


# Demand for bio-based fertilizers from dairy manure in Washington State: a small-scale discrete choice experiment

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## Research Paper

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### Abstract

The use of bio-based fertilizers derived from dairy manure can provide a valuable source of fertility, improve soil health and provide an outlet for manure from dairy operations. We conducted a small-scale discrete choice survey of crop farmers and crop consultants in Washington State to determine the attributes that were important to them in the potential use of a bio-based fertilizer product derived from dairy manure. Of the attributes examined, distribution channel was not statistically significant. Respondents preferred air-dried or pelleted forms to wet forms, though there was no statistically significant difference between air-dried and pelleted forms. As expected, uptake increased as price decreased. Our results imply that respondents would be willing to pay 23 and 39% more for an air-dried or pelleted product, respectively, than for a ‘semi-wet’ product. 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 trial results and data on nitrogen release from the bio-based fertilizer. Greater understanding of willingness-to-pay and attributes important to potential end users is important for the development of markets for bio-based fertilizers.

## Introduction

Historically, livestock and crops were often integrated in a single farm, with manure from livestock an important nutrient source for nearby crops. The advent of commercial fertilizers, increased specialization on farms and more concentrated livestock operations have contributed to a shift from viewing manure as a resource to seeing it as a potential liability. For various reasons, however, there has been renewed interest in the re-integration of nutrient and carbon flows between livestock and non-livestock farms (Bonaudo *et al.*, 2014; Garrett *et al.*, 2017; Ryschawy *et al.*, 2017), where both types of agricultural operations stand to benefit. One reason is that concentrated dairy farms struggle to manage increasing quantities of manure (USDA ERS, 2007; USDA NASS, 2019a, 2019b). In the USA, most of this manure is land applied, and regulations discourage application rates that might exceed what plants can take up. Handling, storage and application of this manure and the associated nutrients to soils have contributed to impairment of air and water quality (US-EPA, 2012; Harter *et al.*, 2017; LCBP, 2018; Ator *et al.*, 2019). Meanwhile, most cropland is fertilized with imported synthetic fertilizers. Improving linkages between dairies (a nutrient source) and non-dairy croplands (a potential nutrient sink) could improve watershed-level nutrient balances and improve water quality in watersheds that contain a mix of livestock and adjacent croplands under separate management.

The distribution of nutrients from dairies to adjacent horticultural farms has been limited because of transportation costs, food safety concerns and concerns about odors (Ribaudou *et al.*, 2003; Norwood *et al.*, 2005; USDA ERS, 2011; US FDA, 2015). While manure can be used to provide crop nutrients, very few farms rely exclusively on manure as a substitute for synthetic fertilizers, in part because a mismatch often exists between crop demands and manure nutrient balances (USDA ERS, 2009). Additionally, nitrogen in dairy manure is predominantly in the organic form and its transformation into crop-available forms can be slow and unpredictable, posing a challenge for matching the timing of crop nitrogen needs (Bary *et al.*, 2016). While large dairies have long used first-generation nutrient recovery systems such as screens and settling basins to recover large solids and/or fibers, more advanced next-generation nutrient recovery systems are of great interest to the dairy industry (Yorgey *et al.*, 2014; Frear *et al.*, 2018). By concentrating and changing the form of nutrients in manure, and reducing or eliminating food safety concerns, these advanced nutrient recovery systems have the potential to reduce transport costs for manure nutrients and in forms that are more appealing to receivers (Benedict *et al.*, 2018).

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Though several advanced nutrient recovery technologies for dairy farms are in development or early commercial deployment, the literature on demand for these products is limited. Existing studies on the demand for fertilizer products derived from dairy manure are all based on responses from European producers; we know of no peer-reviewed study in US agriculture<sup>1</sup>. In a study conducted in Sicily, Pappalardo *et al.* (2018) found that farmers' willingness-to-pay for digestate (a product of anaerobic digestion) was strongly influenced by how much information they had about the digestate. Pampuro *et al.* (2018) conducted a survey and focus groups to determine farmers' attitudes toward using pelletized composted manure in Northwestern Italy and found that nitrogen content was the most important attribute to farmers. Tur-Cardona *et al.* (2018), the study most like ours, conducted parallel discrete choice experiments (DCEs) in seven different European countries to identify key attributes related to the acceptance of bio-based fertilizer products. The authors found that bio-based fertilizer products could be sold at about 65% of the cost of mineral fertilizer. They also found that farmers preferred concentrated products that have certainty in the nitrogen content and cost less than mineral fertilizer.

We focused our efforts on a bio-based product resulting from a next-generation nutrient recovery process called Dissolved Air Flotation (DAF) that separates fine solids from dairy manure liquids (Frear *et al.*, 2018). At the time of this study, commercial scale DAF units had been installed at two dairies in Washington. A related project found that a one-time application of dairy manure-derived fertilizers had no impact on food safety in raspberry production when application occurred more than 4 months prior to harvest (Sheng *et al.*, 2019). Another related project found no difference in growth or fruit yield quantity/quality in raspberries between conventional fertilizer, raw dairy manure, composted dairy manure or DAF solids (Benedict, unpublished data).

The objective of this study was to assess demand for the bio-based fertilizer by surveying those who make decisions about fertilizers and soil amendments on farms. We aimed to understand the attributes that would be important to these decision makers. Specifically, we examined preferences toward the form of the bio-fertilizer, whether the product is available through familiar fertilizer channels, and its cost relative to a grower's existing fertilizer costs.

## Methods

### Survey development and distribution

The team began by meeting with stakeholders (four growers from Northwestern Washington who had agreed to serve on an advisory committee for the project) in March 2018 to discuss ideas for a survey. Based on their feedback, we drafted an initial survey and choice experiment and met with another focus group of growers in September 2018 before finalizing.

The survey (available in the Supplementary material) begins with a description of the DAF process and product, including

key characteristics like %NPK (4-1-1), nitrogen composition [95% organic (slow-release) nitrogen and 5% ammonia nitrogen], carbon-nitrogen ratio (9:1) and salinity level (low-moderate). Because we did not want to exclude organic producers from the survey, we asked respondents to assume that the product could be used on organic ground, though this is currently not true. A polymer used in the DAF process is not allowed under certified-organic production, though research is exploring whether changes to DAF process could result in a product that could be used on certified organic ground (Mehta *et al.*, 2015). While we had hoped to learn about differences in preference between organic and conventional producers, ultimately our sample size did not allow this level of analysis.

We also asked respondents to assume that the product would 'introduce no additional food safety risks and no additional regulatory requirements for your operation'. The survey then described the DCE, described in more detail below, before asking a series of questions on crops, farm size, organic certification, years of experience, current use of manure-based amendments, current amendments or fertilizers, and current spreading equipment.

Written surveys were distributed during three grower meetings held in Washington State in late 2019 [Tilth Conference, Pacific Northwest Vegetable Association (PNVA) and the Small Fruit Conference]. These meetings were chosen to have the best chance of respondents representing a diversity of agricultural production types in the region. Survey recipients were provided with a paper survey, and a postage paid envelope for survey return. Most participants were from Washington State, but some lived in neighboring areas. The Institutional Review Board at the authors' university reviewed the study and determined that it met the criteria for exempt research.

A total of 90 surveys were distributed at the three grower meetings after determining whether the person was an 'individual making fertilizer and soil amendment decisions at their operation'. This included crop consultants. An additional 86 people were approached but determined to be ineligible. Survey recipients were asked for contact information and were contacted three times following the first interaction. Of the 90 eligible contacts, 36 people (40%) declined to participate, 17 (19%) did not reply after three contacts and 37 (41%) returned surveys. Ten of these 37 were crop consultants.

### Stated preferences: discrete choice survey

We used a hypothetical 'stated preference' approach because bio-based fertilizers are not widely available in the US marketplace, so we could not rely on market prices and sales to estimate demand and preferences. Furthermore, these products continue to be refined and developed, and understanding what characteristics are most important to potential buyers can inform research and development priorities. A repeated, DCE where the price of the fertilizer varies along with other characteristics gives us the most flexibility to quantify these preferences, particularly in relation to price. Although we were unaware of the study during development and fieldwork, our approach is very similar to that in Tur-Cardona *et al.* (2018) with several differences that we describe below.

Respondents made five choices, each between two hypothetical new bio-based fertilizers and their status quo nutrient amendment (Fig. 1). Instead of a generic bio-based fertilizer, our hypothetical alternative was identified as a solid produced through the DAF process for digesting dairy manure. We asked respondents to rank all three alternatives rather than only

<sup>1</sup>Newtrient (2018) examined the market potential for a nutrient recovery product from one large-scale, dairy manure-based fertilizer production facility located in NW Indiana (Midwestern BioAg's subsidiary, Terra NU). The product is marketed as a traditional fertilizer with enhanced soil building properties due to the organic carbon content and micronutrients, though the firm's sales volumes, prices and production costs are not publicly available. Newtrient (2018) found that the 75% moisture level would make the product difficult to store and transport. This would limit its market value without further processing and drying (Newtrient, 2018).

## Choice Task 1

	Biofertilizer Option A	Biofertilizer Option B	Option C: Your current soil amendments, no biofertilizer
FORM	Semi-wet (75% moisture)	Pelletized	----
DISTRIBUTION	Through your current distributor	Must be purchased through a separate company	---
COST, APPLIED	75% of your current cost	same (100%) as your current cost	100%
RANK THESE OPTIONS 1= best, 3=worst			

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1.1 In this choice, how certain did you feel about your ranking?

(1)  Very certain    (2)  Somewhat certain    (3)  Somewhat uncertain    (4)  Very uncertain

1.2 In this choice, which of these attributes did you ignore? (check all that apply)

form     distribution     cost

Fig. 1. Example choice task.

choosing their highest-ranked option, providing us more content on preferences. We also asked respondents about their certainty in each task, and any attributes ignored.

The hypothetical products differed along three dimensions. The first attribute was the cost of the product. Like Tur-Cardona *et al.* (2018), we chose to express price not in absolute dollar terms but as a percentage of the status quo soil amendment. We did this because (a) we expected to survey growers using a wide range of fertilizers with varying costs, potentially introducing measurement error in elicitation and (b) because policy discussion around low adoption has focused on how much of a cost reduction (either through production efficiency improvements or explicit public subsidies) would be needed to increase adoption. We chose two price levels implying reductions in costs (50 and 75% of current costs) and one in which the price was the same (100%).

The second attribute was the physical form of the product. The first of three levels was a ‘semi-wet’ form that is ‘75% moisture’ and ‘can be applied using a solid manure spreader’. The second option was an ‘air dried’ form that ‘can be applied using a sawdust spreader or equipment used to spread dry compost’. The third option was a pelletized form that ‘can be applied using a fertilizer spreader and blended with similar products’. The survey contained pictures of all three forms along with the type of spreader needed for that form (see Supplementary material). Respondents were also given three small samples of each form (though the pelletized form was chicken manure, since dairy manure-based products were not available in this form) along with the survey and postage-paid envelope.

The final attribute, and one not explored in Tur-Cardona *et al.*, was the avenue through which the grower would purchase it. During the preliminary focus groups, we heard that distributional channels might be a serious impediment to uptake if transitioning to the bio-based fertilizer. The options for this attribute were either ‘through your current distributor’ (available through the channels where you typically buy fertilizer and soil amendments) or ‘purchased through a separate company’.

We used a fractional factorial experimental design to construct the choice sets. We began by generating a full factorial of the 324 possible choice tasks. We dropped tasks that had identical alternatives, had a dominated alternative (better in all attributes) or were non-orthogonal on all three attributes. This left 27 choice tasks. We randomly chose 12 choice tasks (see Supplementary material), and then randomly split these into blocks of four tasks. We used a random number generator in Excel to generate three random designs of 12 cards each, and chose the one with the best attribute balance. We also checked for attribute balance within the blocks. We also added one task to each block that was non-orthogonal by design, to allow us to see patterns in the raw response data (Sur *et al.*, 2006). The left-right order in which alternatives were placed in each choice task, as well as the order of the choice tasks, was randomized.

We analyze responses from the DCEs using the well-established ‘random utility’ framework that assumes the utility of choices can be decomposed into a component observed by the analyst and a component known to the decision maker but not to the analyst (McFadden, 1974; see Hensher *et al.*, 2015 for an introduction). We model the observable utility of bio-based fertilizer choice as a function of the three attributes, making the common assumption that utility is linearly-additive, with an error term  $e$  that is known to the grower but unknown to the analyst. The utility of choosing alternative  $j$  is:

$$U_{ij} = \beta_1 Cost_j + \beta_2 Form_j + \beta_3 Dist_j + \beta_4 ASC + \epsilon_{ij}$$

The opt-out choice—continue to use current product—is modeled using a dummy variable labeled ASC (alternate-specific constant) that is equal to one when the status quo was chosen. By definition, the cost of the status quo was 100% of current costs, and the distribution type was ‘through your current distributor’. We assigned the form of the status quo based on the response to questions about the soil amendment currently used. If it was missing or if the subject did not report currently using a manure-based product, we assigned the form of the status quo to be ‘pelletized’.

Assuming the unobserved component is an error term that is independently and identically distributed and Type-I extreme value gives rise to the multinomial logit (MNL) model (McFadden, 1974), also called the conditional logit model. The multinomial model requires data where only one of the alternatives is selected; we modeled the choice of which product or the status quo was ranked highest. To make use of the preference information contained in the full ranking of choices, we estimated the related ranked-order logit model ('rologit' in Stata 15). See Supplementary material for more detail on model selection.

## Results

### Farm characteristics

Among the 37 respondents, 27 were growers or managers of single operations (median size 650 acres), while ten were crop consultants (median number of acres managed was 9000). Among all 37, 30% of farms were 10 acres or smaller and 25% of farms were 5000 acres or larger. Nearly all were growing multiple crops. Nearly half (46%) were growing field crops (e.g., wheat, grass, corn, pasture), 76% were growing vegetable crops (e.g., onions, potatoes, sugar beets, beans, asparagus) and 41% were growing berries or tree fruits. The certified organic ground represented by those surveyed was relatively small. Of the 37 respondents, nine reported that 100% of the land they manage is certified organic, 11 reported that none is certified organic. The remaining 17 had some percentage of their land in certified organic production, most frequently 1–10%.

Three-quarters (78%) were already using a manure-based amendment. We classified these roughly according to the texture/form of the final product: 24 of the 28 respondents who used a manure-based amendment used one that is a semi-moist product (e.g., cow manure, horse manure), seven of 28 used an air-dried product (e.g., 'perfect blend') and three of 28 used a pelletized form (e.g., pelletized chicken manure). Note that several farms reported using more than one form of bio-based soil amendment.

Since we expected most growers would not be willing to switch wholesale to a new product, we asked about the dimension they might experiment with the new product, and many specified several dimensions. Seventeen of 36 (47%) responses said they would first try the new product on a specific crop (e.g., carrots, beans, blueberries, potatoes). Eighteen of 36 (50%) said they would restrict it to a percentage of cultivated ground; the median response was 10–15% of acreage. Fifteen of 36 (42%) said they would replace a percentage of nutrients; the median percentage was half of the nutrients. When asked what type of amendment they would replace with the product, the most frequent responses were chicken manure-based products (22%) and compost (11%). Other responses included feather meal, blood meal, dairy manure and granular synthetic fertilizer.

Half of the growers already used a solid manure spreader, 46% used a compost or sawdust spreader and 76% used a fertilizer spreader for pelletized products. In all three cases, approximately 65% owned the equipment, 15% leased the equipment and the remainder used a custom applicator.

### Discrete choice experiments

Two respondents left all of the choice tasks blank. One commented that what they needed was 'a guarantee analysis', and a second rejected the scenario, mentioning that many buyers forbid

manure or compost products being used on crops. We dropped responses from one additional subject who reported confusion in the open-ended comments at the end, leaving a useable sample for the discrete choice analysis of  $n = 32$ .

Although our focus groups raised the issue of the distribution channel, respondents reported ignoring the distributor-type attribute in 53% of 129 choice tasks. They reported ignoring the cost attribute in 29% of choices, and form in 23% of choices.

Ten (31%) respondents always ranked their status quo amendment as their top choice and never ranked a new DAF product as their top choice. Four of these subjects said they thought the DAF product would be too expensive, which we interpret as a rejection of the hypothetical scenario asking them to assume the DAF product would be cheaper. Three mentioned concerns with the timing of nitrogen release, and two said that conventional amendments were quickest, more flexible or more 'effective'. One mentioned a preference for manure, and another mentioned overall uncertainty about the DAF product.

We also designed the choices such that we could make comparisons using raw data, although sample sizes in each cell are very small. For example, nine respondents compared an alternative where the price was 50% of costs, the form was pelletized and the distributional channel was their current distributor. A different nine respondents rated a DAF alternative with the same distribution and form characteristics, but where the price was 75%, and a different 11 respondents were asked about the same product at a cost of 100%. As predicted by economic theory, more subjects (56%) rated the hypothetical alternative higher than their status quo when the cost was lowest compared to when costs were 75% (44% of subjects) and 100% (42% of subjects). This provides some descriptive evidence that subjects were taking the task seriously and were responsive to our key price parameter in ways consistent with theory.

Table 1 (column 1) shows the results from an MNL model of choices where we collapse rank-ordered preferences to the most-preferred option. Because coefficients report the estimated 'utility weight' of an attribute, their magnitude cannot be interpreted directly because utility is a latent concept. A negative coefficient indicates that the attribute provides disutility; a respondent is less likely to choose an alternative with that attribute level. A positive coefficient indicates positive utility and a higher probability of choosing an alternative with that attribute level. A larger magnitude indicates that the attribute is more important (i.e., contributes more utility and makes the person more likely to choose) than another attribute with a smaller magnitude coefficient. A coefficient which is not statistically different from zero provides no utility or disutility to the subject, and it was not a significant factor in the person's choice of manure option. The ratio of an attribute parameter divided by the cost parameter does, however, have an intuitive meaning: this is the willingness-to-pay in dollars (or percent cost reduction) for a marginal increase in the attribute.

As suggested by the raw data comparison above, subjects were responsive to the cost parameter and in the expected direction: they were more likely to choose an alternative as their top choice when costs were 75% of current costs (compared to the omitted category of 100%), and even more likely when costs were 50% of current costs. Subjects also preferred air-dried or pelletized forms to semi-wet forms, though they do not distinguish between air-dried and pelletized (the coefficients are not statistically different from each other). Respondents may be indifferent between air-dried and pelletized forms, or were unsure if one would work better



**Table 1.** Multinomial logit (MNL) and rank-order logit models

	MNL	MNL-trimmed <sup>a</sup>	Ranked logit
50% of current costs	2.617*** (0.445)	3.177*** (0.603)	1.138*** (0.273)
75% of current costs	1.368*** (0.415)	1.781*** (0.530)	0.594** (0.234)
Form: pelletized	1.419*** (0.315)	2.454*** (0.448)	1.321*** (0.233)
Form: air-dried	1.283*** (0.317)	1.421*** (0.409)	1.184*** (0.242)
Requires separate distributor	-0.0580 (0.305)	-0.0807 (0.379)	0.0167 (0.200)
ASC	2.509*** (0.400)	2.766*** (0.510)	1.513*** (0.228)
Observations	450	333	448

Notes: Standard errors in parentheses, \*10% significance, \*\*5% significance, \*\*\*1% significance. Excluded categories are 100% of current costs and 'wet' form.

<sup>a</sup>Trimmed = drop choices where the subject was 'somewhat uncertain' or 'very uncertain' and four subjects who rejected the hypothetical scenario.

for them than the other. We think it is unlikely that they did not understand the difference between them in our description given that we provided color photos and physical samples. Consistent with the number of respondents saying they ignored the attribute, the distribution channel was not a statistically significant predictor of top choices. The variable capturing any unobserved attributes of the status quo amendment use (ASC) is positive and statistically significant. There are other attributes of the status quo soil amendment not captured in our hypothetical exercise that led respondents to stay with the current choice, or respondents are displaying a status quo bias for the known choice (Samuelson and Zeckhauser, 1988). We explored whether select respondent characteristics were related to whether respondents' choice of the status quo amendment over the bio-based fertilizer. Of the factors examined (farm size, grower vs. crop consultant, already use manure-based product), the only characteristic that was significant was whether a manure-based product was already used. Not surprisingly, 75% of the respondents who already use manure were likely to try one of the bio-based fertilizer choices ( $P < 0.01$ ).

The model in column 2 (MNL-trimmed) is an uncertainty calibration: it drops 15% of choice tasks where the subject said they were somewhat or very uncertain about their choice as well as all of the responses from the four subjects who rejected the hypothetical exercise (see above). Results are qualitatively similar except that the point estimates show a stronger preference for pelletized than air-dried, though they are again not statistically different. Finally, the ranked logit model in column 3 takes advantage of the full rank-ordering preference information of subjects (rather than only their top choice preference), and is again qualitatively similar to column 1.

We use the results from column 2 (MNL-trimmed model) in Table 1 to calculate predicted probabilities of uptake by price and form (Fig. 2). Because the form of distribution was not a statistically significant predictor of choices, we omit it from the predicted probability calculations. 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 the current fertilizer costs, dropping to 29% when the price is 75% of current costs, and 7% when costs are the same as the current amendment (see

Supplementary material for detail on calculations). Uptake is much higher for air-dried and pelletized forms, shifting demand: when the price is half of the current costs, the model predicts 86% would choose an air-dried product and 95% would choose a pelletized product (from 60% who would choose a semi-wet form).

Similarly, we estimated a model with price as a continuous variable to be able to calculate part-worth WTP for different forms (by dividing the coefficient for each attribute dummy by the coefficient on price, as in Tur-Cardona *et al.*). We find that the value to users of a product that is pelletized, compared to semi-wet, is the equivalent of 39% of current costs. The value of an air-dried product is 23% of current costs.

### Qualitative responses on acceptability

Several questions with open-ended responses were included in the survey and gave further indications of important factors related to acceptability of the bio-based fertilizer product among survey respondents. Respondents were asked the following open-ended questions:

For respondents that never ranked the biofertilizer as a top choice, 'What is the main reason that you never ranked a biofertilizer product as your top choice?'

'Are there any circumstances under which you would consider choosing a manure-derived [bio-based] soil amendment product? If yes, what would it take?'

'Are there any concerns that you have about using a new soil amendment of the type that we have described? If so, please describe.'

All of the 37 returned surveys were considered in the analysis of qualitative responses and all but one of these 37 surveys included responses to at least one of the open-ended questions. There were several themes that reoccurred in responses to these questions and provide valuable qualitative information. Responses were coded and grouped according to themes, the number of surveys with comments that fit within the thematic groupings was tabulated (Table 2) and the themes are described below.

Not surprisingly, cost was the theme most frequently mentioned (11 respondents; 29%). Themes relating to product composition and quality were also frequently mentioned; specifically, nutrient balance, including mention of salt and pH (nine respondents; 24%), and nutrient release (nine respondents; 24%). In the theme of nutrient release, nitrogen release was specifically mentioned by four respondents, though it can be assumed that nitrogen release would be the nutrient of greatest interest to growers considering this product because it is the most challenging to manage in terms of release timing, particularly when, as with this bio-based fertilizer, 95% is in the unavailable organic form.

The topics of application/spreading, food safety and use in certified organic agriculture were brought up by six subjects (16%), each. Four subjects (11%) brought up concerns in each of the following themes: reliability of supply of the product, potential for weed seeds or other contaminants (e.g., pharmaceuticals), and logistical concerns around transportation or storage. One farmer who manages 10 acres of diversified vegetables said, 'I would be concerned about how the semi-wet product would be supplied/packaged. [The product is] probably not great for a small grower, but ok for a larger operation with space and equipment to handle.'

The need for further information on the bio-based fertilizer was clear from the responses in a number of thematic areas; there were four respondents that mentioned the need for field

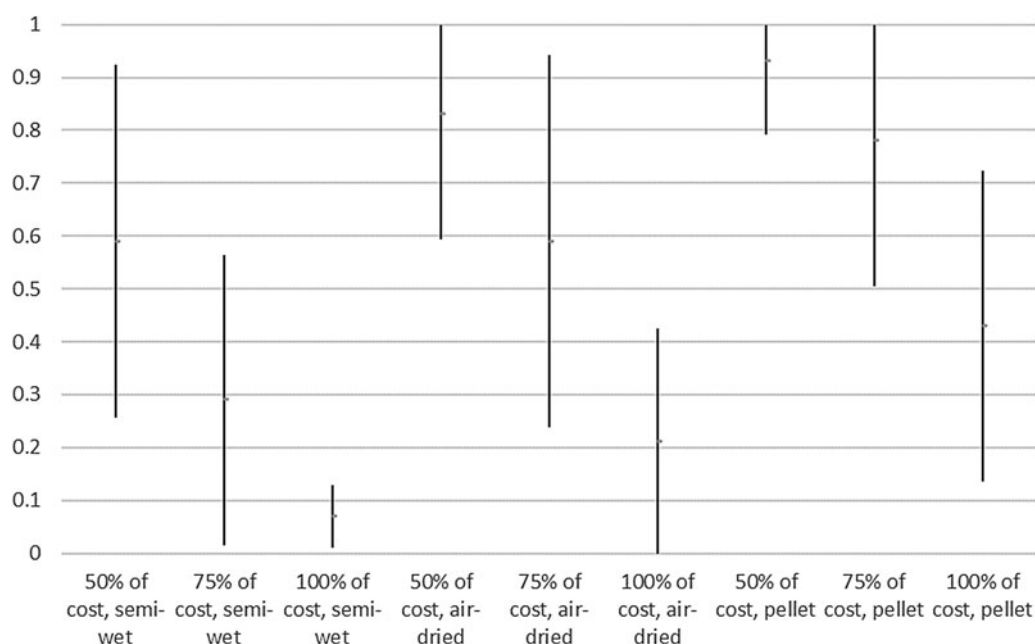


Fig. 2. Predicted probability of using bio-fertilizer by form and cost (95% confidence intervals).

Table 2. Themes mentioned in open-ended survey questions ( $n = 37$ ).

Theme	Respondents	
	Number	Percentage
Cost	11	29
Nutrient balance	9	24
Nutrient release	9	24
Application/spreading	6	16
Food safety	6	16
Use in certified organic	6	16
Available reliably	4	11
Transport/storage	4	11
Weed seeds/contaminants	4	11

trial results using the product. 'Even if you came and gave consultants the data on when to expect the release, we would still need field trial in season to concur. Then usually it is not worth time to growers/consultants to experiment and have yield reductions.' Another responded, 'These products have good soil amendment properties on sandy soils that are more important than nutrient value.' One grower noted concern relating to the possibility of increased regulatory requirements (though this does not currently exist), stating 'I will not buy inputs if it involves extensive paperwork that's not in line with private companies/businesses.'

## Discussion

The results of this survey provide information that can guide potential future market development of DAF solids as a bio-based fertilizer product for crop producers in Washington State and are likely to have some applicability in other areas where crops are grown in proximity to livestock operations and the potential exists for use of

bio-based fertilizers in crop production. Our results indicate that semi-wet DAF alternatives have a lower value than the currently-used 'status quo' fertilizers. Specifically, as described above, the model predicts that 27% of subjects would choose a semi-wet DAF bio-based product when costs are half of the current fertilizer costs, dropping to 8% when the price is 75% of current costs, and 2% when costs are the same as the current amendment. Generally, our results suggest lower willingness-to-pay than was found by Tur-Cardona *et al.* Based on the results of the DCE, distribution channel is not an important factor guiding market uptake of DAF solids bio-based fertilizer, but some amount of processing (drying or pelletizing) of DAF solids would increase its desirability to farmers. As described above, our estimates imply that respondents would be willing to pay 23% more for an air-dried biofertilizer product than a 'semi-wet' product, and 39% more for a pelletized product.

Fertilizer costs vary by crop and farm, but enterprise budgets from Washington State provide some information on typical annual per acre conventional fertilizer expenses for a number of crops grown by survey respondents, including Bing cherries (\$73; Galinato and Gallardo, 2015), red raspberry (\$356; Galinato and DeVetter, 2015), blueberries (\$610; Galinato *et al.*, 2015) and russet potatoes (\$750; Galinato and Tozer, 2015). Though this list is not comprehensive, it provides some background information that may be useful in interpreting survey responses expressed as a percentage of current fertilizer costs.

Regenis, a company that operates a DAF unit at an 1800 cow dairy in Northwest Washington, estimates that it would be necessary to receive a minimum of \$165 per dry ton of pelletized DAF (not including delivery costs) in order to recoup the cost of installing and operating a DAF unit and a drier/pelletizer for DAF solids over 20 years. Of this \$165, \$75 per ton would be associated with covering the cost of drying and pelletizing (Craig Frear, personal communication).

One of the fertilizer products that survey respondents most frequently mentioned as a product that they would consider substituting DAF solids for is a chicken manure-based product called

Perfect Blend. Perfect Blend 4-4-2 was recently being sold for approximately \$320 per ton. While this price would make \$165 per ton seem more competitive, there are important differences between PerfectBlend and the DAF product. PerfectBlend is currently approved for use in certified organic production and poultry manure-based products tend to have a greater nitrogen availability than DAF solids.

An alternate method of valuing a biofertilizer is to calculate its fertilizer replacement value, calculated by determining how much would it cost to purchase the nitrogen, phosphorus and potassium contained within the biofertilizer through a fertilizer dealer. This method has been used by the dairy industry in other parts of the USA, with a report by Newtrient (2018) suggesting applying a factor of 1.2 to the fertilizer replacement value of manure-based fertilizers to account for micronutrient value (Newtrient, 2018), though micronutrients are not routinely applied to most crops in Washington. Based on 2018 fertilizer prices in Whatcom County, Washington, the fertilizer replacement value of DAF solids described in the survey would be \$174 per dry ton (Kaitlyn Reeck, personal communication). However, our results suggest that a fertilizer replacement value may over-estimate the value that non-dairy receivers of bio-based fertilizers may be willing to pay. Paying more attention to the prices that receivers are willing to pay, and the attributes that are important to them, is likely to be important for developing realistic markets for bio-based fertilizer, and realizing the re-integration of livestock and crop farms.

Adoption of advanced nutrient recovery technologies to date has been limited, and current low milk prices make it difficult for dairy farmers to invest in these technologies. The key to their adoption will likely require progress on several fronts, including the expansion of markets for resulting products by focusing on demand-side preferences (our study). Broader social recognition of the value that such systems provide in terms of helping dairies achieve their nutrient management goals and reduce air and water pollution would also speed adoption. Public subsidies, predicated on improved water quality, or increased environmental regulation of dairy manure waste would also increase uptake of nutrient recovery technology from dairies. There may also be an opportunity to focus on the micronutrient and soil organic matter-building properties of the bio-based fertilizer product, which may be more interesting than the macronutrient (NPK) content for some crop farmers.

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