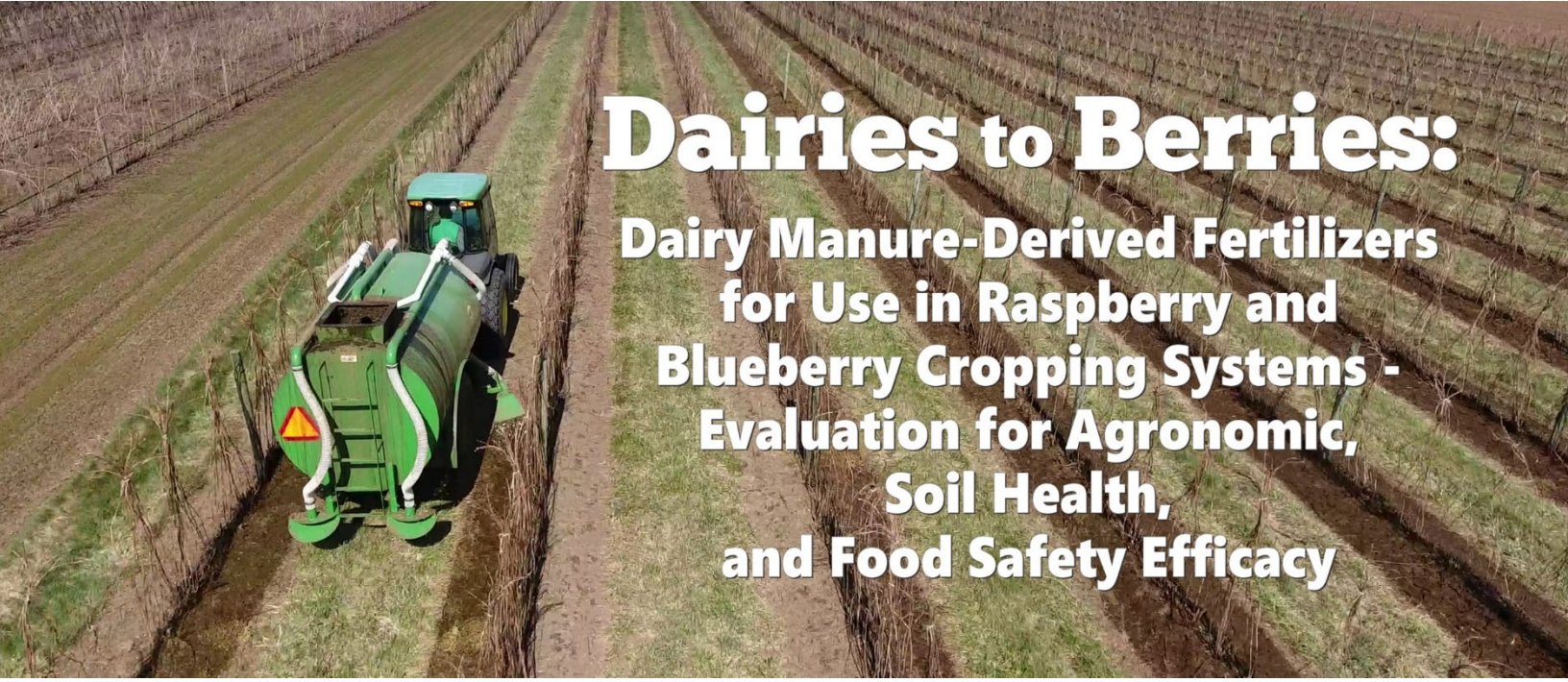


WASHINGTON STATE UNIVERSITY

Project Summary

With increases in herd productivity and concentration over the last half century, the dairy industry has had to manage increasing concentrations of manure. Handling, storage and application of these manures and the associated nutrients to soils have in some areas contributed to air and water quality impairment. Distribution to adjacent horticultural farms, where nutrients are needed, could aid in improving nutrient balances, but in practice has been limited due to costs of handling and transport, problematic nutrient balance, and food safety concerns.

This project:

- Assessed the commercialization of new nutrient-recovery technologies that aim to recover nitrogen, phosphorus, and other nutrients in a concentrated form that can be easily transported off farm.
- Utilized red raspberries and blueberries as the test crop by using manure-derived fertilizer products, facilitating movement of nutrients from “dairies to berries” to improve watershed nutrient balance, soil quality, and horticultural production.
- Tested whether these products might exacerbate food safety risks through on-farm trials.
- Quantified the willingness to pay for such products to support local watershed-level marketing of manure-derived fertilizers.
- Explored the ability of such products to meet nearby crop demands through an analysis of county-wide nutrient flows.

Background

Rapid technological advancement in dairy production has led to unprecedented increases in herd productivity and concentration, as well as manure production. Because manure contains significant amounts of moisture, it is prohibitively expensive to transport more than very short distances from the point of production (Henry and Seagraves, 1960; Ribaudo et al., 2003; Heathwaite et al., 2000). Handling, storage and application of these manures and the associated nutrients to soils have in some areas contributed to air quality as well as surface and groundwater issues (Yorgey et al., 2014).

Nutrient recovery technologies (Ma et al., 2013) have the potential to contribute to a solution to these issues by concentrating a portion of the nutrients and separating them from the remaining bulk of the wastewater. This allows the recovered nutrients to be transported more economically away from impacted fields and watersheds. A recent analysis of commercially available advanced nutrient recovery technologies capable of increased nutrient removal identified cost and management complexity as major adoption barriers (Frear et al., 2018).

One response to this cost burden is to link nutrient recovery to other types of manure management, as recently proposed by the dairy industry (ICUSD, 2013). This strategy employs currently underutilized renewable energy infrastructure, waste heat, and energy off-take revenues that are generated through anaerobic co-digestion of manure and other agricultural/food processing wastes to improve economic viability (Figure 1). Value is generated both from co-digestion products as well as saleable nutrient co-products.

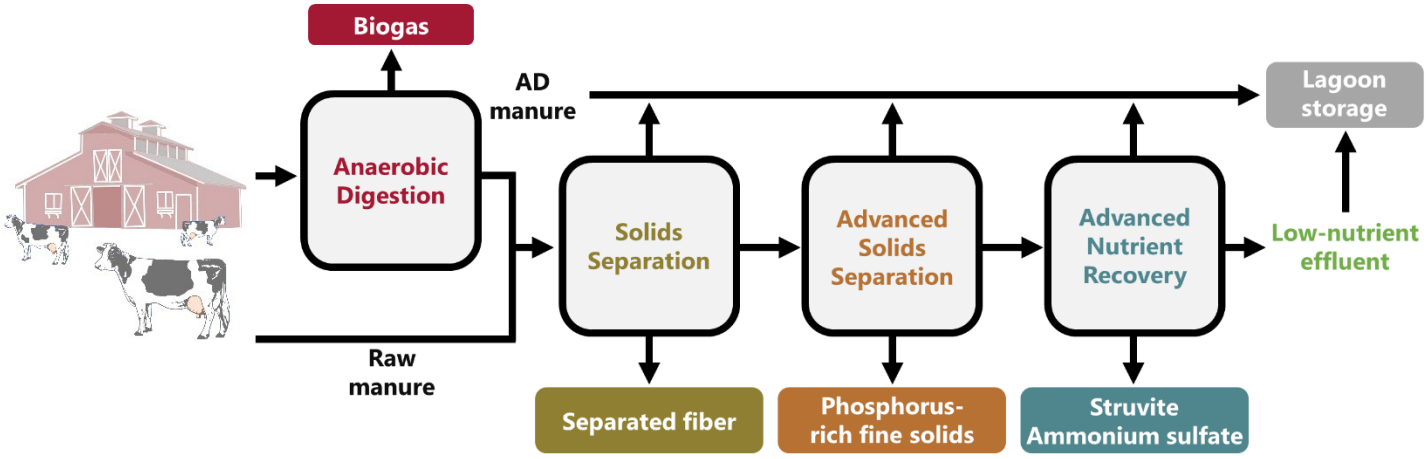


Figure 1: Proposed integration of anaerobic digestion with next-generation nutrient recovery (NR) technology (Manure management technologies are shown in grey boxes; potential revenue-generating co-products are shown in colored boxes.)

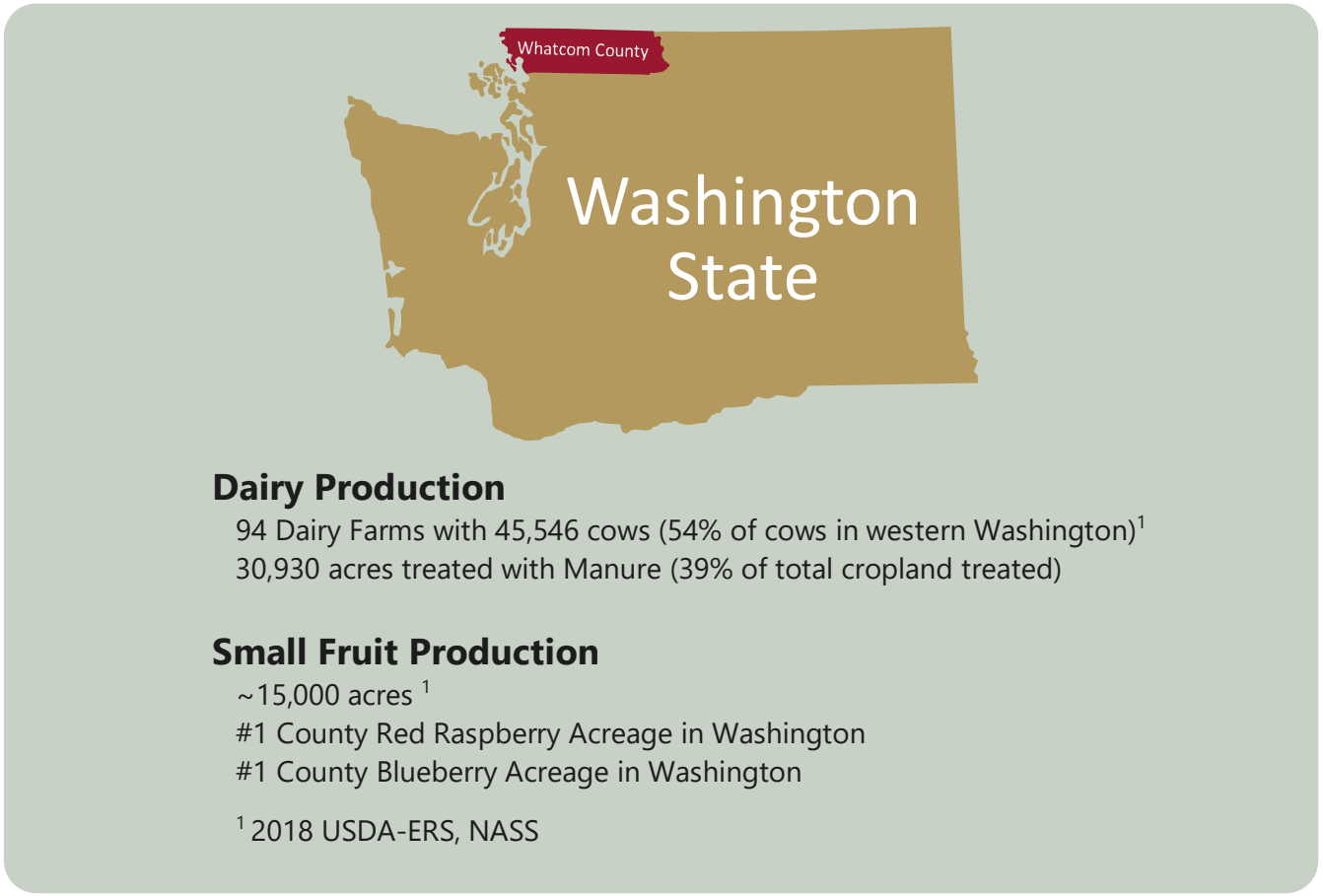


Figure 2. 2017 USDA NASS Agriculture Statistics for Whatcom County, Washington.

Figure 3. Manure-derived fertilizers utilized in the study. For more information on the manufacturing process see Frear, Ma, and Yorgey 2018 Approaches to Nutrient Recovery from Dairy Manure.

Assessment of Agronomics and Food Safety Risks

Dairy manure and its derived fertilizer are good sources of nutrients for crops. However, improper application of soil amendments of animal origin can be a source of contamination of enteric foodborne pathogens. This 3-year field project was conducted to evaluate impacts of dairy manure and dairy manure-derived fertilizers on red raspberry and blueberry production in Whatcom County, WA and the implications for food safety.

Agronomic Assessments

Treatments are outlined in Figure 3. The red raspberry trial occurred in an established commercial 'Meeker' raspberry field and treatments were evaluated for soil and foliar nutrient levels, plant growth, fruit yield, soil bulk density, soil water infiltration, and soil compaction. In the blueberry trial, treatments were evaluated for soil and foliar nutrient levels and plant growth and yield.

Food Safety Risk Assessments

Soil, fertilizer, foliar, and raspberry fruit samples were collected during the cropping season for the quantification of indicator microorganisms (total coliform and generic *Escherichia coli*) and detection of important foodborne pathogens including *E. coli* O157:H7, Shiga toxin-producing *E. coli* (STEC), *Salmonella*, and *Listeria monocytogenes* (Figure 4).

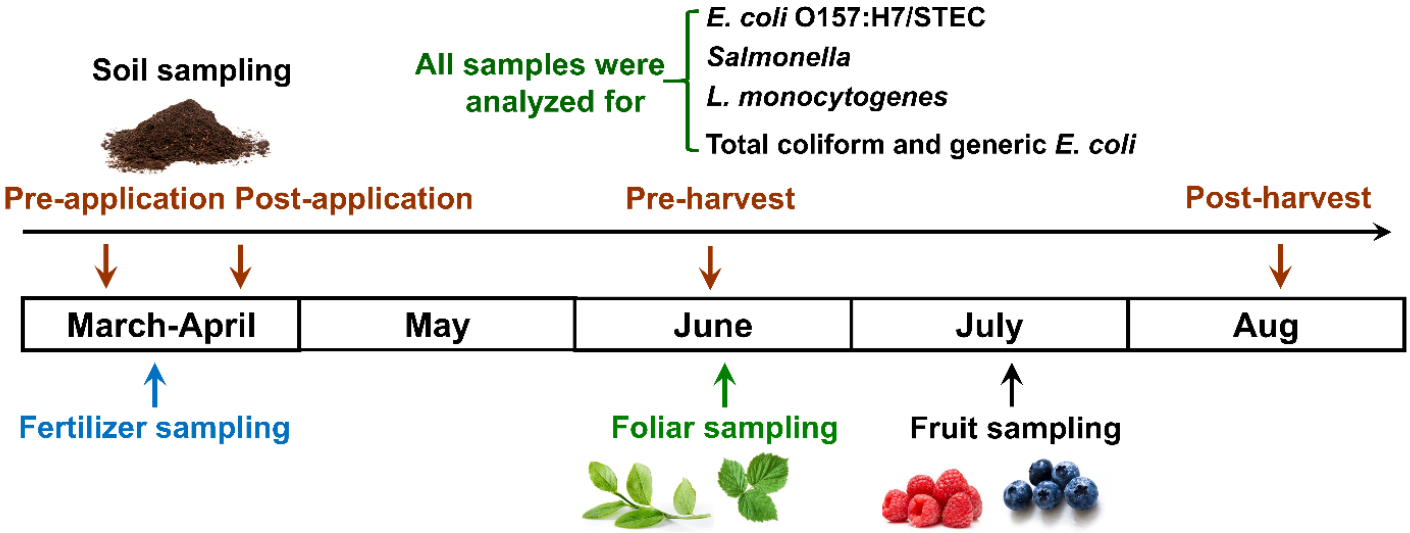


Fig. 4. Overview of sampling schedule and microbiological analyses.

Food Safety Insights:

Total coliform

- Total coliform level in soils from blueberry field remains relatively stable over seasons
- Total coliforms level of soils of raspberry field was higher than those from blueberry field. Varied by years and seasons.
- Coliform was very low in foliar samples and not detectable in fruit samples regardless of fertilizer treatments.

Generic *E. coli*

- Soils from both berry fields contained very low levels of generic *E. coli* regardless of fertilizer treatments.
- Generic *E. coli* in berry fruit samples were below the detectable level regardless of fertilizer types.

Foodborne pathogens

- No *Salmonella*, STEC or *L. monocytogenes* was detected in late season soil samples, foliar and berry samples regardless of treatments.
- *Salmonella* was detected from some fertilizers and early season soil samples.

Application of manure-derived fertilizers had no effect on food safety risks of berry production under a good agricultural practices.

Agronomic Insights:

Red Raspberry

- Yields and plant growth were similar between manure-derived fertilizers and traditional fertilizers.
- Elevated levels of soil nitrogen in late season (September) were observed in the traditional fertilizer treatment. This excess nitrogen will leach out of the soil profile into the groundwater during winter rains.
- Manure-derived fertilizers did not have a positive impact on soil health indicators.

Blueberry

- Yields and plant growth were similar between manure-derived fertilizers and traditional fertilizers.
- Elevated levels of soil nitrogen in late season (September) were observed in the traditional fertilizer treatment.
- Plant available nitrogen was similar between treatments.

Survey of Potential Dairy-Derived Fertilizer Purchasers

To successfully use nutrient recovery technologies to move nutrients from dairies to non-dairy cropland, crop producers need to be willing to purchase the manure-derived fertilizers. To explore this, we conducted a small-scale discrete choice survey of diverse irrigated and specialty crop farmers and crop consultants in Washington State to determine what attributes were important to them in use of a phosphorus solids fertilizer product derived from manure.

Insights from the Choice Survey:

- Respondents preferred air-dried or pelletized forms to wet forms (Figure 5). Our results imply that respondents would be willing to pay 23% and 39% more for a dried or pelletized product, respectively, than for a "semi-wet" product.
- As expected, uptake increased as price decreased. The model predicts that 60% of subjects would choose the bio-based fertilizer alternative that is a semi-wet form when costs are half of current fertilizer costs, dropping to 29% when price is 75% of current costs, and 7% when costs are the same as the current amendment. Uptake is much higher for air-dried and pelletized forms: when price is half of current costs, the model predicts 86% would choose an air-dried product and 95% would choose a pelletized product.
- Distribution channel (meaning whether the fertilizer was available through their normal distribution channel or via a specialized distributor) was not statistically significant.
- Our results indicate that there are other important attributes beyond the ones in the survey that led respondents to stay with their current fertilizer regime. Qualitative responses in the survey pointed to the need for field trials results specific to the crop(s) of potential buyers and data on nitrogen release from the bio-based fertilizer. They also pointed to a continued challenge relating to perceptions of food safety risk.
- A number of crop producers also suggested that manure-derived nutrients could be blended with chemical fertilizers for a final blended product—based on the fact that the product supplies carbon as well as secondary minerals and micro-minerals.

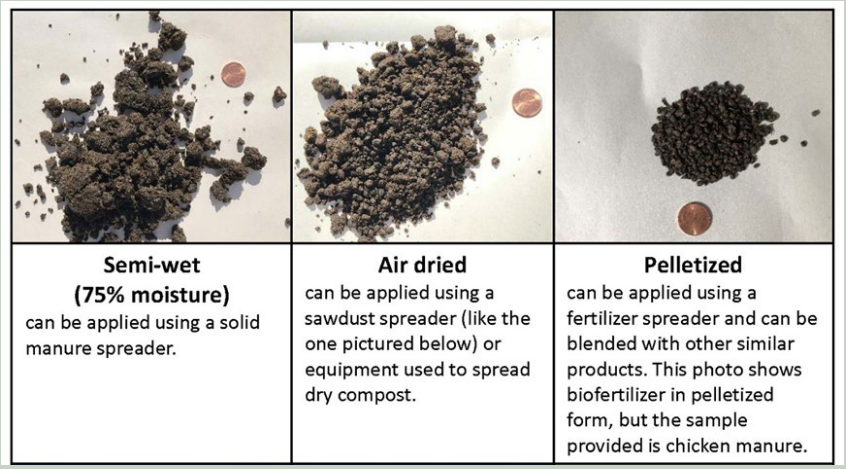


Figure 5: The three possible forms of dairy manure-derived fertilizer products explored during the choice experiment.

Exploration of Role in Meeting County-Wide Nutrient Needs

Our team explored the effect that utilization of the dissolved air flotation (DAF) technology could have on the nitrogen (N) nutrient balance and the cost of transporting N to nearby croplands in Whatcom County. We focused on N, specifically, because it is the limiting nutrient in many cropping systems, is the nutrient of greatest concentration in DAF solids, and is important for the adoption of DAF solids as an alternative to synthetic fertilizer.

Insights from the Analysis of County-Wide Nutrient Needs:

- If nutrient recovery were practiced at all dairies, phosphorus solids could theoretically generate roughly two thirds of the nitrogen needs for the county.
- Transportation costs for N incorporated into DAF solids were only 13% of transportation costs of N in untreated manure. This difference of over seven-fold could be significant in improving the ability to distribute N from dairy manure to cropland throughout Whatcom County, which has a fairly even distribution of dairies and croplands (Figure 6).

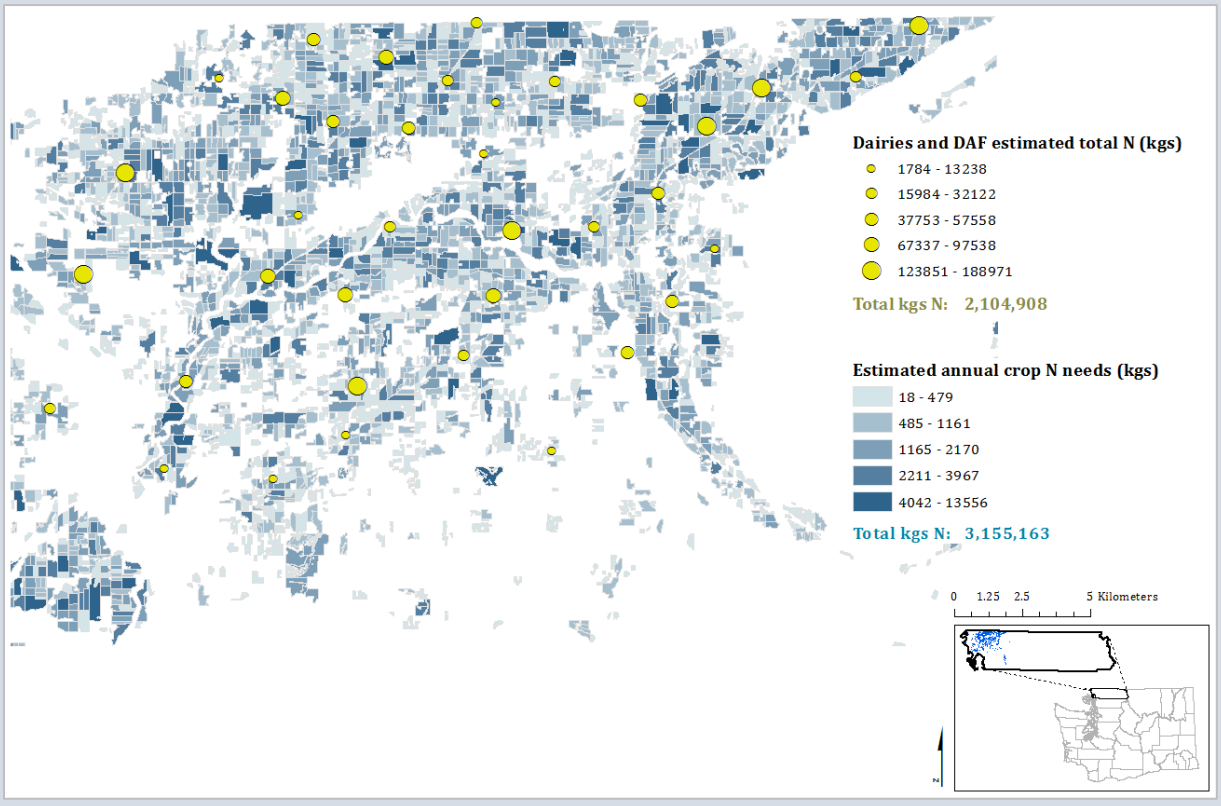


Figure 6: Estimated annual crop N needs and dairy features illustrating potential N availability from dairy manure following DAF process including totals for each.

Challenges and Lessons Learned

Negative perception of manure-derived fertilizers. Despite the project's results indicating that little food safety risk is associated with the use of manure-derived fertilizers, producers of foods generally eaten raw have a perceived risk that limits adoption. Crop producers also prefer manure-derived fertilizers that are in dried or pelletized form.

Little incentive for current fertilizer distributors to adjust to manure-derived fertilizers. Current fertilizer distributors have capital invested in granular fertilizer storage and distribution. Despite project results showing the ability to substitute manure-derived for synthetic nutrient sources, the transition for distributors is difficult and costly.

The economics for production and sale are complicated. Though crop producers are willing to pay more for a dried or pelletized product, the additional costs of drying and pelletizing would need to be carefully weighed. If costs of manure-derived fertilizers are substantially lower than conventional fertilizers, uptake could be substantial. For example, when price is half of current costs (on an N basis), results from our grower choice experiment suggest that 86% would choose an air-dried product and 95% would choose a pelletized product over their current fertilizer.

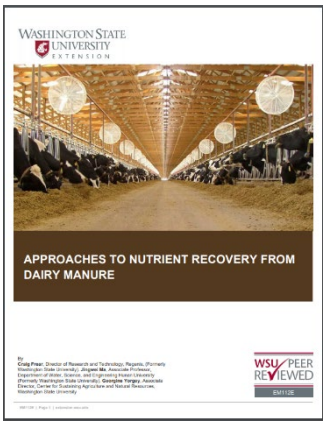
Food safety concerns vary by cropping system. The use of manure-derived fertilizers might be more easily adopted and used by producers in cropping systems that are not consumed raw.

Manure-derived fertilizers could meet substantial amounts of crop needs in areas with interspersed dairies and non-dairy croplands. Greatly reduced transportation costs for manure-derived fertilizers, compared to untreated manure, be significant in improving the ability to distribute N from dairy manure to cropland throughout Whatcom County.

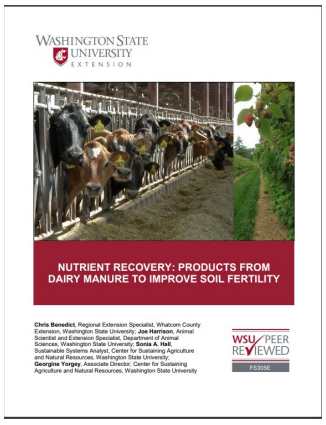
To achieve overall nutrient-related goals. Nutrient recovery technologies need to be part of a comprehensive strategy to ensure appropriate nutrient application timing and methodology at the farm level, and to address issues of nutrient balance at the watershed level.

Outputs and Impacts

• WSU factsheets covering fertilizer production systems and fertilizer product quality.



https://pubs.extension.wsu.edu/approaches-to-nutrient-recovery-from-dairy-manure-anaerobic-digestion-systems-series



https://pubs.extension.wsu.edu/nutrient-recovery-products-from-dairy-manure-to-improve-soil-fertility

• Three field days, two conference presentations, and poster presentations separately targeting information needs of dairy and crop producers as well as agency, agricultural professionals, and allied industry, improving knowledge relating to nutrient recovery for over 324 relevant individuals. Poster presentations targeting scientific audiences were delivered at the national meetings of the American Society for Horticultural Science and American Society for Microbiology. An overview presentation was also delivered at the NRCS CIG Showcase at the 2018 Soil & Water Conservation Society Annual Meeting.

• Development of a project website that houses the details and outputs from the project.

• Scientific publications:

- Sheng L, Shen X, Benedict C, Y. Su, H. Tsai, E. Schacht, C. E. Kruger, M. Drennan, M. J. Zhu. Microbial Safety of dairy manure fertilizer application in raspberry production. Front Microbiol. 2019; 10:2276. Published 2019 Oct 2. doi:10.3389/fmicb.2019.02276

- Shen, X., L. Sheng, C. Benedict, C. Kruger, Y. Su, E. Schacht, Y. Zhang, M. J. Zhu. In revision. Evaluation of microbiological safety of blueberry production using manure-derived fertilizer under different application practices. Submitted to Frontiers in Microbiology.

- Stacey, N., K. Hills, and G. Yorgey. In review. Estimating and comparing nitrogen from dairy manure and crop nitrogen needs in Whatcom County, Washington. Submitted to Renewable Agriculture and Food Systems.

- Hills, K., G. Yorgey, and J. Cook. In review. Demand for bio-based fertilizers from dairy manure in Washington State: A small-scale discrete choice experiment. Submitted to Renewable Agriculture and Food Systems.

- Benedict, C., E. Schacht, M.J. Zhu, C.E. Kruger, G. Yorgey. The use of manure and manure-derived fertilizers in red raspberry production. In preparation.

- Benedict, C., E. Schacht, M.J. Zhu, C.E. Kruger, G. Yorgey. The use manure-derived ammonium sulfate in highbush blueberry production. In preparation.

Next Steps

Continued evaluation of products from new nutrient recovery technologies. As nutrient recovery technologies evolve, fertilizer outputs need to be evaluated for agronomic performance, environmental fate, and food safety (where applicable).

Evaluation in additional cropping systems. As nutrient recovery technologies are adopted by additional dairies in other regions, adjacent cropping systems should be evaluated for compatibility with manure-derived fertilizers. Efforts could be prioritized in crops that are not consumed raw, and therefore pose a lower food safety risk.

Consider policy implications for adoption. State and national policies to incentivize nutrient recovery and redistribution could be prioritized. This may be particularly important given the current low profitability of dairy across the U.S., including in the Pacific Northwest.