Recovery Compost Facility (Chapter 3) and later applied to the pastures. Feedstock materials for composting include cow manure, bedded pack, waste baleage, and wood chips. Vapor drawn down through the composting materials and into the heat exchanger is at 100% relative humidity and is greatly enriched in carbon dioxide and ammonia (Chapter 5). After passing through the heat exchanger, this vapor stream is routed through a biofilter (Chapter 6). Condensation occurs as the vapor cools in the heat exchanger and the resulting liquid condensate is collected in a storage tank. Both the exhaust gases (Chapter 5) and the collected leachate are measurable parts of the nitrogen budget for the farm and are included in this analysis.

Farm nitrogen budget

The ODRF nitrogen budget captures major flows into and out of the farm property as well as transfers between the three major components: Pasture, Animals and Barn, and the Composting Facility (Figure 8.2). Sources for the data used to develop the numbers in this figure are summarized in Table 8.1, and details on sources, methods and calculations can be found in [53].

Because a number of the largest nitrogen flows involve financial transfers as well, detailed information is available from the financial offices at UNH that oversee the farm. These include the purchase of grains, baleage and bedding, and the sale of milk and animals. Other minor inputs include atmospheric deposition and a small input from wood ash added as fertilizer to the pastures.

The largest input not measured directly is biological nitrogen fixation (BNF) by legumes in the pastures. This was estimated using a survey of pasture vegetation [40] to determine the percentage of alfalfa and clover in the pastures matched with average rates of nitrogen fixation by those types of vegetation drawn from the literature (see [53] for sources and methods).

Internal transfers include estimates for forage consumption on pasture as well as manure returned directly to pasture during grazing (based on number of animals, time spent on pasture, and average consumption rates from the literature and from feed records kept at the ODRF as part of the organic certification process), and measured harvest of baleage for later consumption.

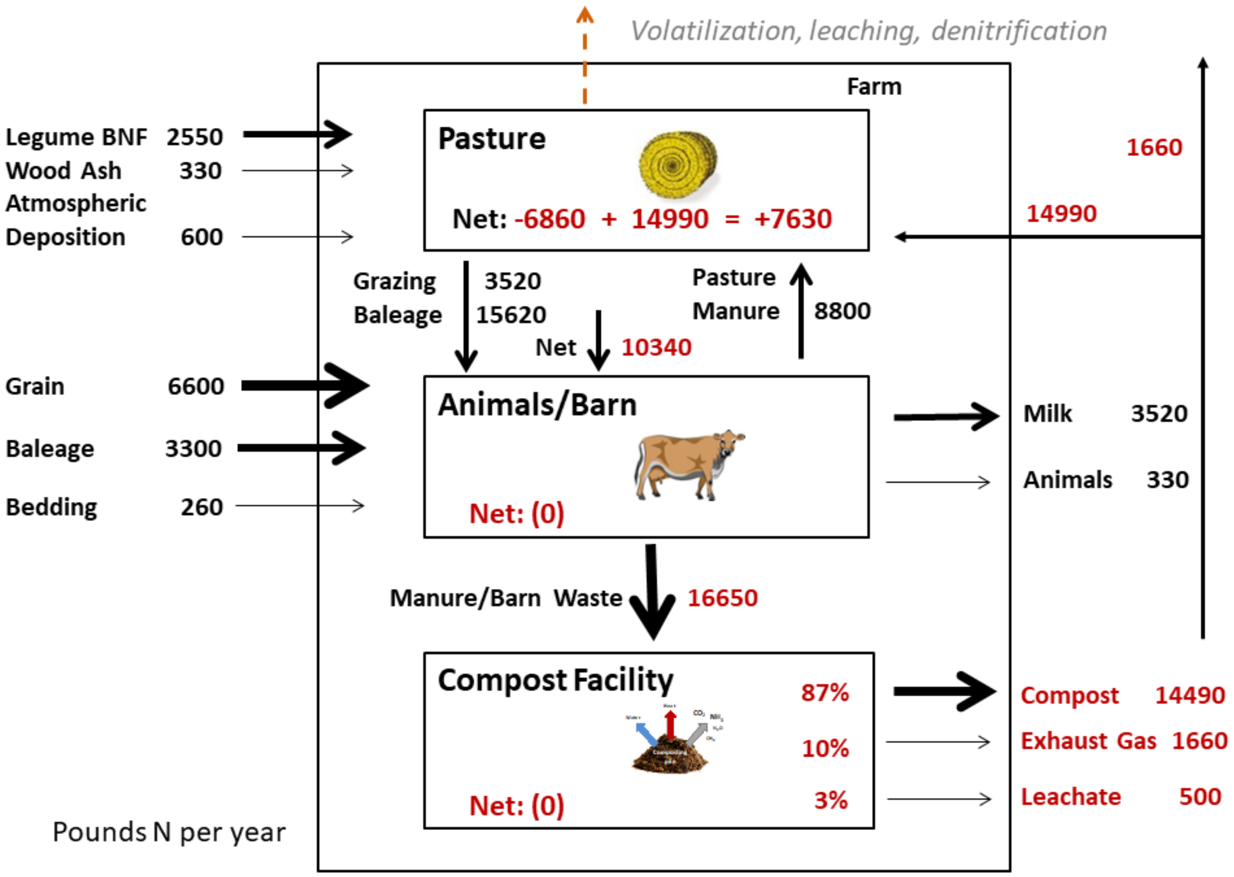


Figure 8.2 Nitrogen budget for the UNH Organic Dairy Research Farm (pounds nitrogen per year). Figures in black are from direct measures or data available from purchase and sale information. Values in red are calculated based on assumptions described in the text.

The remaining major transfers involve the management and processing of the composting feedstock and system. During the years of SARE support, the composting operation was managed for research. This meant that the timing and amount of material actually processed varied from year to year, and did not always include all materials produced in the barns. For some trials, material was imported from the equine operations on the main campus in Durham. To better represent commercial operational conditions, we assume here that all of the manure/bedding mixture generated in the barn, and only that material, is transferred to the composting facility.

Data source	Farm nitrogen budget data sets
Farm Operational and Financial Records:	• Annual milk production and quality • Livestock counts, types, and ages • Feed grain purchases • Baleage (on-site production and purchased) • Pasture grazed by cattle • Purchased and sold livestock • Bedding (purchased) • Manure production and management • Compost feedstock
Other SARE-Related Research:	• Compost exhaust gas emissions • Leachate/condensate [e] • Compost production [e] • Pasture vegetation survey/Literature fixation rates • Groundwater and stream water nitrogen concentrations [d]
Data Shared From Other Projects at UNH:	• Atmospheric deposition (Shattuck, Pers. Comm.)

Table 8.1 Data sources for the farm nitrogen budget at the UNH Organic Dairy Research Farm.

The amount of compost feedstock generated then is best estimated by using well-measured inputs and outputs from the pasture system plus purchased grain, baleage and bedding fed to stock while in the barn. The first step is calculating the balance over the pasture. Including all of the inputs and outputs from pastures (excluding return of compost for now), there is a net transfer of 10,340 pounds per year to the stock and the barn. Adding to this the inputs of grains, purchased baleage and bedding, and understanding that the total amount of nitrogen in cows, heifers and calves will not change significantly year to year "Net: (0)", estimated transfer of nitrogen to the composting facility is 16,650 pounds N per year (Figure 8.2). This is consistent with the numbers on total weight of feedstock used in Chapter 9 to estimate total potential heat production and potential application to greenhouse warming.

Similarly, the net change in total nitrogen content in the composting facility will not change significantly year to year, relative to the amount of material being processed (again Net: (0)). In Chapter 5, the measured partitioning of nitrogen accompanying a 30% loss of mass over 21 days of decomposition was 87% retained in the compost product, 10% lost as ammonia gas, and 3% captured in leachate (Figure 5.3). Using these numbers, and assuming that all of the compost and leachate are returned to the pastures, there is an additional 14,990 pounds of nitrogen per year added to the fields. This results in a total excess nitrogen addition to pastures of 7,630 pounds N per year (Figure 8.2). The fate of this added nitrogen is discussed below.

Farm nitrogen performance indicators

The farm N budget results were used to calculate two N performance indicators (Figure 8.3) - N surplus and nitrogen use efficiency (or NUE) - for three different compost management options: returning all compost to pastures, or selling 25% or 50% of produced compost to off-farm buyers (Figure 8.3). N surplus was also calculated per unit area of pasture (110 acres).

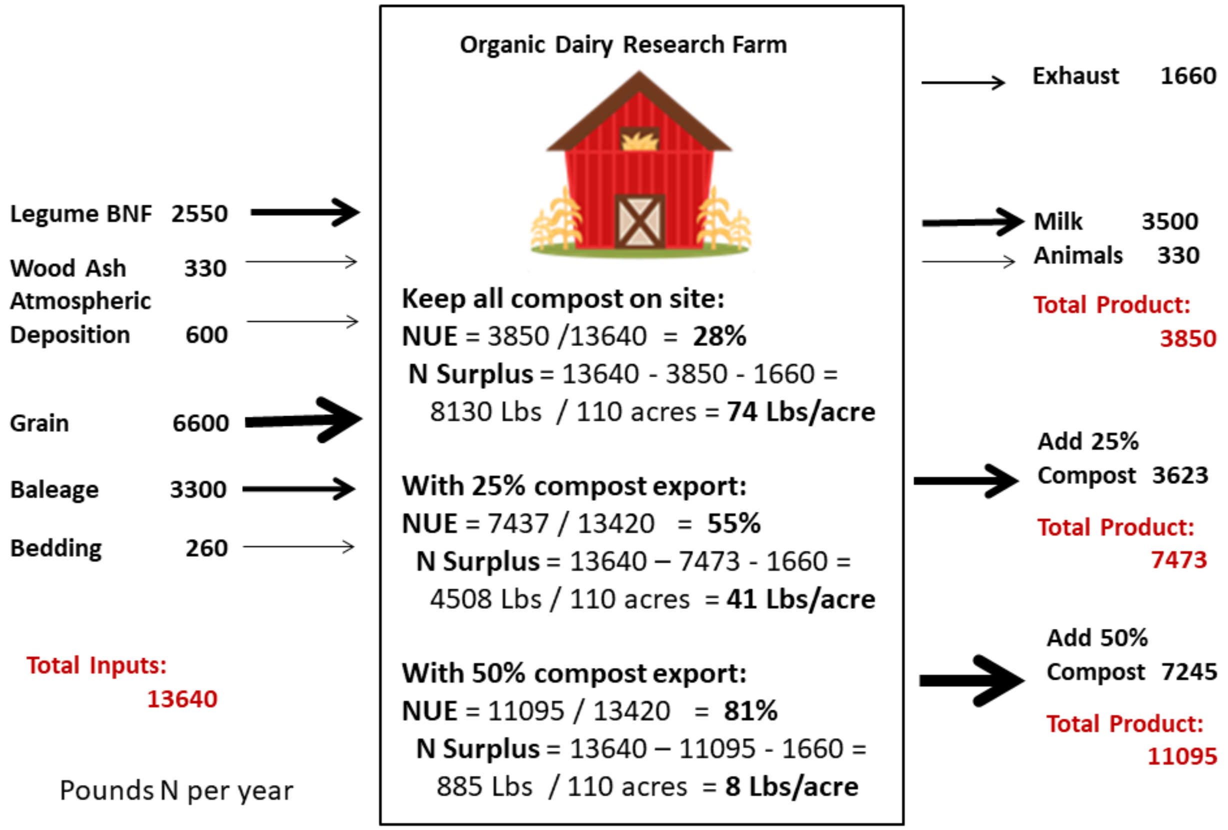


Figure 8.3 Nitrogen performance values for the UNH Organic Dairy Research Farm (pounds nitrogen per year). See text for sources and explanation.

Nitrogen surplus is simply the amount of nitrogen imported on to the farm in grains, baleage, bedding, plus inputs from the atmosphere through deposition and nitrogen fixation by legumes in the pastures, minus exports in products. For the first set of calculations, exports are limited to milk and animals. For the second and third, additional export is calculated to include 25% or 50% of the compost produced on the farm. As shown in Figure 8.3, the surplus retained on site is much higher without the sale of compost (8,130 pounds N), and is reduced through the sale of 25% of compost (4508 pounds N) or 50% (885 pounds N). As this calculated surplus is assumed to accumulate on pastures by addition of non-sale compost to fields, surpluses are also calculated per acre of pasture (Figure 8.3).

Nitrogen use efficiency (NUE) is similarly affected by the sale of compost. Calculated assuming retention of all compost on site, the NUE is 28% meaning that only 28% of nitrogen entering the farm, with grains and baleage the primary purchased inputs, exits in milk and animals. Adding a 50% export of compost increases the total nitrogen in product from 3,830 to 11,095 pounds of nitrogen per year, and increases NUE from 28% to 81%. With the sale of 25% of produced compost, NUE is 55%.

What do these numbers mean for farm management, and how do they compare with other dairies? Answering the second question first, several recent papers in the scientific literature have done these calculations for a large number of farms, mainly in the U.S. Europe, New Zealand and Australia (Figure 8.4, see [53] for sources). Expressed as amount of nitrogen per unit area, the ODRF is among the lowest in terms of nitrogen inputs because it is pasture based, and so much of the nitrogen cycling through the milk production system is recycled through the pastures either by direct deposition of manure, or the return of compost to the fields. Those dairies with very high rates of N inputs and outputs per unit area would be increasingly confined systems with high inputs of grains and crops grown off-site.

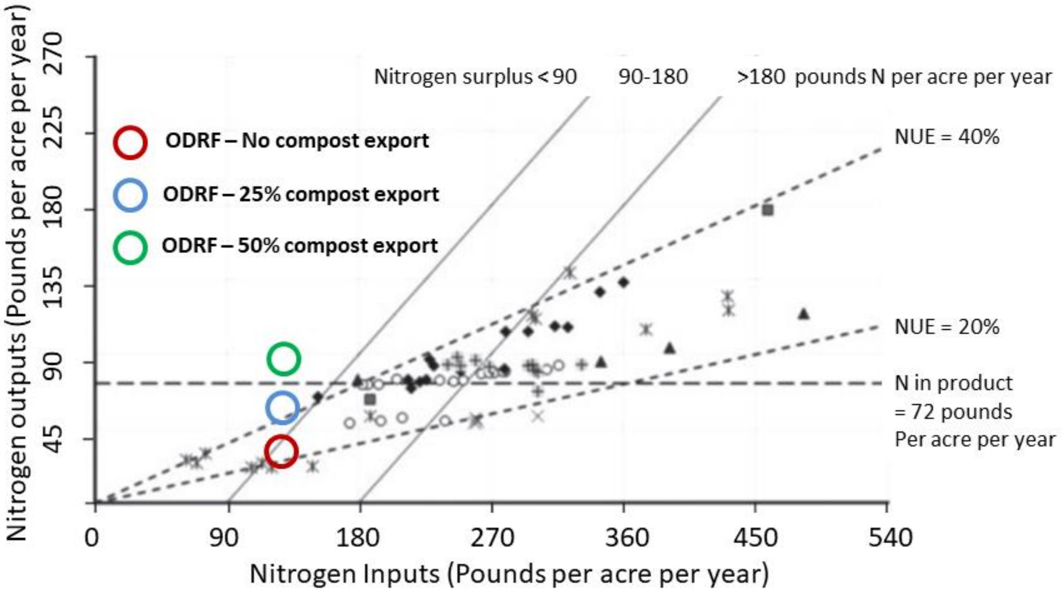


Figure 8.4 Nitrogen performance calculations for the UNH Organic Dairy Research Farm in comparison with data from other dairies [25]. Ranges for both Nitrogen Use Efficiency (NUE) and Nitrogen Surplus are shown. See text for explanations.

Values for NUE fall within a fairly narrow range for all dairies (mostly from 20-40%, Figure 8.4). This is due to the inherent biological limitations of conversion of grains, baleage and pasture fodder to milk, and because milk and animals are the primary products in all cases shown on the graph. At 28% for the milk-only calculation, the ODRF is within this range, but a little below the average of 32%. The very high NUE when compost is included as an additional product results directly from offsetting the high inputs in grains and nitrogen fixation through an additional export of product. Other farms could achieve similar results if their waste management systems were solid manure systems with efficient composting, and a significant fraction of produced compost was sold.

In contrast to NUE, the calculated range for nitrogen surplus, expressed per unit area, increases with the intensity of inputs (Figure 8.4). The ODRF is lower in terms of surplus (66% below the average), again because of the extensive rather than intensive use of land area in pasture-based systems. Including 50% of compost as an additional product, the nitrogen surplus at the ODRF (8 pounds per acre) would be among the lowest in this data set, and total product export would exceed a target value set in the source publication (72 pounds per acre per year). With a 25% export of compost, the N surplus would be 41 pounds per acre).

What do these numbers mean for farm management, in terms of both economic and environmental sustainability? Are there upper or lower limits to NUE and N surplus that would be in keeping with good management practices?

As a first approximation, higher NUE and lower surplus would appear to be both economically and environmentally favorable. Nitrogen inputs in terms of grain purchases or fertilizer amendments to fields (if any) cost money, so making the most effective use of those inputs should increase financial returns (we realize that this is an extremely oversimplified view of the complex topic of cow nutrition and milk production!). Reducing the nitrogen surplus should also reduce the chance for increased nitrate concentrations in surface and ground water.

Two major uncertainties in the budget presented in Figure 8.2 might urge caution in these judgements.

The largest unknown is biological nitrogen fixation (BNF). While this process is very well documented and understood physiologically, the actual rate of fixation has been shown to be highly variable, and dependent on rates of either fertilizer N addition or natural release of nitrogen through the decomposition of soil organic matter (54, 102).

The second important uncertainty is the fate of nitrogen added to pasture soils through BNF, direct manure deposition, or by returning compost to the fields. Figure 8.2 suggests a very large return of N to the fields if compost is not sold. This is the other side of reduced NUE and an increased N surplus. If the numbers in Figure 8.2 are accurate, then a question is: how much of this added N can be stored in the soil and for how long, and how much might be leached to groundwater or lost to the atmosphere through denitrification? These last two processes can have very different environmental outcomes. Nitrogen leached to groundwater can impair water quality. If most of the denitrified N is converted to unreactive nitrogen gas (N_2) and emitted to the atmosphere it will have no impact (See [36 and 53] for a more complete discussion of the fates and impacts of other gaseous forms of nitrogen in general and at the ODRF).

Groundwater well data (Chapter 7) show that past practices have resulted in nitrogen “hot spots” on the farm, but also suggest that these excesses are either diluted effectively, or subjected to denitrification, such that impacts off-farm are minimal. To the extent that this is the case, the extensive application of excess nitrogen in the form of compost over the relatively large area of the farm would not appear to present serious environmental problems.

If actual rates of nitrogen fixation are lower than shown in Figure 8.2, and/or if soil retention of nitrogen added in manures and compost is lower as well, it is conceivable that aggressive sale of compost off-site could result in the “mining” of the nitrogen capital in pasture soils, reducing future nitrogen availability and forage and baleage production. Unfortunately, measuring accurately either soil nitrogen content or rates of release through decomposition are among the most expensive of soil assessments, requiring large numbers of samples due to natural variability. These uncertainties might argue for a conservative approach to selling compost as an additional product from the ODRF.

On the other hand, the revenue to be realized from the sale of compost can be an important offset to the cost of grains. In the first application of an ASP/HRC system at Diamond Hill Farm in Vermont (a heifer operation, not a dairy), sale of compost added significantly to farm revenues (104). As seen both at Diamond Hill, and in the information presented in Chapters 3, 4 and 9, cost reduction in farm operations by capturing heat from the ASP/HRC system could also improve the farm’s bottom line.

Conclusions

As a pasture-based system, the UNH ODRF has a comparable-to-low whole farm nitrogen use efficiency (NUE - 28%) compared to other dairy farms (32% average), but N surplus per unit area is also much lower – about 66% less than the average (Figures 8.3 and 8.4). This means that any N losses are spread over a much larger land area and are less likely to contribute to negative environmental impacts. NUE could be increased and N surplus could be reduced significantly by selling compost off-site as an additional product of the farm, but uncertainties in the N budget calculations, especially for biological nitrogen fixation, and the fate of compost added to fields, suggests caution to avoid mining of soil N. The compost produced could be more valuable as a soil amendment to increase pasture productivity, than as a saleable product

Chapter 9: Putting Compost Energy to Work for Sustainable Agriculture: The University of New Hampshire as a Case Study – John Aber, Dena Hoffman and Matthew Smith

Introduction

The New England Food Renaissance is a term that has been used to describe the rapid changes in consumer preferences and food production systems happening in the region. Farm to table restaurants and farmers' markets have proliferated, and the availability of locally sourced and organic products has increased in mainstream supermarkets as well [19]. Most New England states are highly ranked on a national "Locavore" index [100, 32], and the region hosts the highest density of farmers markets in the country [73].

One manifestation of this change is captured in the New England Food Vision, which has proposed a goal (named 50 by 60) of producing 50% of the region's food requirements within the region by the year 2060 [33]. The 50 by 60 goal promotes sustainable agriculture and fishing as well as healthy food for all of New England. Achieving this goal with existing farm practices would require a tripling in the amount of agricultural acreage.

The New England food renaissance has also led to more interest among college-age students in agriculture education, especially at the Land Grant Universities in the region [64], and an increase in the number of farms, especially new, small, specialty producers [33, 115]. In a region rich in non-profit organizations and state agencies reflecting cultural values and high expectations for landscape preservation and environmental quality, minimizing the environmental footprint of the food production system is a parallel requirement.

Given this cultural and economic context, a focus on sustainable agricultural practices with an emphasis on local production would seem to be an essential part of fulfilling the Land Grant mission for public research institutions in New England.

Short growing seasons are a major challenge for increasing food production in New England, and this has led to increased interest in the use of high tunnels and greenhouses to extend seasons and control growing conditions. While greenhouses tend to be glass-enclosed structures with permanent frames, high tunnels are often simple plastic covers over a temporary or moveable frame. All possible combinations and variations of these kinds of structures can be built [114]. Major private and public investments in these types of structures, which can be especially viable for organic produce production [e.g. 41], are occurring across the region [e.g. 16].

With additional heating, greenhouse production can be maintained year-round, particularly for cool season crops not requiring high light levels. In the long winters in New England, meeting the energy requirement for heat can be expensive, often making a 12-month season cost-prohibitive. Matching ASP/HRC systems with adjacent high tunnels or greenhouses offers the potential to reduce heating costs. It may also be possible to access some of the carbon dioxide produced by the composting process to fertilize plant growth.

Using compost as a source of energy and carbon dioxide for greenhouse operations is not a new idea. In the northeastern U.S., two organizations have done the most to advance and promote this concept, and the information generated by these two is captured in two publications that are now widely available.

Beginning in the 1970s, New Alchemy Institute on Cape Cod, Massachusetts, developed a prototype of a self-contained system for growing food and recycling wastes (the “Ark”). One component of that system was a compost/greenhouse combination. Work in the Ark has provided a basis for continuing efforts to link composting with food production. Much of the information generated by this work is captured in Fulford [35]. That report covers both heat and carbon dioxide generation in a greenhouse with an embedded compost pile, as well as information on biofilters to remove ammonia, and tests of crop production. While our system differs in that the composting facility is adjacent to, rather than embedded within the greenhouse, the concept of using compost to heat a greenhouse is the same.

More recently, Brown [9] provides a full review of different approaches to energy capture from composting, and the application of compost outputs to greenhouse production. Topics include the isobar system used in the UNH composting system [90], as well as smaller-scale Jean Pain systems. Information on greenhouse design and compost feedstocks is also included. This source contains information on the small number of very recent efforts to integrate composting and greenhouse production. This publication is one output of the work at the Highfields Center for Composting.

Interestingly, the concept of compost-powered greenhouses appears rarely in the academic literature. A thorough review of heat capture by Smith et al [94], noted two references, from 1977 and 1995, that report results for compost heated greenhouses. In contrast, several popular websites now touch on the topic of compost and greenhouses, most of which link back to either the New Alchemy or Highfields work. A quick web search returns many links to companies and products that relate to small-scale composting paired with greenhouses, and the presence of at least one informal network of practitioners [19].

Can farmers in the northeast extend their season of production, and reduce both the cost and carbon footprint of heating these structures by combining ASP/HRC composting with greenhouse production? Again, given the trajectory of agriculture in New England, answering this question would seem to be an essential part of the Land Grant mission.

The University of New Hampshire Case Study

The University of New Hampshire is a recognized leader in the development and application of sustainable practices [113]. Over the last decade, it has also invested in and expanded both teaching and research in sustainable agriculture [111]. One important component of that research is directed at increasing the value and productivity of high tunnel greenhouses through crop selection, management techniques, breeding programs, and extension of the growing season [e.g. 110]. Research efforts have focused on cool season greens, fruits and berries, and even crops fairly exotic for the region, like kiwis. Harvested crops, including Brussel sprouts, tomatoes, eggplants, green peppers, okra, radishes, beets, and lettuce are used in the UNH dining halls or at the on-campus restaurant, the UNH Dairy Bar.

UNH has supported a conventional composting program for more than 30 years. Currently, food wastes from the dining halls are combined with barn wastes from the on-campus equine program to generate nearly 1,000 tons of compostable material per year. The conventional method used for composting this material includes the use of windrow piles in which materials are turned roughly once a week for the first month, and then left to cure for the next year, with occasional turning thereafter. Windrow composting operations are still the most common commercial operation in the US. If they are a registered operation that export material off-site, then they also have to comply with the requirements that the pile achieve at least 130^{o}F for at least 15 days with 5 turns of the pile over that period of time [9]. While materials managed in this way generate heat sufficient for producing optimal compost, options for heat capture are limited [95].

UNH and the Town of Durham in which it resides cooperate in providing many basic services, including water supply, waste water management and fire and rescue, among others. In keeping with its own culture and goals for environmental quality, Durham is considering adding composting of organic wastes, an increasing choice around the region, and standard practice throughout much of Europe. In this analysis, we estimate the impact of a joint town/UNH composting operation.

The potential seems to exist to reduce both the operating costs of the UNH composting program, and the cost of heating the set of high tunnel greenhouses if it is possible to link an ASP/HRC system to at least some of the high tunnels on campus. Such a step should also enhance the overall sustainability of operations on campus, and help maintain UNH's standing as a leader in this field.

The goal of the analysis reported here is to test the feasibility of a composting/greenhouse linkage using real information from UNH. The analysis involved four steps.

1) Estimate the quantity of compostable material that could serve as feedstock for an ASP/HRC system located on the UNH campus. This could include on-campus material, as well as barn wastes from the Organic Dairy Research Farm 7 miles from campus, and possibly organic wastes generated by the Town of Durham.

2) Estimate the amount of heat energy that could be derived from this material using a variety of approaches drawn from the literature, and based on results from the UNH ASP/HRC system. This includes values for systems with and without a heat storage water tank.

3) Access data from the UNH Energy Office to estimate the amount of heat energy required by high tunnel and research greenhouses on campus, and match that with results from step 2 to assess the potential value of compost heat in both extending the growing season in on-campus greenhouses and reducing heat energy costs.

4) Generalize these results and provide a framework for analysis by practitioners, by combining the calculations from step 2 with a simple model of energy balances for a greenhouse paired with and ASP/HRC system.

Methods

1. Data on Sources of Compostable Material and Current Management Practices

Data on compostable materials are available from the UNH equine facility, the Organic Dairy Research Farm, and UNH Dining operations, as well as a potential source of organic materials from the Town of Durham (Table 9.1).

Table 9.1 Compostable material available (wet tons). Sources: UNH Dining and Equine Programs, Durham Solid Waste Committee.

Source	per month	# of months	Total	
Food waste	30	9	270	
Equine 2	60	12	720	
On campus total				990
ODRF	68	12	816	
UNH Total				1806
Durham	30	12	360	
Community Total				2166

The equine facility at UNH cares for a number of horses housed in stalls with bedding materials such as hay and wood shavings, and generates a substantial amount of manure/bedding material (Brenda Hess-McAskill, personal communication). Numerous composting trials at the UNH ASP/HRC facility using equine bedding materials generated higher pile temperatures than trials with material from the ODRF barn alone (Matt Smith, personal communication).

UNH dining operates dining halls that, despite programs to reduce this stream, produce large amounts of food waste. An estimate for food wastes created at the three largest dining halls (Holloway, Philbrook and Stillings) is 270 tons per year, with maximum amounts produced during spring and fall semesters, and lesser amounts during January term and summer. Food wastes are sent through an industrial grinder, which reduces particle size and also moisture content. This material is then transported by truck about once per week to Kingman Farm.

Food wastes are combined with manure/bedding from the equine facility and composted using a conventional turned-pile process. Kingman Farm personnel create and maintain windrow piles approximately 10 ft wide, 4.5 ft high, and 200 - 300 ft long using an industrial-scale compost turner. Each windrow is turned every 2 to 3 weeks during the active composting phase, and less frequently during the curing stage. After one to two years the finished compost is spread on UNH fields.

The UNH ASP/HRC system is located at the Organic Dairy Research Farm (ODRF), part of the Burley-Demeritt Farm in Lee, NH. The ODRF houses an average of 40-50 milking cows at any one time, and a total of about 100 animals, including calves, heifers and dry cows. The bedded pack barn at this facility generates about 68 tons of waste per month, or a total of 816 tons per calendar year. Totals are higher during the winter, and lower in the summer when cows spend most of their time on pasture.

One possible additional source of material for composting on campus could be the town of Durham, which is considering the separation of compostable organic materials from the general refuse collection system. According to town sources, as much as 25% of the Town's current waste stream could be compostable, for an estimate of 360 tons per calendar year.

2. Estimating Total Potential Energy Generation from Compost

ASP/HRC systems are a relatively new technology and there are few studies that report heat generation capacity for commercial scale operations. In addition, the few papers available that present data on heat recovery from compost [95] often report rates per hour under ideal conditions, or do not include data on the amount of material composted, or the duration and timing of aeration. This makes it difficult to extrapolate from those studies to an annual potential energy yield from a given amount of compostable material. The most frequently cited number is 1.4 MMBTU (million BTU) of heat energy generated per ton of material [18, 19]. This number is for energy released, not necessarily energy captured and used.

Here we pursue three different methods for estimating not only the amount of heat energy that can be generated, but the fraction of that energy that can be captured and put to use. For each method, we assume an annual throughput at the ASP/HRC facility of 1 new load (one of 4 pairs of bays filled) each month. An average load is ~68 tons wet weight, giving an annual total of 816 tons of material, wet weight. Average holding time for each load would be 1 month. Observations at this facility suggest that composting will reduce total material weight by 20% to 40%. In Chapter 5 (Figure 5.3) we show that a 22 days composting cycle resulted in about a 25% loss of carbon. We assume here that a 1 month cycle will result in a 35% loss of both total carbon and total weight.

One approach to estimating total potential heat generation and capture is to begin with the total energy content of compostable material, and multiply that by the fraction of that material generally decomposed in the composting process. Matt Smith (unpublished) used bomb calorimetry and measured the energy content of material generated at the ODRF as equivalent to 14.4 MMBTU/ton of oven dry material. Assuming a 50% water content in that material yields 7.2 MMBTU/ton of wet material. The lower estimate of 20% weight loss would yield 1.4 MMBTU/ton, equivalent to that most frequently cited value above. At 35% weight loss, the total energy released would be 2.45 MMBTU/ton. At 816 tons total per year, this means an energy release of ~ 2,000 MMBTU per year, or ~ 5.5 MMBTU per day.

A second approach is to work up from the measured rates of energy capture at the UNH ASP/HRC. In Chapter 4 we report maximum energy capture rates ~200,000 BTU per day for one pair of bays. With 4 sets of bays in the facility, maximum energy capture could reach ~800,000 BTU/day at full capacity. This translates to 292 MMBTU per year.

A third approach is essentially a computational check on the second. Based on the model discussed in Chapter 4, which takes basic measurements from the ASP/HRC facility used above and combines them with the same assumptions about pile temperature and aeration time used for the first two methods, energy capture can approach 200,000 BTU/day under ideal conditions (Table 4.1). With 4 sets of bays, a daily total of ~800,000 BTU/day or about 292 MMBTU per year, is possible.

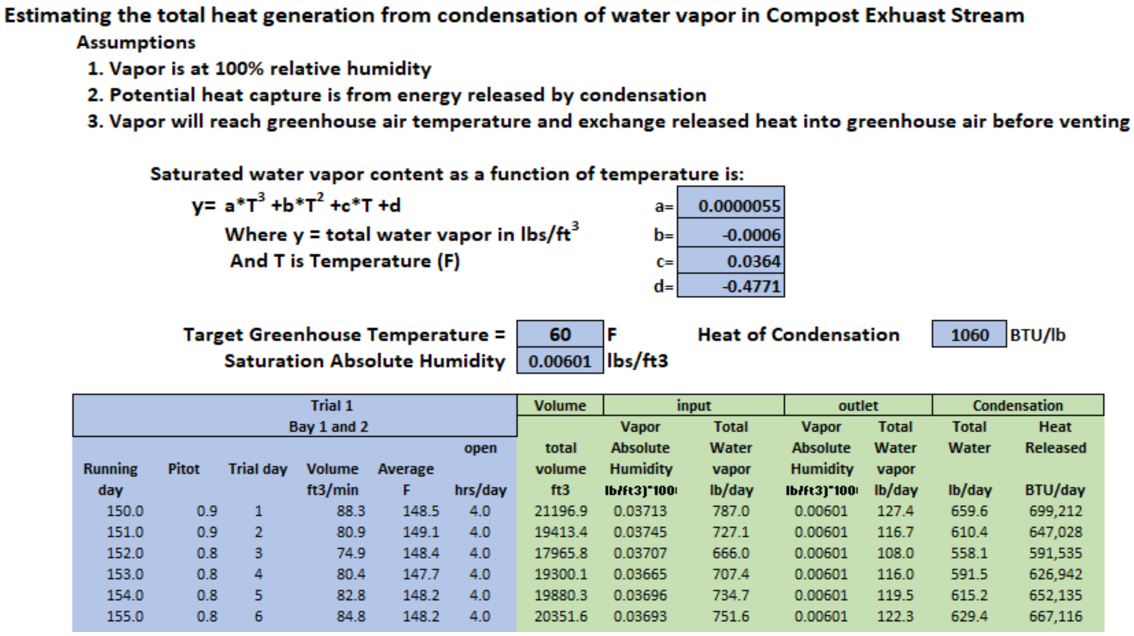
These values represent a relatively small faction of the estimated total energy release of ~5.5 MMBTU/day (see Table 9.2 below). Why would this value be so low? We have noted two possible reasons for this. The first is that a system using a heat storage tank is inefficient as the heat recovery rate decreases as the difference in heat source and sink approaches zero. Even at relatively low tank water temperatures, exhaust gases from the facility are often elevated relative to ambient conditions (Figure 4.1). A second possible reason would be insufficient insulation around the bulk storage tank itself, which loses energy especially during the cold winter months (Table 4.1).

It is possible to eliminate both of these issues through direct piping of compost vapor to the attached structure, and using standard heat exchange pipes or radiators to capture the heat of condensation as the vapor cools to greenhouse temperature (as the vapor can be corrosive, stainless steel materials might be required). How might this work in the UNH case, and how much might this approach increase total energy capture?

The method for estimating potential heat capture by this process is very different. We assume that vapor from the compost facility is piped directly to the greenhouse and then through standard baseboard heat types of piping within the structure, with enough length of pipe in the greenhouse to reduce the temperature of the vapor to that of the target temperature in the structure. As the temperature drops, vapor will condense within the pipes, releasing energy to the structure. The calculations that follow assume that all of that condensation occurs within the heating pipes within the greenhouse.

This calculation requires that, in addition to vapor temperature, the total volume of vapor passing through the condensation system be known. Data on rate of air movement through the UNH ASP/HRC system (cubic feet per minute) was recorded continuously as part of the data acquisition system. Knowing the volume of vapor moving through the pipes per unit time as well as the temperature, and assuming 100% relative humidity (saturation) in the vapor stream, the total weight of water in the vapor stream can be calculated using a standard relationship between temperature and total amount vapor content at saturation [17, 29]. As the temperature drops to the target temperature in the greenhouse, the vapor remains at saturation, and moisture condenses in the pipes. The total amount of condensation in the pipes can be calculated as the difference between saturated moisture content at the vapor and greenhouse temperatures. Then the amount of energy released can be calculated using a standard value for the energy released through condensation of water (1060 BTU/pound, [17, 29]). Figure 9.1 is a screenshot of the spreadsheet used to calculate the amount of energy released by condensation according to these calculations.

It may be that vapor temperatures in the heating pipes cannot be reduced to the temperature in the greenhouse, as heat transfer becomes very slow when the differential between pipes and ambient air in the structure approaches zero. In this case, the following calculations would relate to the lowest temperature achievable in the pipes.



Estimating the total heat generation from condensation of water vapor in Compost Exhuast Stream

Assumptions

1. **Vapor is at 100% relative humidity**
2. **Potential heat capture is from energy released by condensation**
3. **Vapor will reach greenhouse air temperature and exchange released heat into greenhouse air before venting**

Saturated water vapor content as a function of temperature is:

y= a*T^3 +b*T^2 +c*T +d

Where y = total water vapor in lbs/ft^3

And T is Temperature (F)

a= 0.0000055
b= -0.0006
c= 0.0364
d= -0.4771

Target Greenhouse Temperature = 60 F
Saturation Absolute Humidity 0.00601 lbs/ft3
Heat of Condensation 1060 BTU/lb

Trial 1 Bay 1 and 2						Volume	input		outlet		Condensation	
Running day	Pitot	Trial day	Volume ft3/min	Average F	open hrs/day	total volume ft3	Vapor Absolute Humidity lb/ft3)*100	Total Water vapor lb/day	Vapor Absolute Humidity lb/ft3)*100	Total Water vapor lb/day	Total Water lb/day	Heat Released BTU/day
150.0	0.9	1	88.3	148.5	4.0	21196.9	0.03713	787.0	0.00601	127.4	659.6	699,212
151.0	0.9	2	80.9	149.1	4.0	19413.4	0.03745	727.1	0.00601	116.7	610.4	647,028
152.0	0.8	3	74.9	148.4	4.0	17965.8	0.03707	666.0	0.00601	108.0	558.1	591,535
153.0	0.8	4	80.4	147.7	4.0	19300.1	0.03665	707.4	0.00601	116.0	591.5	626,942
154.0	0.8	5	82.8	148.2	4.0	19880.3	0.03696	734.7	0.00601	119.5	615.2	652,135
155.0	0.8	6	84.8	148.2	4.0	20351.6	0.03693	751.6	0.00601	122.3	629.4	667,116

Figure 9.1. Daily estimates of heat release by condensation of vapor drawn from compost piles by the ASP/HRC system at UNH (see text for explanation).

Data from two different compost trials at the UNH ASPHC system were used to generate estimates of heat energy that could be captured using these assumptions (Figure 9.2). The two were chosen as they varied widely in terms of initial temperature, change in temperature over time, change in amount of air drawn through the piles and amount of energy released. It is important to note that each of these two data sets are for just one of 4 sets of bays in the facility. At full operation, potential heat capture could be up to 4 times those presented here. Note also that the second pile generates more captured heat than the first (Figure 9.2) even with a lower pile temperature, due to higher total volume of airflow. This again emphasizes the concept that the kind of system visualized here might be managed differently to maximize heat gain rather than rate of throughput of material.

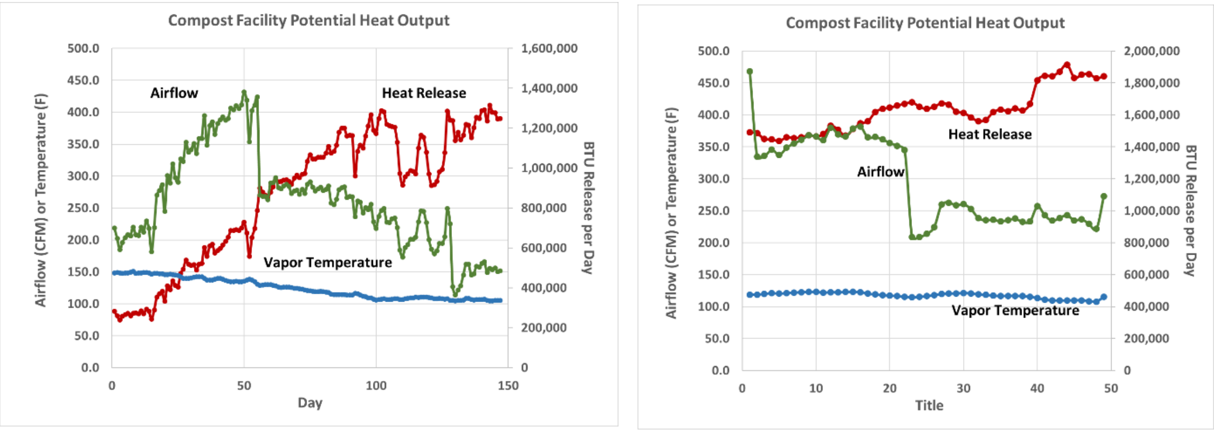


Figure 9.2 Data from two different composting trials at the UNH ASPHC facility. Green line – air flow (CFM), Blue line - pile and vapor temperature (F), Red line – heat released using assumptions described in the text (BTU/day).

Over the first 35 days (for comparison with results from the first three methods), the first trial averaged ~1 MMBTU heat energy capture per day. The second trial averaged closer to 1.2 MMBTU per day. These values are again for one of four sets of bays in the facility, yielding estimates of 4.0 to 4.8 MMBTU per day at full capacity. Using the lower of these two values, potential efficiency of heat capture appears to be much higher for the direct use of heated vapor (Table 9.2).

	MMBTU/day	Efficiency
Estimated Energy Release	5.5	
Energy Capture by Method		
With Heat Exchanger	0.8	15%
Direct Use	4.0	73%

Table 9.2 Comparison of apparent efficiency of heat capture as measured at the UNH ASP/HRC system (with heat exchanger) and estimated for a direct use system involving condensation of vapor in baseboard/type heating pipes in a greenhouse or other structure.

3. Estimating Energy Requirements for Greenhouse Heating on an Annual Basis

Data are available from the UNH Energy Office on the quantity of heat required for year-round operation of three different high tunnel/greenhouse systems, one at Kingman Farm and two adjacent to the Fairchild Dairy (Table 9.3). Data are recorded as "therms" of propane, with a therm being equivalent to 100,000 BTUs. Kingman #5 is actually a set of 3 steel frame houses with double-wall polycarbonate cover, used as part of the aquaponics/lettuce production system described above. The Fairchild high tunnels are covered in sheet plastic. The average annual total for energy demand is about 3125 therms (312.5 MMBTU) per greenhouse per year.

Table 9.3. Annual Energy Requirement for high tunnel greenhouses (Propane Therms : 1 Therm = ~100,000 BTUs)

Fiscal Year	Fairchild #1	Kingman #5	Fairchild #3
2015	4,378.30		
2016	2,754.70		
2017	3,112.90		
2018	3,442.00	9,657.00	
2019	3,654.30	6,412.40	4,084.40

Data from Tables 9.1 – 9.3 can be used to determine the potential for heating UNH greenhouses with available compostable materials and an ASP/HRC composting system. Amounts of material in Table 9.1 are combined with energy release and efficiencies of capture with a heat exchanger or by direct use (Table 9.2) to determine the total amount of energy captured. These values are divided by the annual heat demand for a greenhouse at UNH (Table 9.3) to produce an index of the number of units that could be heated. The estimates for direct use assume a target greenhouse temperature of 60F (Table 9.4).

Table 9.4 Potential energy generation in relationship to annual heat energy demand for high tunnel greenhouses on the UNH campus. Material values from Table 7.1. Efficiencies from Table 7.2.

Source	Material	Total Energy Release	Total Energy Captured		Greenhouse Heat Demand	Greenhouses Heated	
			Exchanger	Direct		Exchanger	Direct
	Tons	MMBTU/yr	MMBTU per year		MMBTU/year		
On-Campus	990	2,425	364	1770	312.5	1.2	5.7
All UNH	1806	4,425	664	3230		2.1	10.3
Plus Durham	2166	5,307	796	3874		2.5	12.4

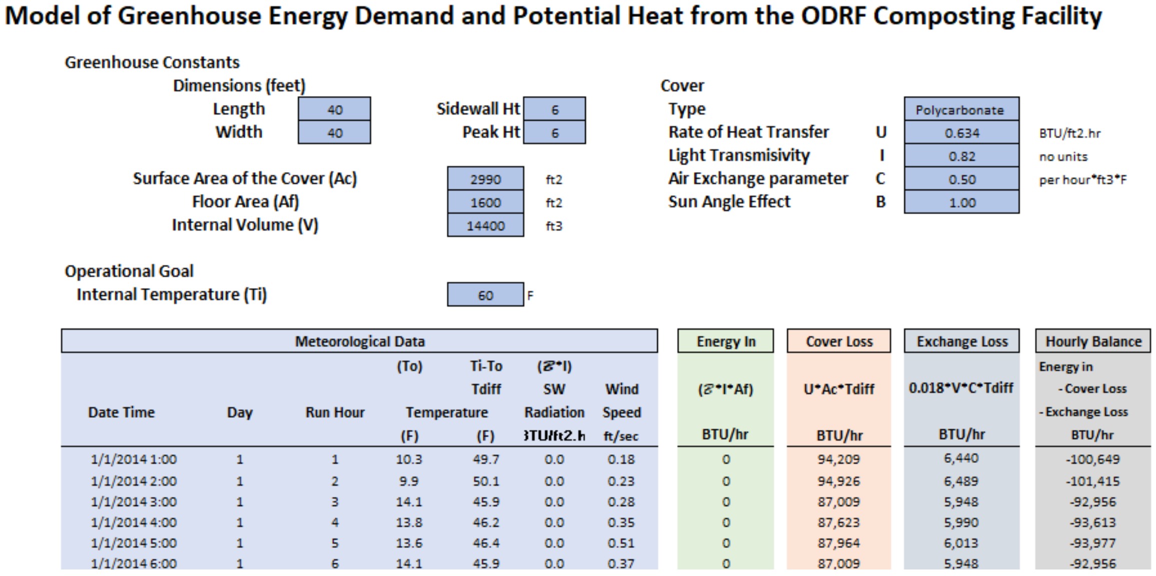
4. A Generalized Model of an integrated Compost/Greenhouse System

Data at the annual time step as presented above provide a rough assessment of the potential for compost energy to heat greenhouses at UNH. However, for this combination of technologies to be successful, the timing of energy supply and energy demand must coincide. To allow this more detailed analysis, a model of energy demand based on high-resolution weather data was developed and linked to measured rates of energy generation and capture described above.

The model was constructed in Excel to increase accessibility to practitioners and general audiences. The model includes 1) an hourly time step calculation of solar energy gain and heat losses through the greenhouse surfaces and by air turnover, 2) a summation of hourly data to daily totals, and 3) the addition of heat energy from a module estimating heat capture from compost using the analysis presented here. Calculations are summed at a daily timestep. The size of both the simulated greenhouse and the composting facility can be modified in the model to test different potential combinations of facilities. The spreadsheet model is available from the first author of this chapter.

Characterization of the greenhouse as well as target internal temperature and example hourly calculations are summarized in Figure 9.3. Length, width, and sidewall and peak height values are used to calculate the surface area of the cover and the internal volume of the structure. The type of cover is defined along with the energy exchange characteristics of that cover. The target internal temperature is specified. It should be noted that this temperature is actually the final temperature in the heating pipes before the vapor exits the system. Again, the actual temperature in the greenhouse may be lower if the exhaust vapor cannot be reduced to the internal temperature, as discussed above.

For this example, hourly meteorological data were acquired from a station located at Kingman Farm, ~3 miles from the UNH campus [109]. Weather data are combined with greenhouse dimensions and cover characteristics to estimate solar energy gain and heat loss through the cover and by air exchange, yielding an energy balance for the structure (Figure 9.3).



Model of Greenhouse Energy Demand and Potential Heat from the ODRF Composting Facility

Greenhouse Constants

Dimensions (feet)

Length	40	Sidewall Ht	6
Width	40	Peak Ht	6

Surface Area of the Cover (Ac)	2990	ft2
Floor Area (Af)	1600	ft2
Internal Volume (V)	14400	ft3

Cover

Type		Polycarbonate	
Rate of Heat Transfer	U	0.634	BTU/ft2.hr
Light Transmisivity	I	0.82	no units
Air Exchange parameter	C	0.50	per hour*ft3*F
Sun Angle Effect	B	1.00	

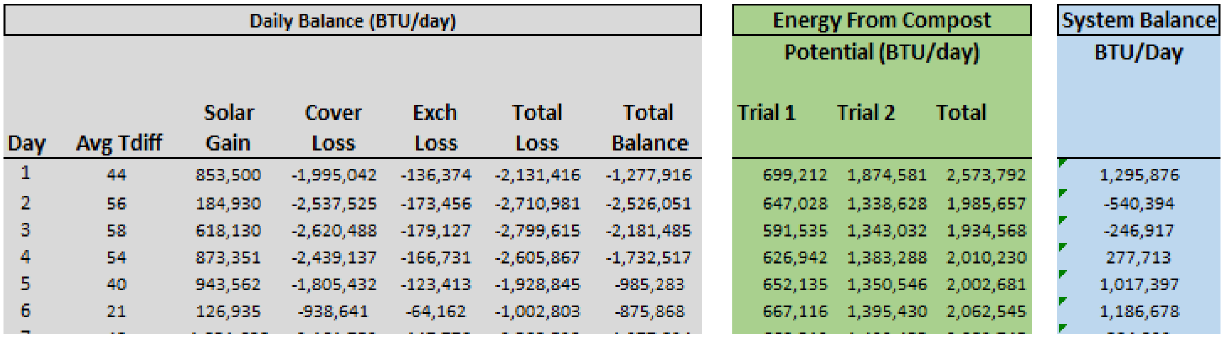
Operational Goal

Internal Temperature (Ti) 60 F

Meteorological Data							Energy In	Cover Loss	Exchange Loss	Hourly Balance
Date Time	Day	Run Hour	(To) Temperature (F)	Ti-To Tdiff (F)	(Ƨ*I) SW Radiation BTU/ft2.h	Wind Speed ft/sec	(Ƨ*I*Af) BTU/hr	U*Ac*Tdiff BTU/hr	0.018*V*C*Tdiff BTU/hr	Energy in - Cover Loss - Exchange Loss BTU/hr
1/1/2014 1:00	1	1	10.3	49.7	0.0	0.18	0	94,209	6,440	-100,649
1/1/2014 2:00	1	2	9.9	50.1	0.0	0.23	0	94,926	6,489	-101,415
1/1/2014 3:00	1	3	14.1	45.9	0.0	0.28	0	87,009	5,948	-92,956
1/1/2014 4:00	1	4	13.8	46.2	0.0	0.35	0	87,623	5,990	-93,613
1/1/2014 5:00	1	5	13.6	46.4	0.0	0.51	0	87,964	6,013	-93,977
1/1/2014 6:00	1	6	14.1	45.9	0.0	0.37	0	87,009	5,948	-92,956

Figure 9.3. Sample inputs and outputs from a simple greenhouse energy balance model. See text for explanation.

Hourly balances for each day were summed over the 24-hour period to calculate total energy gain and loss. These values were paired with estimated energy capture from two sets of measured data drawn from 2 different trials at the UNH ASPHC facility (Figures 9.1 and 9.2), and a total daily estimated energy net gain or loss calculated for each day (Figure 9.4).

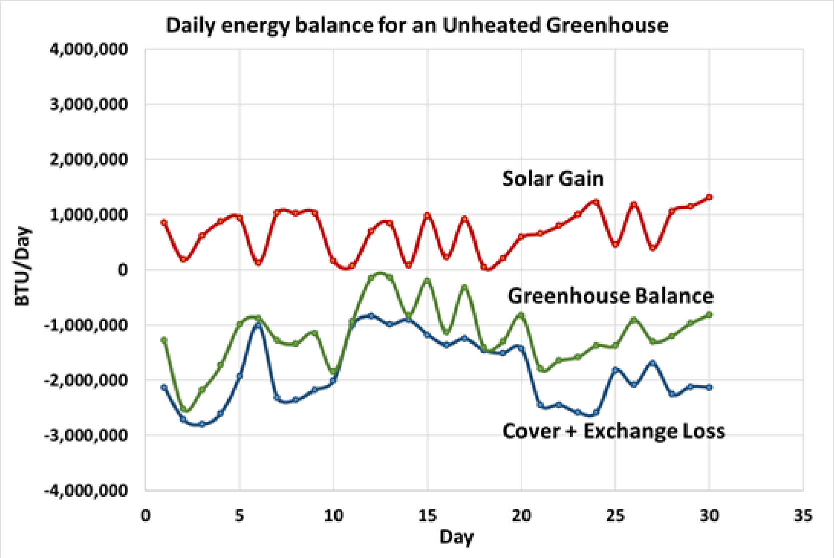


Daily Balance (BTU/day)							Energy From Compost Potential (BTU/day)			System Balance BTU/Day
Day	Avg Tdiff	Solar Gain	Cover Loss	Exch Loss	Total Loss	Total Balance	Trial 1	Trial 2	Total	
1	44	853,500	-1,995,042	-136,374	-2,131,416	-1,277,916	699,212	1,874,581	2,573,792	1,295,876
2	56	184,930	-2,537,525	-173,456	-2,710,981	-2,526,051	647,028	1,338,628	1,985,657	-540,394
3	58	618,130	-2,620,488	-179,127	-2,799,615	-2,181,485	591,535	1,343,032	1,934,568	-246,917
4	54	873,351	-2,439,137	-166,731	-2,605,867	-1,732,517	626,942	1,383,288	2,010,230	277,713
5	40	943,562	-1,805,432	-123,413	-1,928,845	-985,283	652,135	1,350,546	2,002,681	1,017,397
6	21	126,935	-938,641	-64,162	-1,002,803	-875,868	667,116	1,395,430	2,062,545	1,186,678

Figure 9.4 Daily total energy balances estimated for the first 6 days in January 2014 including estimated energy availability from an ASPHC facility of the size at UNH (see text for explanation).

We used data from a colder-than-average January (2014) to compare estimated greenhouse requirements with potential heat capture from 2 pairs of bays UNH ASP/HRC system with direct use (Figure 9.5). The top graph shows the net energy balance for an unheated greenhouse specified as in Figure 9.3. Solar gain was insufficient to heat the greenhouse on every day of the month.

The bottom graph adds heat input from the two pairs of bays described in Figure 9.2. With only two of the four pairs of bays, the greenhouse energy balance is positive on all but one extremely cold day. A small amount of supplemental heat would be required to maintain temperatures of 60F and above. Lowering that target greenhouse temperature to 50F would create a positive balance for all days.



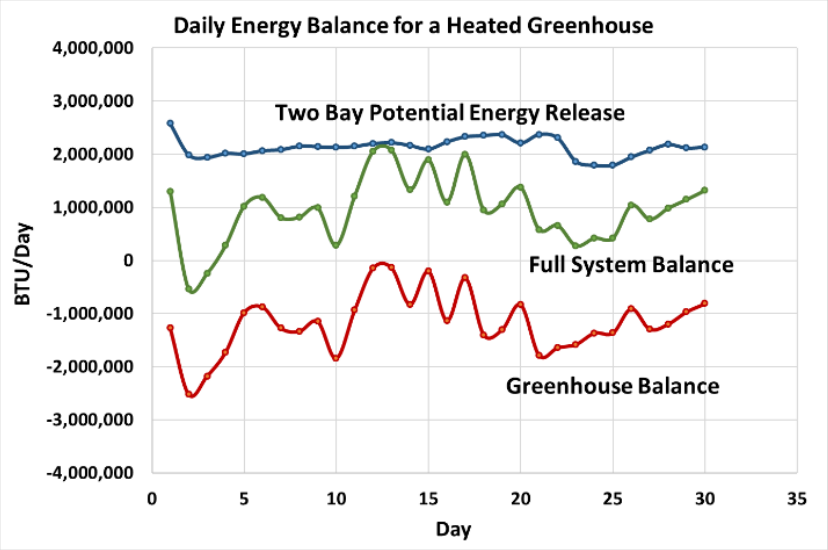


Figure 9.5. Energy balance for unheated greenhouse and one heated with vapor from an ASP/HRC system.

Top: Daily heat energy balance for an unheated greenhouse as described in Figure 7.1 for the month of January 2014.

Bottom: the same balance with estimated heat gain potential from two sets of bays using data from two trials of the UNH ASPHC system (from Figure 7.4).

E. Conclusions

In this chapter we assess the potential for heating high tunnel greenhouses on the UNH campus using heat energy generated by an ASP/HRC system in a total of four ways.

Results suggest large differences in heating capacity based on the method used to capture the heat generated by the facility, with the efficiency of the direct use option apparently up to 5 times that of the heat exchanger/storage approach. Using a heat exchanger and water heat storage tank, 1-2 high tunnels could be heated using campus-only or campus plus ODRF and Durham sources, respectively. With the direct use approach, an estimated 5-10 high tunnels could be heated. It should be stressed that the direct use estimates needs to be tested in a real application.

A model of greenhouse energy balances is presented that offers the potential for a more detailed analysis using an hourly-to-daily time step. This simple spreadsheet model could be of value to practitioners who need to know not only annual balances, but the management steps that would be needed to maintain greenhouse conditions within acceptable bounds under extreme conditions caused by daily weather fluctuations.

Results presented here suggest that it would be valuable to undertake a physical trial of the direct use method of linking an ASP/HRC system with one or more existing high tunnels on the UNH campus.

Epilogue - Composting and High Tunnels at UNH: A Modest Proposal – John Aber

The agroecosystem research summarized in this set of chapters was never intended as a purely academic exercise. From the beginning, in keeping with the goals of the USDA Sustainable Agriculture Research Education (SARE) program and the Land Grant Mission of UNH, we hoped to provide information and new approaches that would increase the sustainability of organic dairies in New England. While a wide variety of topics has been examined, including alternative energy sources, innovative management of farm woodlots, dairy farmer preferences and practices for bedding, water and nitrogen usage and cycles (all summarized on the project website [1]), two ideas appear to have potentially valuable applications in the farm operations at UNH, and perhaps to farms across the region.

The first is the use of the wood shaving machine to produce bedding. Results from that work suggest that there is a business opportunity for producing bedding from low quality softwoods if that enterprise is embedded in a concentrated dairy farming region. For farmers wanting to produce bedding for on-farm purposes, the breakeven volume of bedding was found to be dairy operations with greater than 170 milkers [96]. Our survey of dairy farms across New England revealed that most farms had woodlots, and the average size of those woodlots was sufficient to provide bedding for those farms. The value of low quality softwoods as bedding far exceeds its value as pulp. The quantitative financial analysis in Smith et al [96] provides a basis for planning a bedding production enterprise, which could be a regional cooperative, a profit-making venture, or a large farm operation, either dairy or equine, with sufficient bedding demand.

The second system, and one that may have real potential for UNH, is the Aerated Static Pile/Heat Recovery Composting (ASP/HRC) system. Chapter 9 tallies the available organic waste resources on and near campus, and pairs the estimated heat energy yield with measured energy requirements for high tunnel greenhouses on campus. The comparison is so positive and favorable, that a proposal to test the idea at the campus agricultural facilities seems warranted.

A major hinderance to advancing this possibility is the known initial cost of the current ASP/HRC system at the Organic Dairy Research Farm (ODRF). That facility was designed with research-quality infrastructure and to the University's 100-year lifetime standard. At $550,000, the cost is prohibitive for implementation across other agricultural locations on campuses with similar building requirements.

However, our earliest research on this approach (Chapter 1) demonstrated that low-cost alternatives are also capable of generating high temperatures in compost vapors. Can a low-cost alternative to the research-grade facility at the ODRF be designed and paired with high tunnel greenhouses on campus? Results in Chapters 4 and 9 suggest that the answer is yes. What might such a system look like, what would it cost, and how much energy might be generated to heat those structures? In addition, how much money might be saved by removing the need to tend and turn compost as handled in the existing conventional, windrow-based system in use at UNH? Is there reputational value in applying advanced composting methods to the handling of campus wastes, as has been done at the University of Maine [108]? Here we can only begin to suggest some answers to these questions using information from the agricultural facilities in place at UNH.

Opportunities for Linking ASP/HRC Composting to High Tunnels at UNH

Four potential opportunities can be identified for linking ASP/HRC composting with existing or envisioned high tunnels on farms operated by the New Hampshire Agricultural Experiment Station (NHAES) and UNH: 1) Add a simplified ASP/HRC system to an existing high tunnel with a heat storage water tank and reversible heat pumps, 2) Include a simplified ASP/HRC system in plans for construction of two new high tunnels adjacent to the Fairchild Dairy, 3) Add a simplified ASP/HRC system to three relatively new greenhouses at Kingman Farm, the location of the current composting program, and 4) Construct a high tunnel over or adjacent to the biofilter area already in place at the ASP/HRC system at the Organic Dairy Research Farm (ODRF). Each of these concepts provides opportunities for faculty and student research.

1) Add a simplified ASP/HRC system to an existing high tunnel with a heat storage water tank and reversible heat pumps,

A high tunnel located at the Woodman Farm and used by the Organic Gardening Club was the location for a research project by a now-departed faculty member who partnered with a local sustainable energy company to test the potential for using reversible heat pumps to buffer internal temperatures during shoulder seasons. The installation included a large water storage tank adjacent to the high tunnel and two reversible heat pumps located inside (Figure 66).

Figure E.1 Left: Image of a high tunnel at Woodman Farm with insulated water heat storage tank used to capture heat removed from the structure and then as a source for the heat pumps within the structure. Right: Two reversible air-to-water heat pumps inside the high tunnel pictured at left. See text for additional explanation.

The purpose of the tank and reversible air-to-water heat pumps was to extract heat from hot air in the high tunnel during periods of high solar input and high temperatures in the structure, and store that heat in warmed water in the insulated tank. At night or during cloudy or cold periods, the warmed water in the tank could be used as the heat source to be multiplied by the reversible heat pumps, producing warmed air for the high tunnel.

The efficiency of heat pumps in heating mode is related to the temperature of the heat source to be multiplied (although there are operational upper limits to this temperature source). While this application fell short of what was envisioned, the concept of using a much warmer water source would seem to have potential.

Behind the high tunnel and water storage tank is a large, flat, sandy area that is ideally constructed for composting. The concept presented here is to use this space for a simplified ASP/HRC system that is vented into the insulated box containing the water tank in order to heat the water in that tank (Figure E.2). With this warmer water source, the efficiency of the heat pumps, to be operated then only in air-heating mode, should be increased.

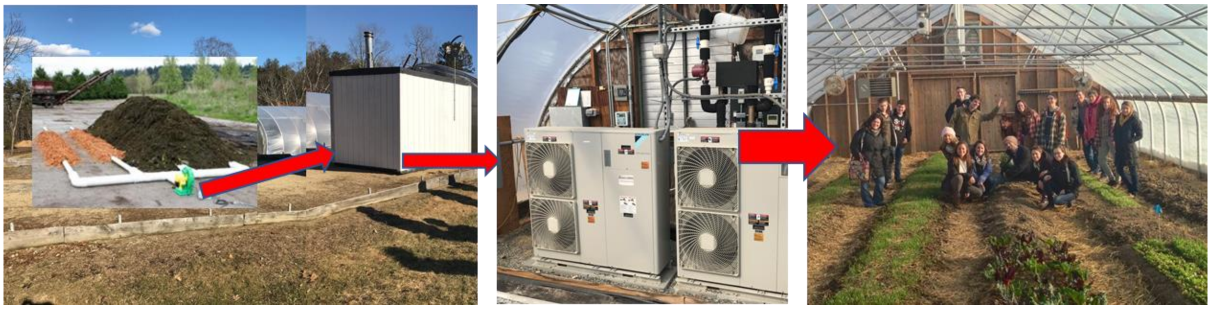


Figure E.2 A simplified ASP/HRC system like the one pictured (Left) would be placed on the sandy pad area behind this high tunnel. Vapor would be piped through the structure housing the insulated water tank to increase water temperature in the tank. The existing heat pumps in the structure would draw on this warm water source to operate at high efficiency in producing warm air for the structure.

Cost for implementation of this concept should be relatively low. The ASP system pictured is decidedly low-tech. The heat pumps and high tunnel are in place. Some engineering would be involved in connecting the vapor flow from the compost into the insulated shed, and, as with all application, providing for outflow of condensate produced during heat transfer. The on-campus location and tie to the Organic Garden Club should assure high student interest and participation.

2) Include a simplified ASP/HRC system in plans for construction of two new high tunnels adjacent to the Fairchild Dairy

UNH has approved funds for construction of two new high tunnels adjacent to the Fairchild Dairy. During construction, a small space would be reserved for baseboard-like heating pipes within the structure (Figure E.3). A simplified ASP system would be located adjacent to the structures and heated vapor from the composting system would be pumped through these pipes as needed to warm the structure. Again, providing for outflow of condensate would be required.

Adding the heat transfer pipes and preparing a site like that near the high tunnel in option 1 to support the simplified ASP system should not represent a substantial increase in the cost of the structures themselves.

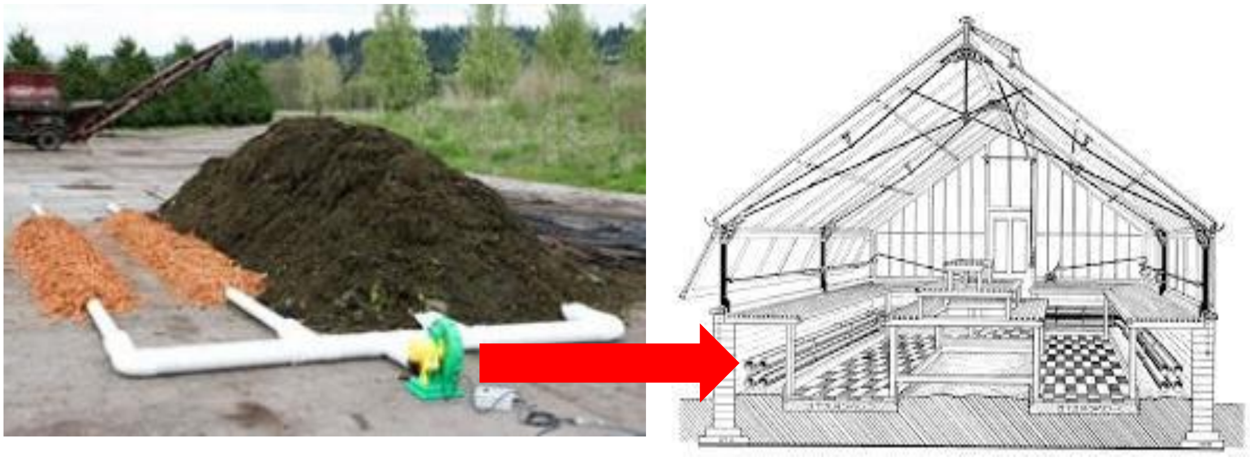


Figure E.3. Conceptual diagram of a high tunnel/greenhouse system heated by direct piping of vapor from an ASP system into heat transfer pipes within the structure.

3) Add a simplified ASP/HRC system to three relatively new greenhouses at Kingman Farm

The concept here is the same as for 2 above, but would include the addition of a connection from the ASP system to the greenhouses and the addition of heating pipes within the structures. One potential advantage of this concept is that the houses are located near the current composting operation at Kingman Farm. In addition, the houses have been used for an innovative project involving raising of tilapia through aquaculture techniques, with wastes from the fish tanks being processed in part by use in a hydroponic system for growing lettuce (Figure E.4 [66]).

Figure E.4. Lettuce growing in a hydroponic system used in part to process wastes from an aquaculture project [66].

4) Construct a high tunnel adjacent to the biofilter area already in place adjacent to the ASP/HRC system at the Organic Dairy Research Farm (ODRF).

This may be the simplest option in that all of the infrastructure for composting and energy extraction is in place, as we all an operational biofilter (see Chapter 6 and Figure E.5). All that would be required for this application is the construction of a new high tunnel adjacent to the biofilter. An optimal configuration might route the compost vapor through baseboard-like heating pipes in the added greenhouse first, followed by passage through the biofilter.

Figure E.5. The biofilter in place at the Organic Dairy Research Farm (see Chapter 6).

Challenges Become Research Opportunities

This short presentation is not intended to minimize the logistical and operational challenges and opportunities that each realization poses. Among these are:

- Designing and testing low cost alternatives for achieving ASP/HRC system results
- Designing the heat transfer system to deliver energy captured in the ASP/HRC system to the attached greenhouse/high tunnel
- Engineering a control system for this integrated food production system that optimizes aerations timing for both energy generation and greenhouse heating
- For option 1, restarting the existing heat pumps and configuring the connection between the composting system and the water storage tank
- For all options, exploring the potential to tap into the exhaust vapor stream to “bleed” carbon dioxide into the structure to fertilize plant growth

A number of comparisons could be made between and among these 4 options, but any more detailed analyses at this time and in this document would seem to be premature. The best next step would be to convene a group of interested faculty, staff and students to explore the possibilities and generate proposals for one or more of these options.

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