



2014 Final Report

Project Number : ONE13-188

Type : On Farm Research/Partnership Project

Region : Northeast

SARE Grant : \$14,876.00

Coordinators:

Abraham Noe-Hays

Rich Earth Institute

44 Fuller Drive

Brattleboro, VT 05301

802-387-5357

E-mail: abe@richearthinstitute.org

Kim Nace

Administrative Director

Rich Earth Institute

44 Fuller Drive

Brattleboro, VT 05301

802-579-1857

E-mail: kim@richearthinstitute.org

Summary

The Rich Earth Institute (Rich Earth Institute) is pioneering the use of sanitized human urine as an innovative and sustainable fertilizer. Wide-scale reuse of urine as fertilizer would provide a stably-priced, locally produced, and sustainable source of fertilizer for farms, while directly alleviating the growing problem of nutrient pollution of surface waters by septic systems and wastewater treatment facilities.

At the conclusion of Rich Earth Institute's second season of research, we have produced immediately applicable experimental results, increased farmer demand for urine-based fertilizers, and achieved substantial organizational growth. The SARE-funded research yielded practical insight into optimum application methods for human urine as fertilizer and has clarified questions and experimental parameters for future research. Advances were made in the infrastructure for collecting and processing urine, notably through the automation of urine pasteurizing equipment and the creation of urine collecting portable toilets for use at public events. At 3,000 gallons, urine donation increased by a factor of 5 over 2012, with 170 donors participating.

The 2013 field trials demonstrated that dilution of urine prior to application was not a necessity. Existing literature for gardeners suggest dilution at ratios up to 1:10, which has been identified as a practical barrier to widespread adoption of urine as a farm fertilizer. This experiment showed that second cut hay yields were comparable between subplots

fertilized with undiluted urine, urine diluted 1:1 and 1:3 (urine to water ratios), or with synthetic fertilizer. There was some indication that 1:1 dilution might improve yield somewhat, but further research is needed.

Efficient handling and low-cost storage were identified as the two most important factors in making sanitized urine a cost-effective source of fertility for farms.

Introduction

As fertilizer prices climb and the cost of conventional sanitation rises, converting urine into fertilizer will be an increasingly profitable solution for both those with fertilizer needs—farmers—and those with wastewater disposal problems—homeowners and municipalities. To reap the benefits of this novel strategy, American farmers need well documented guidance based on practical experience in successful demonstration projects. The Rich Earth Institute's research establishes workable solutions to the regulatory and logistical challenges in urine reuse, helping farmers to implement it successfully on their own farms.

Agronomists in Europe and Asia have completed field trials and pilot projects showing that urine-derived fertilizers can produce yields on par with conventional fertilizers. Rich Earth Institute's project built upon this expanding international body of research on the use of urine as fertilizer, as well as the results of our 2012 proof-of-concept experiments, conducted at Fairwinds Farm in Brattleboro, VT.

Hay was selected for these initial trials because of its significant fertilizer demand and the fact that it is not consumed by humans, avoiding any potential consumer aversion to using urine to grow food. Hay farmers have been very interested in urine fertilizer, and the Institute has a waiting list of farms that want to participate in the program as the supply increases. Field tests in Germany and Sweden have proven that urine-based fertilizer can be used effectively for growing wheat and rye, but Rich Earth Institute is the first organization to work with perennial hay, or to implement such a project in the United States.

Excellent work has already been done to address the human health issues, resulting in research-based guidelines issued by the Stockholm Environment Institute for treatment of urine prior to application. Storage at specific temperatures for predetermined lengths of time allows the ammonia naturally present in urine to destroy pathogenic contaminants. Eawag Aquatic Research in Switzerland has conducted studies and published white papers concerning the stabilization, concentration, and distribution of urine and urine-derived fertilizers.

Our project built on this existing knowledge, and is unique for several reasons: it was conducted in the U.S., we fertilized perennial hay, and urine fertilization will continue as

an ongoing part of farm operations on the participating farm, rather than being a one-time demonstration. It provides farmers in the region with an accessible and ongoing case study documenting the practical details of using urine-based fertilizer on a working farm.

In 2012, we processed 600 gallons of urine and used it as fertilizer on hay in a controlled field trial. In 2013 we collected, transported, treated and applied 3000 gallons. The project: 1) increased the volume of urine handled to reduce per-unit costs of collection, treatment, and application; 2) used knowledge gained in the first season to make the treatment and application steps faster and more labor efficient; 3) transitioned from a proof-of-concept system to a practical system capable of fertilizing multiple acres.

The Rich Earth Institute has also received EPA funding to determine the fate of pharmaceuticals in urine when used as an agricultural fertilizer, an issue of great importance for the future of source separated urine collection and nutrient recapture on farms. Field trials for the study will span two seasons, in collaboration with researchers from the University of Michigan and the University at Buffalo as well as industry engineers from Brown and Caldwell and Ostara, leaders in advancing wastewater treatment options. This is an example of how Rich Earth Institute's other collaborative research enhances the practical value of the studies funded by USDA SARE grants.

Objectives/Performance Targets

The Rich Earth Institute accomplished all of the main goals set out in this project. The primary objective was to investigate the effect of various dilution ratios of urine to water on hay yield. Experimental field plots received sufficient urine to supply 50 pounds of nitrogen/acre, mixed with varying amounts of dilution water. In addition there was a control plot, a synthetic fertilizer plot, and two plots receiving urine at rates 50% and 100% higher than the standard rate. An additional seven strips of hay (5.5 m by 100 m) were fertilized with urine. Yields were quantified and forage samples were analyzed.

The purpose of the experiment was to find the minimum dilution rate necessary to maximize crop yield and minimize labor associated with application. The finding of this season's research is that undiluted urine can be applied as fertilizer on established hayfields without causing damage to the crop. This is in contrast with recommendations commonly found in urine fertilization guides written for gardeners: namely that urine should be diluted with water before application, using urine:water ratios ranging from 1:3 to 1:10, to prevent damage to plant tissues by concentrated ammonia. Results were unclear on whether 1:1 dilution had a positive effect, and, a follow-up study is planned for 2014.

Goals relating to improving the urine processing equipment were met as well, with the automated pasteurizer performing as intended and reducing labor requirements dramatically.

Other goals included farmer outreach and increased public awareness of the concept of

urine nutrient reclamation. Although we were not able to attend the winter NOFA conference, as mentioned in our proposal, we attended the summer NOFA conference and numerous other relevant conferences. We exceeded our expectations for outreach, education, and media coverage, and had the notable achievement of supporting a spin-off urine-to-fertilizer pilot program in Durham, New Hampshire, described further listed under Impact/Outcomes.

Materials and Methods

Upon notification of the SARE grant, the Rich Earth team set a urine collection target (3,000 gallons), submitted a state permit application, and began preparatory work at the farm.

On 4/30/13, our partners at Best Septic Service transported 600 gallons of urine from our collection depot to Fairwinds Farm, an event attended by local municipal leaders, EPA personnel from Boston, and several town engineers from New Hampshire who were interested in initiating a urine recycling project in their town. Over the next three months, we continued to collect urine at the urine depot and transfer it to the farm.

Most of the urine was collected by volunteer participants using urine-only collection devices. But several participants used urine-diverting toilets—commodes with divided bowls where urine falls into the front basin and then drains through dedicated piping to a urine storage tank, while feces fall into the back half of the bowl and are thereby kept separate. Because it is possible for fecal particles to occasionally end up in the urine collection basin, the decision was made to sanitize the otherwise non-pathogenic urine to eliminate any intestinal pathogens that might be present.

The urine was sanitized and stored onsite until use. Two methods of sanitization were used in order to assess their practicality at the farm scale, but a given batch of urine received only one of the two treatments:

One treatment consisted of storing urine at a temperature of 20 degrees C or above for a period of at least 30 days. This method is documented in “Urine diversion – hygienic risks and microbial guidelines for reuse” by Caroline Schönning (2003) and depends on high pH and the presence of free ammonia to inactivate pathogens. Four 275 gallon palletized tanks of urine were placed in an unheated greenhouse constructed for the experiment on 6/22/13. Temperature monitoring probes were submerged in the urine tanks and positioned inside and outside the greenhouse to measure the ambient air temperature. This urine was used on the long strips.

The other treatment involved heating batches of urine in a solar pasteurizer to 70 degrees C for 30 minutes. This method is accepted by the EPA for the treatment of sewage sludge, a material much higher in pathogens than urine, which led the research team and the Vermont Department of Environmental Conservation to consider it adequate for the sanitization of urine. This urine was used on the grid plot.

Both methods provide suitable treatment, but are different strategies that provide options for others who adopt urine recycling on their farms. The greenhouse storage required more time for treatment but was technically very simple, while the more complex solar pasteurizer was able to process urine much more quickly.

The Rich Earth Institute had built the solar pasteurizer in 2012, but all controls were manual and it required considerable labor to operate, particularly for draining and refilling the pasteurizer vessel. As part of the 2013 grant project, we added automated monitoring of the temperatures of the urine and working fluid, and automated control of the circulator pump. Electric pumps controlled by float switches drained finished urine from the pasteurization tank and refilled it automatically. The only demand on the operator was to check an indicator light confirming that each batch was pasteurized, and then initiate the transfer process. Operator time and electricity usage by the circulator pump and transfer pumps were monitored as part of the cost/benefit analysis.

Field trials took place on two different hayfields, (a small grid on one field and large strips on the other) and followed two different protocols. Soil tests from both fields showed adequate phosphorus and potassium, so application rate was calculated to deliver recommended nitrogen levels. Fertilization was done after first cutting, and yield impact was measured at the second cutting.

Small grid:

The first trial (small grid) was a replicated trial on a 25 m x 30 m plot divided into 30 subplots measuring 5 m x 5 m. No soil amendments or fertilizer were added in the spring, and hay was allowed to grow until 7/12/13. At this point, the 4 m x 4 m zone in the center of each subplot was cut using an electric sickle-bar mower, air dried, and placed into paper leaf-collection bags. The collected hay was weighed to compare baseline yield differences between subplots. The remaining 0.5 m border left around the perimeter of each subplot was mowed with a flail mower, resulting in complete mowing of the entire study area.

Based on relative yield masses, subplots were assigned to one of four groups: high, moderately high, moderately low, and low. Each group contained seven subplots for a total of 28, with two of the original 30 subplots being excluded because they accidentally received a small amount of fertilizer during the spring application. Each group was treated as a randomized block, with individual replicates of each treatment being randomly assigned to one of the seven subplots within each block. The purpose of this approach was to compensate for the natural variation in grass stand quality and yield within the study area, by ensuring that each block would contain subplots of similar quality, reducing the effect of local stand quality variation on the final results.

Urine for this plot was sanitized using the Rich Earth Institute's solar-heated batch

pasteurizer, which was improved in 2014 by the addition of an automatically controlled pumping system. Urine in the 55-gallon pasteurizer tank was heated over a period of one to two days by a submerged, stainless steel heat exchanger carrying hot water from the solar panels. Urine and working fluid temperatures were monitored and recorded using Dallas Semiconductor DS18B20 digital sensors connected to an Arduino Mega microcontroller with datalogging attachment, which also controlled the urine transfer and solar circulation pumps. A sample of the treated urine was sent to TestAmerica Laboratories, Inc. in Westfield, MA, where a fecal coliform test was performed with negative results (detection limit 50 MPN/100 ml).

Prior to fertilizer application, the University of Vermont Agricultural & Environmental Testing Laboratory performed a fertilizer analysis of the treated urine, which found 4.41 g/L total N, 0.31 g/L total P, and 1.62 g/L total K. A urine application rate of 1362 gallons/acre was calculated to deliver 50 pounds of nitrogen per acre, as recommended by Nutrient Recommendations for Field Crops in Vermont, published by University of Vermont Extension. This application rate also delivered 3.4 lbs total P and 18.2 lbs total K per acre, which, expressed in N-P-K units are 8 lbs P₂O₅ and 22 lbs K₂O per acre. Soil samples taken prior to fertilizer application contained 16% moisture by weight, determined by air drying at room temperature.

Pasteurized urine and chemical fertilizer were applied to this study area on 7/21/13 using a 1 m long, handheld irrigation boom fed by an electric pump. Urine was applied evenly over each 5 m x 5 m subplot, in discrete streams coming from 5/16" inch holes at 6" spacing on the irrigation boom. The boom was held within 0.3 m of the soil surface to minimize splashing and odor volatilization. Urine and chemical fertilizer applications were performed with the aid of guide strings placed across the subplots at 1 m intervals to ensure even application.

There were five urine treatments, one chemical fertilizer treatment, and a no-fertilizer control. The urine treatments consisted of: 1) pure urine, 2) urine diluted 1:1 with water, 3) urine diluted 1:3 with water, 4) pure urine followed by 1/4" of irrigation water, and 5) pure urine preceded by 1/4" of irrigation water. Each urine-fertilized plot received 32 L of urine, along with 0 to 160 L of dilution or irrigation water. The chemical fertilizer treatment contained measured quantities of urea, triple superphosphate, and potassium chloride that contained the same total NPK content as the 32 L of urine. It was applied using handheld containers with perforated bottoms, which allowed precise control over the area of application. The no-fertilizer control received no amendment of any kind. Because treatments varied so widely in total volume of water applied, a water-only treatment was not performed.

Hay on the small grid plot was cut using a BCS walking tractor with 30" front-mounted sickle-bar mower. On 9/16 and 9/17 the outer 0.5 m buffer zone of each subplot was mown, removed, and discarded. The remaining 4 m x 4 m interior of each subplot was mown on 9/24/13 and spread evenly on the ground to air dry. Hay was tedded by hand

using rakes in the afternoon of 9/25/13, then tilled again on 9/26/13 and then bagged in large paper leaf bags.

Hay from each subplot was weighed on 9/27/13 and a sample was taken for analysis by Cumberland Valley Analytical Laboratory. Hay from each subplot bag was cored four times to full depth using a 3/4" drill-powered probe. On 12/6/13, seven composite samples representing each treatment were prepared according to the lab's subsampling instructions, combining material from all four subplots within each treatment. Each composite sample was therefore drawn from 16 cores.

Large strips:

The second study area (large strips) was a 38.5 m x 100 m plot, divided into seven 5.5 m x 100 m subplots. The original application called for only five treatments, but two more were added to test yield response at higher urine application rates. All fertilized subplots received nitrogen at a rate of 50 pounds/acre, with the exception of two extra subplots described below. Treatments consisted of 1) urine diluted 1:3 with water, 2) urine diluted 1:1 with water, 3) undiluted urine, 4) undiluted urine applied at 150% the standard rate (75# N/acre), 5) undiluted urine applied at 200% the standard rate (100# N/acre), 6) chemical fertilizer, and 7) no-fertilizer control.

Urine for this trial was sanitized by storing it in a mini-greenhouse that held it at temperatures of 20 C or more for 30 days. Urine temperatures and air temperatures inside and outside of the greenhouse were monitored and recorded using Dallas Semiconductor DS18B20 digital sensors connected to an Arduino Uno microcontroller with datalogging attachment. A solar-powered fan (+/- 60 CFM) provided air circulation during the daytime to equalize air temperatures within the greenhouse.

As in the first study area, analysis results from the University of Vermont Agricultural & Environmental Testing Laboratory (showing 6.08 gN/L, 0.23 gP/L, and 1.44 gK/L) were used to calculate an application rate of 985 gallons/acre in order to deliver 50 pounds N/acre. This rate also supplied each acre with 3.1 lbs total P and 11.3 lbs total K, which, expressed in N-P-K units are 7 lbs P₂O₅ and 14 lbs K₂O. This translated to 506 L of urine for each 5.5 m x 100 m strip. Soil samples taken prior to fertilizer application contained 11% moisture by weight, determined by air drying at room temperature.

Urine was applied to the study area on 8/3/13, using a purpose-built application machine consisting of a 200-gallon trailer-mounted tank plumbed to a transverse boom with gravity-fed trailing hoses mounted every 6". A remotely actuated valve on the back of the tank allowed the driver to easily initiate or shut off flow when the applicator reached the ends of the study plot. Chemical fertilizer (a blend of urea, triple superphosphate, and potassium chloride) was applied at a rate supplying equivalent NPK as the urine, using the same hand-held applicators as were used on the other study area, in conjunction with guide strings.

Hay was cut on all strips on 9/18/13 with a sickle bar mower and left to dry until 9/20/13. Tedding was done with a horizontal axis tedder to avoid mixing hay between adjacent rows. On 9/20/13, hay was manually raked away from the edges of each strip, raked into rows, and baled. Bales were weighed and cored on 9/26/13 using the same 3/4" corer. All bales were cored, and all cores from the same treatment were combined into a single sample, resulting in seven samples, each consisting of at least 20 cores. Samples were sent to Cumberland Valley Analytical Laboratory for forage quality analysis.

Results and Discussion/Milestones

Urine characteristics:

Analysis by the University of Vermont of the largest batch of urine used in the field trials (applied on the long strip) showed each liter of urine containing 6.1 g ammonium-N, 0.34 g total phosphorus, and 1.4 g total potassium. In NPK fertilizer analysis units, this translates to 6.1 g N, 0.85 g P₂O₅, and 1.7 g K₂O. Converting from g/L to lbs/1000 gallons gives us 51 lbs N, 7.1 lbs P₂O₅, and 15 lbs K₂O. This is equivalent to 110 lbs of urea, 16 lbs KCl (muriate of potash), and 24 lbs triple superphosphate in each 1000 gallons of urine.

The urine used in the two trials had considerably different nutrient content, with the pasteurized urine used on the grid plot containing 27% less N, 16% less P, and 13% more K than the stored urine used on the long strips. One might imagine that pasteurization had driven off ammonia-N, but testing in the previous season showed that ammonia-N was conserved during pasteurization in a closed vessel. Furthermore, P and K are non-volatile, so it may be that the variation comes from differences in the diet and water consumption of the individuals contributing the urine used for the two trials.

Sanitization:

Both sanitization methods were successful, with no major technical obstacles.

The first attempt at using the long-term storage method (30 days at 20 C or higher) took place inside an unheated greenhouse that was also used for vegetable starts and then for raising turkeys. This ended up not being a suitable location, because although the greenhouse never got cold, it never got very hot either, as ventilation was needed in the daytime to keep the seedlings and turkeys from overheating. Afternoon shade from an opaque end wall also limited the sunlight that reached the tank.

The second location was a low, purpose-built mini-greenhouse just big enough (10' x 10') to contain the four tanks being housed. This greenhouse had no ventilation, in order to maximize heat absorption by the stored urine during sunlit hours. There was a solar-powered circulation fan (approx 65 CFM) that kept the air from stratifying. Image 1 shows temperatures of the urine, and the air inside and outside of the greenhouse during the 30-

day treatment period.

Pasteurization was much more streamlined than in 2012, due to the automated pump controls. Two surplus domestic solar hot water panels heated water that circulated through a site-built stainless steel heat exchanger made from 1/2" coil tubing submerged in the pasteurizer vessel. The hot water was circulated by an electric pump, which was controlled by a circuit that powered the pump only when the temperature of the panels was higher than the pasteurizer. The pump therefore switched off at night or during cloudy periods to conserve the heat within the pasteurizer. Once pasteurizing temperatures of 70 C had been reached and maintained for 30 minutes, the automated controller logged the fact that pasteurization had occurred and then ran the circulator pump overnight to cool the treated urine. In the morning, the farmer verified that there was space in the treated urine holding tank, and then pushed a confirmation button to initiate the automatic draining and refill of the pasteurizer, followed by a new pasteurization cycle.

The automated controls effectively eliminated the labor requirement for pasteurization, which the previous year had required about 30 minutes of labor for every draining and refilling of the pasteurizer.

The main limitation of this system was its treatment capacity. At 50 gallons/day maximum capacity, treatment is limited to 1500 gallons/month, given optimum conditions. For a discussion of how to increase capacity while lowering per-unit treatment cost, please see the economics section of this report.

Urine from both treatment methods tested negative for fecal coliform by a third-party lab.

Urine application:

Odors were modest during urine application at both sites—far less pronounced than is typical from the spreading of animal manure—possibly because the urine was applied in gentle streams at ground level and soaked into the soil immediately.

Four days after fertilization of the small grid plot, slight damage to leaf tissue was visible on subplots fertilized with pure urine or urine diluted 1:1 with water, including subplots receiving irrigation before or after fertilization. Damage occurred only where the urine streams had directly contacted the grass and was characterized by darkening, drying, and loss of turgor. Because the streams were narrow and spaced at 6", the total fraction of leaf tissue affected was very small. No damage was visible on subplots fertilized with urine diluted 1:3, chemical fertilizer, or the no-fertilizer control.

Yield:

Urine-fertilized and chemically-fertilized treatments produced yields markedly higher than

the control treatment in both trials. No significant difference was shown between yields from urine-fertilized and chemically-fertilized treatments.

Yields in the small grid trial are shown in Image 5. Yield of the urine-fertilized treatment was 37% +/- 8% higher than the no-fertilizer control, while the chemically fertilized treatment yielded 31% more than the control. The difference in average yield between the highest- and lowest-yielding urine treatments was 8%. Yield differences were significant between urine fertilizer and the control, and between chemical fertilizer and the control. No statistically significant differences were found between yields of different urine treatments when compared with each other or with the chemical fertilizer. For details of the statistical analysis, including the efficacy of using first cut yields as a proxy for stand fertility, see Appendix A, prepared in collaboration with Michael Keim, Ph.D.

Yields from fertilized strips in the long strip trial were all considerably higher than the unfertilized strip, with increases of 99% to 158% above the control. Of the strips receiving 50# N/acre, the 1:1 diluted urine treatment showing the highest yield at 133% above control, with only the 100# N/acre urine application yielding higher, as shown in Image 3. Because there were no replicates, it is not possible to say with confidence whether the differences between different urine treatments were real or artifacts caused by local variation. However, there is one trend that warrants further investigation:

Three of the treatments involved undiluted urine, applied at different rates: 50, 75, and 100# N/acre. The control strip can be considered to be part of the same series, receiving 0# N/acre. Taken together, the yield response clearly shows yield increasing with urine application rate in a smooth manner, as shown in Image 4. Because there are only four data points, meaningful statistical tests were not possible—but given the smoothness and positive slope of the response curve for undiluted urine, it seems likely that the random variation between subplots is moderate compared to actual variation as a response to treatment.

Interestingly, when the yield from the strip receiving 1:1 diluted urine at 50# N/acre is plotted on the same graph, its yield falls between that of the 75# and 100# N/acre undiluted urine treatments. If this difference is real, then applying a given volume of 1:1 diluted urine was nearly as effective at increasing yield as applying the same volume of pure urine.

To determine if this is actually the case, further research with replicates of each treatment is needed. An experiment with this objective will be part of the Rich Earth Institute's 2014 research program.

Forage quality:

Forage quality analysis showed similar results for all the large strips, with Relative Feed Value (RFV) ranging from 105 to 108, indicating that while yield was strongly affected by

fertilization, forage quality remained relatively constant. Values for the small grid trial were more variable, with results ranging from 100 to 110, but judging by the large variation in yield within each treatment in the small grid trial, it seems likely this the RFV variation may also be due to local variation between the small subplots.

Impact of Results/Outcomes

The main objective of this study was to determine whether dilution of urine was necessary or advantageous for the fertilization of second-cut hay. The conventional wisdom in using urine as fertilizer is that it should be diluted from 1:3 up to 1:10 with water before application, but this is very labor-intensive when spreading already large quantities of urine at the farm scale.

We established two useful findings: 1) that application of undiluted urine had a strongly positive effect on yield of second-cut hay, increasing with application rate, and 2) that diluting urine 1:3 with water did not have a discernible positive effect on yield. We were unable to establish with confidence whether 1:1 dilution affected yield.

We therefore recommend applying urine either undiluted or mixed 1:1 with water when fertilizing second-cut hay, and recommend against dilution rates above 1:1, due to the high labor requirement and lack of benefit. Because of unclear results concerning 1:1 dilution, and will conduct a follow-up experiment in 2014 with large strips in replicate.

Hay yields increased on our partner farm, producing a substantial second cut yield where typically there is not enough hay to be worth harvesting. The farmers are continuing to use urine in 2014 and have requested all extra urine that is available after planned trials on other farms.

As a result of this research and outreach, two new farmers will receive urine fertilizer in 2014 and participate in field trials. A third farm is slated for EPA studies and additional farms are eager to receive urine for their hay fields as the urine collection program increases in scale. Currently, the demand for urine is higher than the supply.

Fostering replication of urine recycling programs in other communities is another major objective of the Rich Earth Institute. In early 2014, Durham, New Hampshire became the first community to implement a urine recycling program inspired by the Rich Earth Institute's work. Through a collaborative effort involving the Town of Durham, the University of New Hampshire, the engineering firm Wright-Pierce, urine is being collected in a trailer-mounted mobile restroom for recycling into fertilizer, for use on two farms for growing hay. The engineers who initiated the project did so after attending one of the Rich Earth Institute's outreach events in 2013, and they have stated that the Institute's example was critical for gaining approval of their project from skeptical officials, and for avoiding technical pitfalls. See

<http://www.unh.edu/news/releases/2014/04/bp10diversion.cfm> and

<http://nhpr.org/post/unh-students-urine-diversion-program-cleans-water-fertilizes-farms>

for further details.

Economic Analysis

Because recycling urine provides value both to farmers (as fertilizer) and to municipalities (by helping them comply with nitrogen and phosphorus limits in wastewater permits), a full economic analysis would include both sectors. This study focuses on on-farm cost and benefit, but it is important to bear in mind that additional farm income related to urine recycling may be available.

For instance, septage haulers typically pay treatment plant tipping fees anywhere from \$60-150 per 1000 gallons to empty their tanks—fees they would not pay the treatment plant if they were delivering urine to farms. Municipalities facing major costs to install new nitrogen and phosphorus removal technologies could reduce or avoid those costs by incentivizing the source-separation and recycling of urine, keeping nitrogen and phosphorus out of the sewer in the first place. Offering value to septage haulers and municipalities by providing an alternative disposal method for urine and receiving income in exchange could approach or even exceed the value of the fertilizer in the urine.

Analysis of the urine used in the long strip trial showed that each 1000 gallons of urine contained the equivalent of 110 lbs of urea, 16 lbs triple superphosphate, and 24 lbs KCl (muriate of potash). At current prices at the time of writing, this equates to roughly \$50/1000 gallons of urine in NPK value. Urine also contains many other macro- and micro-nutrients, but monetary values for these were not calculated. (Fertilizer equivalents calculated from UVM Extension lab testing results, showing each liter of urine containing 6.1 g ammonium-N, 0.34 g total phosphorus, and 1.4 g total potassium. In terms of the units of NPK fertilizer analysis, this translates to 6.1 g N, 0.85 g P₂O₅, and 1.7 g K₂O. Converting to lbs/1000 gallons gives us 51 lbs N, 7.1 lbs P₂O₅, and 15 lbs K₂O.)

Given the small scale of this project, and the fact that it was carried out as a controlled field trial using methods and equipment under active development, the labor and equipment expenditures do not accurately reflect what would be incurred in a larger-scale operation. It is therefore not possible to use this trial to directly calculate the cost/benefit of using urine as a fertilizer at scale. However, the project did illustrate which steps were the most labor- and capital- intensive, and which would need to be optimized for a cost-effective urine fertilization program.

Sanitization by pasteurization required negligible labor, consisting only of checking the output tank each morning and pressing a button to cycle the next batch if there was tank space available. But the solar-powered pasteurizer's suitability was limited by its maximum output rate of a single 50-gallon batch per day, resulting in an unreasonably high capital cost per gallon treated. Electric usage of this pasteurizer went primarily to running the 85 W circulator pump, which was oversized for the application. When cloudy weather drew the heating process out to more than one day, electric usage reached 2.5 kWh, which at \$0.15/kWh is \$8.65/1000 gallons.

The Institute's next pasteurizer will use a continuous flow process, rather than batches, processing urine more quickly and at higher efficiency. It will be equipped with a highly-efficient heat exchanger (+/- 90%), and is projected to have a maximum output rate of 1400 gallons/day. Using electric resistance heating with an energy cost of \$0.15/kWh, the total operational cost per gallon treated will be about 0.5 cents/gallon (\$5 per 1000 gallons). The construction costs of the new pasteurizer are estimated at \$3,000, and it will be portable, allowing it to be shared by multiple farms.

For room-temperature storage under ideal conditions (when a sheltered space is available with an average temperature of 20 C or above) the only labor requirement is pumping the urine into the storage tank(s) and then back out after treatment.

In actual practice during the course of this project, room-temperature storage was more labor-intensive than necessary due to two reasons. Firstly, the low speed of the Institute's transfer pump (20 GPM) required 50 minutes minimum for each transfer of 1000 gallons into and out of the storage tanks. To resolve this problem, the Institute acquired a 180 GPM trash pump to reduce transfer times by nearly 90% in 2014. Secondly, tanks left outdoors in Vermont's climate will not generally reach 20 C for 30 days. For the experiment, a temporary cold frame made of lumber and sheet polyethylene was built to increase the storage temperature, but it was time- and material-intensive to build and dismantle. In warmer climates or in settings where existing greenhouse space or a warm storage area is available for the treatment period, room-temperature storage would be more practical from a labor perspective.

Storage tanks represented a large equipment cost for this project. The tanks used were 275-gallon palletized polyethylene tanks, aka totes or IBCs, and they cost \$100 each. At \$0.36/gallon (\$360 per 1000 gallons) of storage capacity, they would need to be filled and emptied eight times before the value of the urine passing through them exceeded the purchase price of the tanks. Lower cost bulk storage systems, such as are used for containing liquid animal manure, would be more cost-effective. Farms already having liquid manure storage facilities could potentially store urine at no additional cost.

Other possibilities for reducing storage costs include using sanitized urine as a feedstock in on-farm composting operations, reducing its volume through reverse osmosis, or adding it to anaerobic digesters. The Rich Earth Institute will begin small-scale urine co-composting trials in 2014.

The time required to apply the urine to the field was dictated mainly by the 20 GPM capacity of the transfer pump, which took 10 minutes to fill the 200-gallon applicator tank. This is reduced by almost 90% by using a 180 GPM pump. Using an applicator with a larger tank, such as a retrofitted liquid manure spreader, would reduce the frequency of stops for refilling.

Based on the practical considerations encountered in this project, it seems that the two most significant costs to farmers using urine as fertilizer at any scale will be the infrastructure for urine storage and the labor for handling and applying the urine. Keeping these costs to a minimum is the key to making urine-based fertilizer economical.

Publications/Outreach

The Rich Earth Institute has an energetic public outreach program, and project visibility has increased dramatically over the past year. In 2013 we presented at the following conferences:

New England Water Environment Association (NEWEA), Boston MA, January

Slow Living Summit, Brattleboro, VT, June

NOFA Summer Conference, Amherst MA, August

VT Biosolids Forum, Waterbury, VT, November

World Toilet Day, United Nations, November

VT Grazing and Livestock conference, January (2014)

We had a booth and/or urine collecting portable toilet at the following events:

Vermont Organics Recycling Summit, Randolph, VT, March

Strolling of the Heifers, Brattleboro, VT, June

Vermont SolarFest, Tinmouth, VT, July

International Biochar Conference, Amherst, MA.

In February of 2013 we presented to the Brattleboro Agricultural Advisory Committee. One farmer commented, "This is the most interesting topic we have discussed in my 30 years on this committee." He is now a collaborating farmer in the project, participating in the expanded hay field trials under the 2014 SARE grant.

Additionally, we presented to our representatives from Windham County in Montpelier. Our delegates expressed support for the future of this work.

To solicit the support and endorsement of local leaders, we have held open houses and targeted, round table discussions at the home of the Rich Earth Institute. Stakeholders saw the demonstration urine diverting toilet, were presented with the scientific principles of urine nutrient reclamation, and had an opportunity to raise questions about the project. In this manner, we have reached out and received endorsements by the Brattleboro Department of Public Works, the Windham Solid Waste Management District, the Windham Regional Commission, and the Brattleboro Waste Water Treatment Plant. The latter provided winter storage space for 1,000 gallons of urine.

Our partner farmer, Jay Bailey attended the VT Grazing and Livestock conference with us and joined our presentation. We were prepared with a small survey to farmers to gauge the interest level for future urine use at their farms. Our workshop was not well attended,

due to competing workshops of high interest to the group. Therefore, we did not glean significant survey results to report, but organizers offered us access to the regional list of grazing and livestock farmers so that we can conduct such a survey in the coming year.

The Institute hosted a film crew from Vermont Public Television, including extensive interviews and a tour of the farm. The resulting video segment provided a thorough and accurate summary of the 2013 field season. It aired on "Out and About" (archived at <http://www.vpt.org/clip/3621>) and includes an enthusiastic testimonial by one of the beneficiary farmers. Two other teams of documentary makers have conducted interviews and filmed our project, though neither is slated to complete films in the immediate future.

This contents of this report are being shared with Eawag Aquatic Research in Switzerland and posted on the SuSana(Sustainable Sanitation Alliance) Forum, as well as the Institute's own website.

We received extensive media coverage during this granting period at the national and international level. Modern Farmer Magazine, National Geographic Daily News, Grist, BBC Mundo (Spanish), and Greenspec are a few online publications which have featured our work. Local articles and radio coverage, as well as Vermont Public Radio spots have publicized our message. Our website media page (http://richearthinstitute.org/?page_id=487) demonstrates the extensive coverage we have enjoyed as the concept of recycling urine begins to take hold. We have been responding to a flood of inquiries as a result of this attention, using this opportunity to accomplish our mission: *"to advance and promote the use of human waste as a resource."*

Farmer Adoption

"This year was the first year that this farm has ever produced a significant amount of second cut hay, and that was a direct result of more nitrogen than we have ever been able to produce on this farm." --Jesse Kayan

Our farmer partners were very satisfied with the results, and are continuing to use urine fertilizer in 2014. In fact, they would like to increase the total volume used on the farm, and have allocated additional space for new tanks in case more urine is available.

As a result of outreach, three new farmers will be using urine fertilizer on their farms and/or participating in additional field trials funded by USDA SARE and the EPA in 2014. Two additional farmers requested urine to test on their farms, but because of the current limits of the Rich Earth Institute's urine collection capacity there will not be enough urine available in 2014 to supply their requests.

Areas Needing Additional Study

While this study established that diluting urine 1:3 with water prior to application is not beneficial, it remains uncertain whether the lower dilution rate of 1:1 is helpful. A follow up

SARE-funded study in 2014 will attempt to answer this question using large strips in replicate.

Alternative methods for urine storage should be investigated. The substantial cost of storage tanks might be avoided if urine is incorporated into on-farm composting operations or existing manure storage, improving the economics of urine fertilization. Our 2014 SARE project includes a laboratory-scale composting experiment investigating co-composting urine with high-carbon feedstocks.

Developing methods for reducing the volume of collected urine, through a combination of reverse osmosis, biological nitrification, and/or evaporation, would provide additional avenues for reducing the cost of urine storage.

The most common concerns raised about urine fertilization relate to pharmaceutical residuals. The 2014-2015 EPA-funded field trials that the Rich Earth Institute is participating in will help establish what, if any, steps are necessary to reduce levels of pharmaceutical residuals in urine when growing row crops. Extending this study to include milk from cows fed with urine-fertilized hay would be very relevant to agriculture in the Northeast.

Participants:

Jay Bailey

Farmer

Fairwinds Farm

511 Upper Dummerston Road

Brattleboro, VT 05301

(802)254-9067

E-mail: jay@fairwindsfarm.org

Supporting File(s):

Unheated mini-greenhouse for room-temperature sanitization treatment:

<http://mysare.sare.org/mySARE/assocfiles/987056greenhouse.jpg>

Urine applied to grid subplots using handheld boom:

<http://mysare.sare.org/mySARE/assocfiles/987056Konrad applying urine with handheld boom 2013.jpg>

Temperature of urine in mini-greenhouse. Diagonal line represents a period of data logger failure.:

http://mysare.sare.org/mySARE/assocfiles/987088greenhouse_temperatures.png

Hay yield on long strips: http://mysare.sare.org/mySARE/assocfiles/987088strip_yield.png

Pasteurizer for sanitizing urine. Hot water from panels circulates through a stainless steel coil in the pasteurizer tank.: <http://mysare.sare.org/mySARE/assocfiles/987056pasteurizer.jpg>

Drying hay on grid subplots: <http://mysare.sare.org/mySARE/assocfiles/987056Abe and Ben tedding randomized plots 2013.jpg>

Urine being spread on long strips using tank applicator:

http://mysare.sare.org/mySARE/assocfiles/987056tank_applicator.jpg

Yield response to undiluted urine at various rates:

<http://mysare.sare.org/mySARE/assocfiles/987088undilute vs others.png>

Hay yields in small grid plot: http://mysare.sare.org/mySARE/assocfiles/987088grid_yields.png

Appendix A: Statistical analysis of grid plot yields:

http://mysare.sare.org/mySARE/assocfiles/987088statistical_analysis.pdf

View this report online: http://mysare.sare.org/mySARE/sare_main.aspx?do=viewRept&pn=ONE13-188&y=2014&t=1

This project and all associated reports and support materials were supported by the Sustainable Agriculture Research and Education (SARE) program, which is funded by the U.S. Department of Agriculture- National Institute of Food and Agriculture (USDA-NIFA). Any opinions, findings, conclusions or recommendations expressed within do not necessarily reflect the view of the SARE program or the U.S. Department of Agriculture. USDA is an equal opportunity provider and employer.

Total Number of Pages : 17