From: Dr. Scott Leibsle
To: Janis Perry
Subject: FW: {External}Negotiated Rulemaking
Date: Tuesday, June 16, 2020 12:13:21 PM
Attachments: Manure Variability from Solid Stacked Manure.docx
lagoonCharact.pdf

Comment/Publication from April Leytem.

From: Leytem, April <april.leytem@usda.gov>
Sent: Tuesday, June 16, 2020 11:18 AM
To: Dr. Scott Leibsle <Scott.Leibsle@ISDA.IDAHO.GOV>
Subject: {External}Negotiated Rulemaking

Hi Scott,

I want to submit this comment again as there still seems to be some concern that there is a large variability in manure stacks/lagoons within a farm that would make sampling an unreliable way to determine nutrient concentrations and therefore makes book values better. It is clear that on-farm sampling is reliable and it will always be a better option for determining nutrients on-farm.

Thanks,

April

From: Leytem, April
Sent: Tuesday, June 11, 2019 8:49 AM
To: Dr. Scott Leibsle <Scott.Leibsle@ISDA.IDAHO.GOV>
Cc: Bjorneberg, Dave <Dave.Bjorneberg@ARS.USDA.GOV>
Subject: manure variability

Hi Scott,

I wanted to provide some input into the issue of manure nutrient variability. It has been argued several times in the negotiated rulemaking that the variation in manure sources on a given farm is extremely large (as much as 100%) and therefore using a book value is more accurate than testing the manure as it is too difficult to obtain a representative sample. I have included an analysis of the variability in solid manures sources used at 17 different field sites over the last 7 years. I also attached a study that looked at the variability of lagoon nutrient content spatially and temporally. These studies indicate that there is little variability within a given manure source on farm (~10 to 15%) and therefore obtaining a representative sample should be quite easy. However the variability between farms can be very large which makes using book values an unreliable way to determine the amount of nutrients applied to any given field.

Thanks,

April

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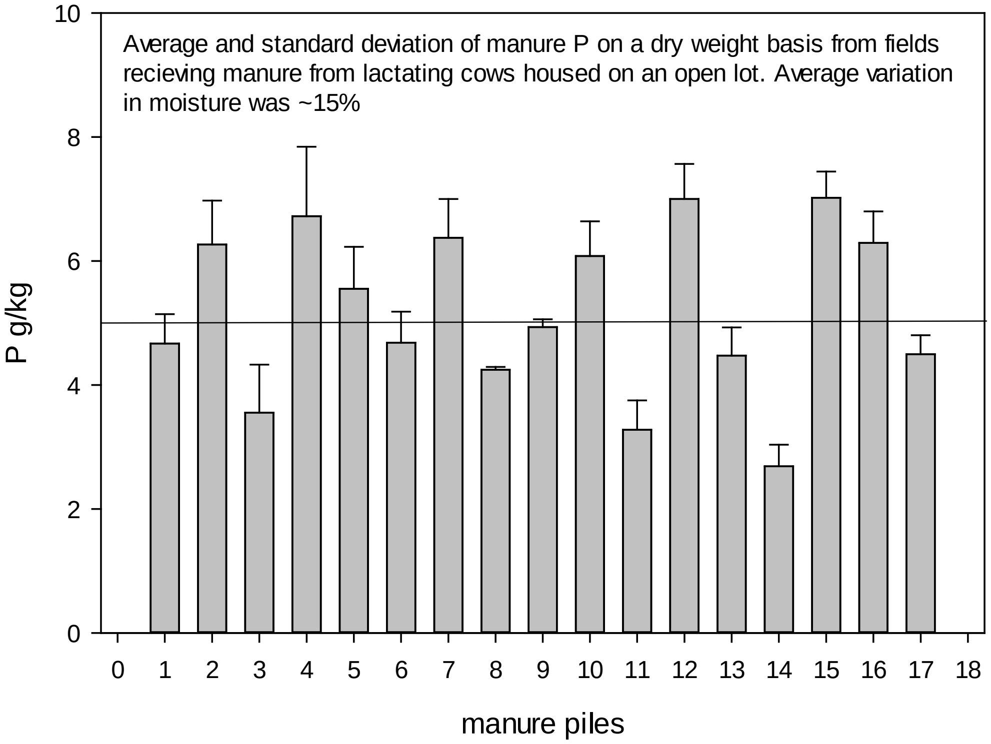
Manure Variability from Solid Stacked Manure

April Leytem, USDA-ARS, NWISRL, Kimberly, ID

We have been using solid stacked manure in our long-term field studies since 2012. The first three years we obtained manure from a local dairy. The following years manure was hauled in by Magic Valley Compost. We asked that they bring us manure from lactating cows on an open lot. In some years you could see obvious variations in the manure with some being a lot more fresh than other parts of the pile. In some years there was a lot of bedding as well. When manure is applied we set out trays in each plot to capture a subsample of manure from each plot as we have assumed that there will be some variability in the manure nutrient content. We have as many as 48 plots in some studies, so 48 subsamples of manure. The manure is then dried and analyzed to determine moisture and nutrient content.

Below is a figure that shows the average and standard deviation of all the samples that were collected from each field study over the last 7 years. I also included a line that represents the book value for manure from lactating cows on an open lot (ASABE March 2005). The data below is on a dry matter basis. The manure moisture has been close to 50% each year, however that could vary by dairy which would add more variability in the year to year nutrient content if measured on a wet basis. Within a given pile, the moisture content varied by ~ 15%.



As indicated in the figure, the variation within a given manure source tends to be relatively small. In most years it was ~10% there were a couple of years where it was closer to 20%. However, the annual variation is quite large with values from ~2.6 to 7 g P/kg of manure (280% difference). In only 5 out of 17 instances did the manure P value come close to the book value. In other years the values were either quite a bit over or under the book value. The first three values are from the same farm, even on this farm the manure P content was very different depending on the year.

This data indicates that it is likely that producers would be able to obtain better manure P values by testing their manure vs. using book values. The variation within a given manure source is likely to be much lower than the annual variability or the variability between farms or between manure sources (lactating, dry-cow, heifer). Therefore, obtaining a representative sample of each manure source on the farm should be fairly easy.

In another study (attached), we looked at the variation of nutrients within six lagoons over the course of a year. We grid sampled at two depths (just below surface and just above sludge layer). There was no statistically significant effect of location or depth on P content of the lagoon water. However, in some lagoons there was a difference in lagoon characteristics over time with higher concentrations in the summer. There was up to ~320% difference in P content between lagoons sampled at any given time. As with the solid manure sources, it should be fairly easy to obtain a representative sample of lagoon water if taken close to the time of application.

I looked at several manure testing labs for pricing on analysis for P which is typically included in the basic price. Sample analysis ranged from $32 to $85, with the majority below $40. The average farm might have up to 5 different manure sources which would be approximately $200/year in manure testing, plus the cost for having someone collect the samples if not done by the producer. Many farms will not have as many manure sources therefore costs would be lower than this.

SPATIAL AND TEMPORAL VARIATION IN PHYSICOCHEMICAL PROPERTIES OF DAIRY LAGOONS IN SOUTH-CENTRAL IDAHO

A. B. Leytem, R. S. Dungan, D. L. Bjorneberg

ABSTRACT. *Large quantities of wastewater are generated on dairies in south-central Idaho, which can be a source of valuable nutrients as well as contribute to air quality and climate change issues via ammonia (NH_3) and greenhouse gas (GHG) emissions. The objective of this study was to examine the range of lagoon water properties among dairies in the region and to determine how they varied spatially and temporally. Twenty-seven lagoons were sampled twice in a nutrient survey to determine physicochemical characteristics, while six lagoons were sampled (3 to 27 times) over a longer period to determine how these characteristics changed with space and time. Lagoon properties measured consisted of total solids (TS), volatile solids (VS), chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), total ammoniacal nitrogen (TAN), total phosphorus (P), total potassium (K), temperature, pH, dissolved oxygen (DO), and specific conductivity. Results indicate that all lagoon characteristics varied greatly between dairies and with sampling date. Seasonal trends indicated that N decreased from spring to fall, while specific conductivity, total P, total K, and in some instances TS and VS increased over the same period. There was an effect of housing type on these properties, with freestall dairies having higher concentrations of TS, VS, COD, TKN, TAN, and specific conductivity than dry-lot dairies. There was little effect of dairy size on the physicochemical characteristics measured. These results suggest that it is important to account for the nutrients applied with lagoon water in nutrient budgets in order to prevent over-application of N and K, which could lead to N leaching and forage quality issues. In addition, capturing the temporal variation in lagoon properties is important to accurately model seasonal variations in NH_3 and GHG emissions.*

Keywords. *Dairy, Lagoon, Nutrients, Solids.*

In Idaho, the dairy cattle population has doubled since the late 1990s (NASS, 2015), with approximately 70% of the state's 579,000 dairy cattle located in south-central Idaho. Large quantities of water are used on dairies for sanitation, including washing the milking parlor and, depending on manure management, flushing the alleyways within the housing area. The amount of water used varies by farm and even over time on any given farm due to the management practices. Meyer et al. (2006) found that the wastewater generated on 16 dairies in California ranged from 320 to 960 L cow^{-1} d^{-1} from 1 December to 30 March, with an average of 520 L cow^{-1} d^{-1}. Bjorneberg and King (2014) estimated an average wastewater volume of 130 L cow^{-1} d^{-1} on dairies in southern Idaho, which varied between housing types, with a freestall dairy generating 2.3 times more than a dry-lot dairy. In western semi-arid to arid dairy production regions, wastewater is generally stored for up to six months and is either pumped out of the lagoon twice a year onto cropland or is used to irrigate crops throughout the growing season. Currently, producers do not typically account for the nutrients applied with lagoon water (personal communication with multiple producers). This lack of accounting for nutrients in the lagoon water could lead to over-application of nutrients on cropland, particularly when continually applied to the same field, and could potentially have negative impacts on groundwater quality (Phillips, 2002; Stone et al., 1998). There is also a potential concern for crop productivity and quality related to salt accumulation on fields where lagoon water is continually applied over time (Segal et al., 2010; Shapiro et al., 2005). The amount of nitrogen (N) and solids (particularly volatile solids, VS) within a lagoon can also influence the amount of ammonia (NH_3) and methane (CH_4) emissions generated from the lagoon, which is a concern from an air quality and climate change perspective (IPCC, 2007; Huang et al., 2010; Montes et al., 2009; Fangueiro et al., 2008; Ni, 1999). The spatial variability and seasonal dynamics of these lagoon characteristics are important for understanding the potential variation in emissions.

Few published studies have looked at the variation of dairy lagoon characteristics and in particular the variability of these characteristics over space and time. Table 1 provides a summary of studies from the U.S., Ireland, New Zealand, England, and Wales that have examined the composition of wastewater generated on dairies (Hickey et al., 1989; Cumby et al., 1999, Singh et al., 2007; Martinez-Suller et al., 2010; Minogue et al., 2015). Total N, phosphorus (P), and potas-

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Table 1. Summary of average dairy wastewater characteristics reported in the literature.

TN (mg L^{-1})	NH_4-N (mg L^{-1})	TK (mg L^{-1})	TP (mg L^{-1})	COD (mg L^{-1})	TS (mg L^{-1})	pH	Location	No. of Farms	Source
	82	-	26	-	-	7.8	New Zealand	11	Hickey et al., 1989
95	117	243	21	522	1,570	7.9	U.S.	2	Sweeten and Wolfe, 1994[a]
282	267	398	55	5,467	5,068	7.7	U.S.	1	Sweeten and Wolfe, 1994[b]
825	457	1,175	-	13,383	10,800	-	England and Wales	20	Cumby et al., 1999
479	-	-	111	12,312	10,775	7.4	U.S.	8	Singh et al., 2007
351	32	415	44	-	-	6.6	Ireland	1	Martinez-Suller et al., 2010
587	212	568	80	-	-	-	Ireland	60	Minogue et al., 2015

[a] Secondary lagoons from dry-lot dairies receiving mainly parlor washwater.

[b] Secondary lagoons from dry-lot dairies receiving parlor washwater and manure from feed alleyways.

sium (K) ranged from 95 to 825 mg L^{-1}, from 21 to 111 mg L^{-1}, and from 243 to 1,175 mg L^{-1}, respectively, suggesting that dairy wastewater could provide valuable nutrients for crop production. Minogue et al. (2015) estimated that, for a typical Irish dairy, wastewater could provide 13, 2, and 12 kg ha^{-1} of total N, P, and K, respectively, replacing some of the synthetic fertilizer needs. However, this N can also be lost as NH_3 via volatilization from the manure storage areas as well as when applied to crop land (Montes et al., 2009). Martinez-Suller et al. (2010) reported that the nutrient content of dairy wastewater in storage varied over time and could be estimated using either the dry matter content or specific gravity of the liquid, which could assist producers in nutrient management planning. The total solids (TS) and chemical oxygen demand (COD) ranged from 1,570 to 10,800 mg L^{-1} and from 522 to 13,383 mg L^{-1}, respectively, while pH ranged from 6.6 to 7.9. These physical and chemical characteristics of the wastewater suggest potential for CH_4 emissions from stored liquid manure (Rico et al., 2012) and indicate that the variability of these characteristics by lagoon may be of interest to those attempting to model emissions or calculate emission inventories.

Because the physicochemical properties of dairy lagoons are a concern for nutrient management, air quality, and potentially climate change, it is important to understand the variation of these properties among lagoons and understand how they change seasonally to better determine sampling times for nutrient management as well as the dynamics that may affect modeling efforts aimed at estimating emissions from these sources. Therefore, the goal of this study was to evaluate the characteristics of dairy lagoons on farms located in south-central Idaho and to examine both the spatial and temporal variation of these characteristics at some selected sites.

Materials and Methods

Dairy Lagoon Nutrient Survey

A total of 27 dairies in south-central Idaho were targeted for a study to characterize the physicochemical properties of their lagoons (table 2). These dairies had either dry-lot or freestall housing and were assigned to one of four different size classes (<1,000, 1,000 to 5,000, 5,000 to 10,000, and 10,000+ lactating cows). There were three main manure handling strategies on these farms:

Scrape systems: Manure was scraped and stacked in the lots (dry-lot dairies), while the washwater from the milking parlor flowed to the lagoon system.

Table 2. Characteristics of the 27 dairies in the nutrient survey study located in south-central Idaho.

Dairy Type	Manure Handling System	No. of Lactating Cows	No. of Dairies
Dry-lot	Scrape	<1,000	2
	Scrape	1,000 to 5,000	10
	Scrape	5,000 to 10,000	3
	Vacuum	10,000+	2
	Flush	5,000 to 10,000	1
Freestall	Scrape	1,000 to 5,000	1
	Flush	1,000 to 5,000	2
	Flush	5,000 to 10,000	1
	Flush	10,000+	3
	Vacuum	1,000 to 5,000	1
	Vacuum	5,000 to 10,000	1

Vacuum systems: Manure was vacuumed from alleyways (dry-lot or freestall dairies) and placed into a pit (concrete or earthen) for separation. The liquid from this pit flowed into a lagoon system, while the solids were either dried and re-used as bedding or composted. In these systems, washwater from the milking parlor flowed to the lagoon system.

Flush systems: Manure was flushed from alleyways (dry-lot or freestall dairies) and pumped though a mechanical solid separator and then into a series of lagoons. In these systems, washwater from the milking parlor flowed to the lagoon system.

Surface samples were obtained from the lagoons during August and October of 2011. Eight 500 mL samples were collected from the perimeter of each pond and then composited in a sterile 4 L container. The composited samples were transferred to the laboratory in coolers and stored under refrigeration at 5°C until analysis. Upon arrival at the laboratory, the specific conductivity and pH were measured with a YSI 556 Multiprobe System (YSI Inc., Yellow Springs, Ohio), and a 125 mL subsample was taken and mixed with 1 mL of concentrated sulfuric acid to stabilize the sample for total Kjeldahl nitrogen (TKN) and COD analysis. Samples were analyzed for total ammoniacal N (TAN) within 24 h of collection and for TKN, TS, VS, and COD with 36 h.

Seasonal Study

Over the period from September 2010 to September 2015, six dairy lagoons were selected for characterization of the physicochemical properties typically related to emissions of NH_3 and CH_4 as well as total nutrient and salinity content. The six dairies ranged in size from less than 1,000 to 10,000 cows, with five dry-lot dairies and one freestall operation (table 3). The dairy manure handling systems varied by farm and are described below and in table 3.

Table 3. Descriptions of dairies used in long-term seasonal lagoon monitoring study.

Dairy	Housing	No. of Lactating Cows	Lagoon Water Source	Lagoon Surface Area (m^2)	Lagoon Depth (m)	No. of Sampling Points	Sampling Dates	No. of Days Sampled
D1	Dry-lot	1,000 to 5,000	Parlor washwater	26,628	2.4 to 2.7	9	10 Sept. to 11 June	3
D2	Dry-lot	5,000 to 10,000	Parlor washwater	47,398	1.5	10	10 Sept. to 11 June	4
D3	Dry-lot	1,000 to 5,000	Parlor washwater	19,621 to 23,237	1.2 to 1.9	9	12 to 13 May	14
D4	Freestall	5,000 to 10,000	Flush system from barn and parlor washwater	4,005 to 13,220	0.9 to 1.6	6	12 June to 13 May	10
D5	Dry-lot	1,000 to 5,000	Parlor washwater	1,300 to 3,373	0.3 to 1.3	4	13 July to Oct. 14	16
D6	Dry-lot	< 1,000	Parlor washwater and runoff	2,101	0.3 to 0.9	5	13 July to 15 Sept.	27

D1: Dry-lot dairy with manure from the lots scraped and stacked. Fresh water was used to wash down the milking parlor, and the washwater flowed into a series of three settling basins and then into the main lagoon. The water from the main lagoon was pumped out in the spring and fall onto the surrounding cropland, while sludge was cleaned out of the lagoon on an infrequent basis. The main lagoon was sampled in this study.

D2: Dry-lot dairy with manure from the lots scraped and stacked. Fresh water was used to wash down the milking parlor, and the washwater flowed into a series of four settling basins and then into the main lagoon. The water from the main lagoon was pumped out in the spring and fall onto the surrounding cropland, while sludge was cleaned out of the lagoon on an infrequent basis. The main lagoon was sampled in this study.

D3: Dry-lot dairy that was recently converted to a heifer operation. However, during the study period, there were times when there were lactating animals on the farm. Manure from the lots was scraped and stacked, while fresh water was used to wash down the milking parlor. The washwater flowed into a series of five settling basins and then into the main lagoon. The water from the main lagoon was pumped out in the spring and fall onto the surrounding cropland, while sludge was cleaned out of the lagoon on an infrequent basis. The main lagoon was sampled in this study.

D4: Freestall dairy that used a flush system to remove manure from the alleyways in the barns. The flush water went through a screen separator and was then pumped into a series of three settling basins, after which the liquid flowed by gravity into three main lagoons. Some of the water from the main lagoons was re-used to flush the barns. Fresh water was used to wash down the milking parlor, and the washwater was then pumped into the lagoon system. The water from the main lagoons was pumped out to a satellite lagoon on a regular basis (during the irrigation season) and used as irrigation water on the surrounding cropland. The sludge from the satellite lagoon was pumped out infrequently. The satellite lagoon was monitored in this study.

D5: Dry-lot dairy with manure from the lots scraped and stacked. Fresh water was used to wash down the milking parlor, and the washwater flowed into a concrete settling cell and then into three lagoons. Water from the third lagoon was pumped out in the spring and fall onto the surrounding cropland, and this lagoon was monitored during the study.

D6: Dry-lot dairy with manure from the lots scraped and stacked. Fresh water was used to wash down the milking parlor, and the washwater flowed into a settling basin and then into the main lagoon. On this farm, the dry-lots were upslope of the lagoon, and runoff from these lots during the spring was captured in the lagoon. The water from the main lagoon was pumped out in the spring and fall onto the surrounding cropland, while sludge was cleaned out of the lagoon on an infrequent basis. The main lagoon was sampled in this study.

The lagoons were sampled (500 mL) on a grid with the number of sampling points (4 to 10) related to the size of the lagoon and distributed as evenly as possible across the lagoon surface. Lagoon depth was determined with a sampling rod that was marked for depth. The rod was allowed to sit on top of the sludge layer of the lagoon to determine the depth of the water column. This rod was connected to a container with a retractable lid to collect samples at specific depths. When lagoons were deeper than 1 m (D1 to D4), samples were collected from the surface (0.15 m below surface) and 0.3 m above the top of the bottom sludge layer at each sampling location; otherwise, only surface samples were collected. Initially (lagoons D1 and D2), all of the samples were composited by depth in the field. Later (lagoons D3 to D6) samples were collected for each individual location and depth to characterize the effect of sampling location on lagoon characteristics. Immediately after collection, a 125 mL subsample was taken and mixed with 1 mL of concentrated sulfuric acid to stabilize the sample for TKN and COD analysis. All samples were transferred to the laboratory in coolers, stored under refrigeration at 5°C, and processed within 24 h for TAN and within 36 h for all other analyses. In addition to collecting samples for analysis, the temperature, pH, DO, and specific conductivity were determined *in situ* with a YSI 556 Multiprobe System (YSI Inc., Yellow Springs, Ohio) at each sampling location and depth. These measurements were typically made in late morning or early afternoon.

LAGOON WATER ANALYSIS

All collected samples were allowed to come to room temperature and thoroughly mixed prior to subsampling and analysis. Analysis was as follows: TAN, TS, and VS were performed according to Standard Methods 4500-NH_3, 2540B, and 2540E, respectively (Eaton et al., 2005). Total Kjeldahl N and COD were performed using U.S. EPA Methods 351.2 and 410.4, respectively (USEPA, 1993). Total P and K were determined on the TKN digested samples via inductively coupled plasma optical emission spectroscopy (ICP-OES; Optima 4300 DV, Perkin Elmer, Wellesley, Mass.).

STATISTICAL ANALYSIS

All statistical analysis was performed using SAS (ver.

9.3, SAS Institute, Inc., Cary, N.C.). All data were tested for normality prior to analysis; data that were not normally distributed were log-transformed prior to statistical analysis, with the untransformed numbers shown in the tables and text. The data from the seasonal study were analyzed using analysis of variance (ANOVA) to test for the main effect of sampling date by dairy. The effects of strata and sampling location were then tested using a MIXED model for each dairy with sampling date as a repeated measure. The seasonal data were then averaged (across locations and depths) to generate an average value for each lagoon at each sampling date, combined with the nutrient survey study data, and then analyzed using a Pearson correlation to determine relationships between lagoon characteristics. An average value was then calculated for each lagoon, and these combined data were then grouped together by housing type (dry-lot or freestall) and farm size (<1,000, 1,000 to 5,000, 5,000 to 10,000, or 10,000+) and analyzed using ANOVA to evaluate the main effects and interactions of housing type and farm size on physicochemical characteristics. Data were also grouped by manure handling practice (flush, vacuum, or scrape) to determine the main effects of manure handling on physicochemical characteristics. In both cases, means separation was performed with Duncan's multiple range test. Lagoons with similar manure handling practices (scraping) were grouped and identified as either having or not having the presence of purple sulfur bacteria (PSB) and analyzed using one-way ANOVA to determine the relationship of PSB to physicochemical properties. Means separation was performed with Duncan's multiple range test. Analyses were considered to be significant in all instances at $p < 0.05$.

RESULTS AND DISCUSSION

EFFECTS OF HOUSING, FARM SIZE, AND MANURE HANDLING ON MANURE PROPERTIES

There was a significant main effect of housing type on TAN, TKN, COD, TS, VS and specific conductivity ($p < 0.0001$), while farm size was only significant for specific conductivity ($p = 0.01$), and the interaction of housing and farm size was not significant for any of the variables. The dry-lot dairies had 65% and 68% less TAN and TKN, respectively, than the freestall dairies (table 4), while TS, VS, and COD were 66%, 68%, and 65% lower, respectively, on the dry-lot dairies versus the freestall dairies. These differences would be expected, as all but one of the freestall dairies used either vacuum or flushing to handle the manure in the housing area and therefore would have a much higher manure loading rate in the lagoons. Specific conductivity was 53% lower on the dry-lot versus freestall dairies and less on the dairies with 1,000 to 5,000 cows than the other size classes. While we would expect the specific conductivity to be higher in the lagoons with higher solids loading rates, there was no indication why dairies in the one size class differed from the others. Singh et al. (2007) found an effect of farm size on COD, TKN, and total P, with TKN and total P being higher on large farms, followed by mid-size and small farms. Because Singh et al. (2007) provided no information related to housing and manure management, it is not possible to discern why these differences occurred.

The average TAN (233 mg L^{-1}) and TKN (439 mg L^{-1}) measured at lagoons on dry-lot dairies fell within the ranges reported in the literature (32 to 457 mg L^{-1} and 95 to 825 mg L^{-1}, respectively; table 1). The same was seen for TS (8,824 mg L^{-1}), COD (7,010 mg L^{-1}), and pH (7.8), where average literature values ranged from 1,570 to 10,800 mg TS L^{-1}, from 522 to 13,383 mg COD L^{-1}, and pH from 6.6 to 7.9. The concentrations of TAN (719 mg L^{-1}), TKN (1,241 mg L^{-1}), TS (25,781 mg L^{-1}), and COD (20,076 mg L^{-1}) measured at the freestall dairies in this study were higher than the reported literature values. This trend is likely due to the fact that the published literature reports wastewater coming either from milking parlors or a dry-lot dairy that flushed the alleyways, where solids loading into the lagoons would be expected to be less than at dairies that manage the majority of manure in a lagoon system.

There was a significant main effect of manure handling on lagoon physicochemical properties (table 5). Measured TAN, TKN, and COD were greater at dairies that used a vacuum or flush system (which were not significantly different) than at dairies that used a scrape system. Lagoon TS and VS were higher at dairies that used vacuum than scrape systems,

Table 4. Physicochemical characteristics of lagoons by dairy housing type (dry-lot or freestall).

	Dry-Lot				Freestall			
Variable	Mean[a]	Min.	Max.	SD	Mean[a]	Min.	Max.	SD
TAN (mg L^{-1})	233 b	48	661	166	719 a	186	1,511	347
TKN (mg L^{-1})	439 b	74	1,057	283	1,241 a	734	2,283	460
Specific conductivity (mS cm^{-1})	7.0 b	1.9	16.4	3.5	14.9 a	10.3	22.1	3.3
TS (mg L^{-1})	8,824 b	1,812	23,486	5,984	25,781 a	11,850	52,773	11,254
VS (mg L^{-1})	4,227 b	476	12,335	3,226	13,299 a	6,150	30,348	6,796
COD (mg L^{-1})	7,010 b	549	24,459	6,028	20,076 a	11,067	34,087	7,693
pH	7.8 a	7.1	8.4	0.4	7.7 a	6.8	8.3	0.4

[a] Means followed by the same letter within each row are not significantly different at $p < 0.05$

Table 5. Physicochemical characteristics of lagoons by manure handling system (flush, vacuum, or scrape). Values are means ± standard deviations. Means followed by the same letter within each row are not significantly different at $p < 0.05$.

Parameter	Flush	Vacuum	Scrape
TAN (mg L^{-1})	637 ±188 a	723 ±580 a	218 ±163 b
TKN (mg L^{-1})	1,079 ±345 a	1,168 ±840 a	439 ±296 b
COD (mg L^{-1})	17,221 ±8,145 a	16,442 ±12,230 a	7,545 ±6,820 b
TS (mg L^{-1})	20,214 ±8,541 ab	23,930 ±21,057 a	9,683 ±7,058 b
VS (mg L^{-1})	10,158 ±4,378 ab	13,347 ±12,207 a	4,550 ±3,675 b
Specific conductivity (mS cm^{-1})	13.2 ±3.5 a	12.1 ±8.0 ab	7.4 ±3.9 b
pH	7.8 ±0.2 a	7.2 ±0.3 b	7.8 ±0.4 a

while dairies that used flush systems did not differ from either of the other two manure handling practices. The lagoon specific conductivity was greater at dairies using flush versus scrape systems, with vacuum systems being similar to the other two. The pH values of the lagoons that used flush and scrape systems were similar and significantly higher than at the dairies with vacuum systems. These trends would be expected as scrape systems are mainly employed at dry-lot dairies, which would have less total manure going into the lagoon system. We were unable to identify studies in the literature that specifically examined the effects of manure handling systems on lagoon physicochemical characteristics. Sweeten and Wolfe (1994) evaluated three dairy lagoon systems: two contained mainly parlor washwater, and the third lagoon also contained manure that was flushed or scraped from feed alleyways. The lagoons that did not contain additional manure from the housing area had 66%, 39%, and 62% less total N, K, and P, respectively, than the lagoon that received alleyway manure. The researchers also noted 90% and 53% reductions in COD and TS, respectively, in the lagoons that did not contain alleyway manure.

SEASONAL TRENDS IN PHYSICOCHEMICAL CHARACTERISTICS OF LAGOONS

Lagoon characteristics varied widely among dairies in the nutrient survey. However, there was no significant effect of sampling date (August or October) on these characteristics. While these characteristics did not vary with sampling date, the sampling times were fairly close (within three months), which may not have been a long enough period to see changes in the lagoons. In the seasonal study, date had a significant effect ($p < 0.0005$) on all physicochemical properties of lagoons D3 to D6 except for COD ($p = 0.10$) and TKN ($p = 0.92$) at D5. At D1 and D2, there was no significant effect of date on lagoon properties except for temperature, specific conductivity, and pH ($p < 0.0001$). The samples collected at both D1 and D2 covered a much shorter period than the other lagoons, which likely reduced the variation seen over these sampling times. Minogue et al. (2015) reported a significant effect of sampling date with all biochemical parameters measured on parlor washwater in Ireland; however, no clear seasonal trends were observed. The authors suggested that seasonal trends may have been masked due to the high number of dairies sampled in the study with a large range in management practices, as well as the effects of rainwater input.

In the seasonal study, there was no significant effect of sample location or strata for any characteristics at any of the lagoons. Therefore, means were calculated across locations and depths for each sampling date. The means and standard deviations of TAN and TKN were 190 ±172 mg L^{-1} and 353 ±196 mg L^{-1}, respectively. The mean and standard deviation of total K in the lagoons was 1,232 ±586 mg L^{-1}, while total P was 47 ±15 mg L^{-1}. The means and standard deviations of TS, VS, and COD were 8,465 ±3,302 mg L^{-1}, 3,691 ±1,475 mg L^{-1}, and 5,348 ±2,964, respectively. The specific conductivity ranged from 3.5 to 14.5 mS cm^{-1}, while the pH ranged from 7.1 to 9.0. The mean lagoon temperature was 15.4°C and ranged from 0.8°C to 21.2°C. The average TKN:P, TAN:P, and K:P ratios were 7.3, 4.0, and 26, respectively. These lagoon physicochemical characteristics fall in the range of those reported in the literature. As all but one of these lagoons was located at a dry-lot dairy, we would expect their loading rates to be somewhat similar to the studies listed in table 1.

Figures 1 and 2 present select physicochemical properties for lagoons D3 to D6 over time, with time represented as Julian day in order to more easily present the data from multiple years. Because D1 and D2 had a much shorter sampling interval, they were left out of the figures for simplicity. The data points were first averaged by depth (where relevant) and then averaged across locations within each lagoon, with the mean and standard deviation shown in the figures to indicate the spatial variability of the lagoon characteristics (i.e., the size of the error bar represents the deviation from the mean of sampling location).

The temperature profiles of the lagoons over time were similar, even though samples were taken over multiple years (fig. 1a). Temperatures peaked at approximately 20°C near day 200 (mid-July), with the lowest temperature measured in December (0.8°C, D3). The variation with sampling location was minimal at most dairies over time, with D5 showing the largest variation in temperature in late October when the lagoon had been pumped out. The lagoon was very shallow at this time, and therefore there was a much larger variation in temperature, likely due to different water depths across locations. The pH of the lagoons tended to be lowest in late winter and early spring (February to March) and in most cases increased by the end of October when most lagoons would be pumped out prior to winter (fig. 1b). The largest increases in pH appeared to be from late summer (August) to fall (late October), except for D6, which also showed a large increase from winter (February) to spring (April). Singh et al. (2007) also reported seasonal variation in pH in wastewater on dairy farms in Kentucky, while Lovahn et al. (2009) reported an increase in pH from early winter/spring until fall in a swine lagoon. Changes in lagoon water pH can vary with the emissions of both NH_3 and CO_2. The formation of NH_3 in solution generates H^+ and reduces the pH, and the formation of CO_2 (utilization of H^+) in solution increases pH (Ni, 1999; Chaoui et al., 2009). It has been demonstrated on dairies in southern Idaho that emissions of both NH_3 and CO_2 occur from lagoons and typically increase from spring to fall following increases in temperature (Bjorneberg et al., 2009, Leytem et al., 2011, 2013). As the amount of CO_2 generated from lagoons is much greater than the amount of NH_3 (Leytem et al., 2011), the pH of the lagoon water would likely increase as these emissions increased, which was demonstrated in the lagoons in the present study. The specific conductivity tended to increase over time, with D5 and D6 showing the strongest trends (fig. 1c). Total K also increased similarly (data not shown). As these two lagoons were shallow, they likely experienced evaporation over the summer; therefore, this concentration in salt content would be expected. The large separation between sample points on D5 was due to annual differences, with the samples ranging from ~10 to 14 mS cm^{-1} collected in 2013, while the lower concentration samples were collected in 2014. We are unsure why this change occurred, as many different factors can

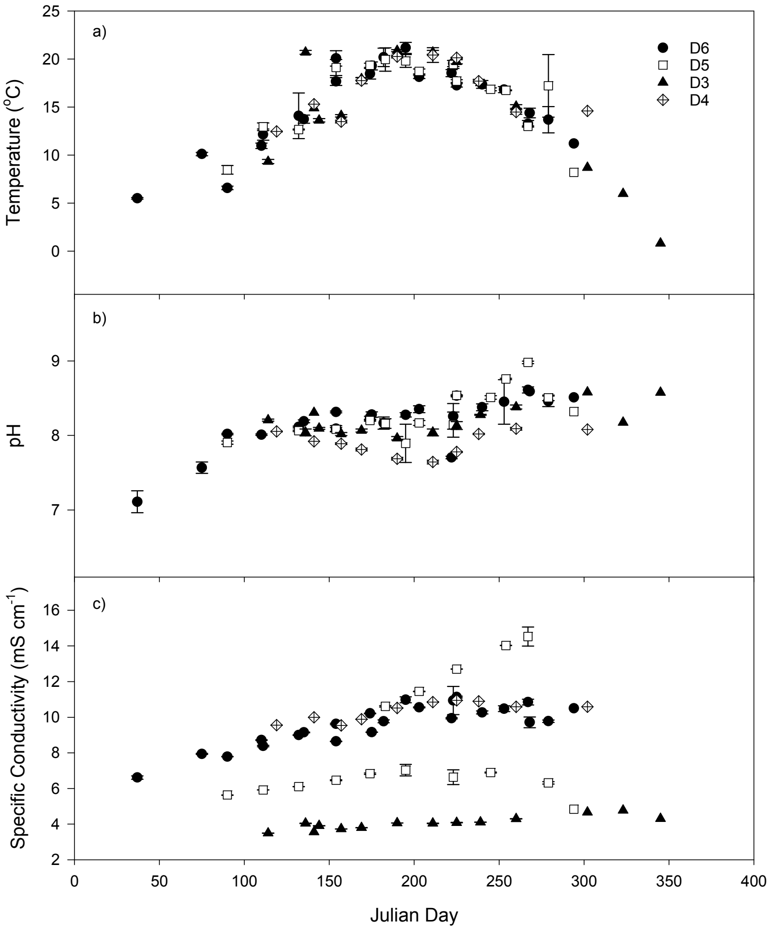

Figure 1. Seasonal variability of (a) temperature, (b) pH, and (c) specific conductivity in lagoons D3 to D6. Data were averaged by depth and then by location, with error bars representing the standard deviation across location to provide an indication of spatial variability.

affect the salinity of a lagoon, such as cleaning products, feed formulation, manure management practices, and the amount of washwater used, as well as weather effects, such as differences in evaporation.

The TS concentrations tended to increase from early spring to fall at the lagoons and then decrease following pumping of the lagoons (late fall; fig. 2a). At D5, there was a large variation in TS content with sampling location at the end of the season when the lagoon had been recently pumped. This variability was likely due to the shallow depths and turbulence generated during pumping. There was very little change in TS at D3. This lagoon was unique in that it did not consistently receive new water in the pond for most of the summer as the herd was changed from a lactating operation (the previous year) to a heifer operation (although there were times when lactating cows were present). Thus, there was very little effect of time on many of the lagoon characteristics. Hickey et al. (1989) reported that only suspended solids changed significantly with season (winter vs. summer) within one of the two regions studied in New Zealand, with no seasonal effects on other pond characteristics, whereas Singh et al. (2007) reported seasonal variation in TS on dairy farms in Kentucky. The VS showed little trend with time except at two lagoons (data not shown) where there was a slight increase in VS from spring to late fall (D5 and D6) but few discernable trends at the other lagoons. The COD of the lagoons showed the most spatial variability of all the physicochemical properties measured, particularly on D5 following pumping of the lagoon (data not shown). Although there was a significant effect of time on COD concentration, there did not seem to be a discernable trend with time in the data.

TAN varied with time in all lagoons, with higher concentrations in the spring, decreasing through the summer with the minimum values in early September, and then in most cases increasing again after the ponds were pumped out in the fall (fig. 2b). The TKN values did not show as much variation over time, with slight decreases toward the end of summer (data not shown). Total P concentrations increased steadily over summer in most lagoons (fig. 2c), particularly in the two shallow lagoons (D5 and D6). These same seasonal trends in N, P, and K have been seen in other studies. DeRouchery et al. (2002) found increases of both total P and K and decreases in total N in Kansas swine lagoons from early spring through fall. They attributed the decrease in N to increased microbial activity during the warmer season with conversion of total N into NH_3 and loss by volatilization. Westerman et al. (2010) also showed decreasing N concentrations in swine lagoons from spring to fall in North Carolina. McLaughlin et al. (2012) reported increases of total P and decreases of total N concentrations in swine lagoons in Mississippi from early spring to fall. They reported a dec-

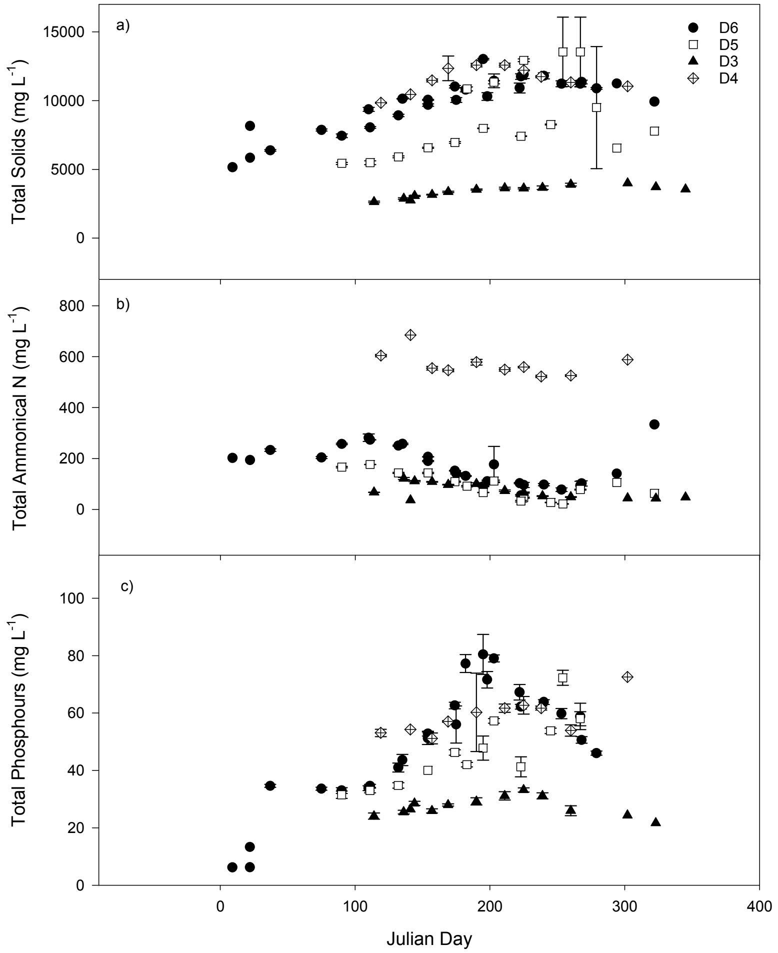

Figure 2. Seasonal variability of (a) total solids, (b) total ammoniacal nitrogen, and (c) total phosphorus in lagoons D3 to D6. Data were averaged by depth and then by location, with error bars representing the standard deviation across location to provide an indication of spatial variability.

rease in the N:P ratio in lagoon water from spring to fall of 71%, while in the present study the TKN:P ratios decreased by 26% to 65%. More pronounced, in the present study, was the decrease in TAN:P by 63% to 90% from spring to fall on the dry-lots and by 30% on the freestall dairy.

Correlation of Physicochemical Characteristics of Manure

Pearson correlation analysis was performed on the averaged combined data from the nutrient survey and seasonal study to determine relationships between variables (table 6). The greatest correlations were between TS and VS (r = 0.97), TAN and TKN (r = 0.94), and TKN and VS (r = 0.92). Lagoon pH was not highly correlated with any of the other characteristics (r < 0.5). Overall, TS had the highest correlation with other parameters (excluding pH), ranging from r = 0.73 to 0.97. Mukhtar et al. (2004) also reported strong linear correlations between TS and TKN, total P, and total K (r^2 = 0.27 to 0.62) for 12 dairy lagoons in Texas, while Hickey et al. (1989) reported strong relationships between total P and suspended solids (r = 0.83) in dairy oxidation ponds in New Zealand. Hickey et al. (1989) also found strong relationships between conductivity and total P (r = 0.90) and suspended solids (r = 0.82). The correlation of specific conductivity with total P and TS content in the present study was slightly less at r = 0.79 and 0.80, respectively. Because the TS content of the lagoons in the present study had strong relationships with many other characteristics, it could provide a simple index for other constituents, such as VS, COD, TKN, TAN, total K, and total P. Martinez-Suller et al. (2010) suggested that the nutrient content of Irish dairy wastewater could be determined rapidly using either dry matter concen-

Table 6. Pearson correlation coefficients between lagoon characteristics for all samples (nutrient survey and seasonal study combined).

	TAN	COD	TS	VS	SpCon	pH	TKN	K	P
TAN	1	-	-	-	-	-	-	-	-
COD	**0.73**	1	-	-	-	-	-	-	-
TS	**0.73**	**0.82**	1	-	-	-	-	-	-
VS	**0.80**	**0.83**	**0.97**	1	-	-	-	-	-
SpCon	**0.56**	**0.61**	**0.80**	**0.69**	1	-	-	-	-
pH	**-0.50**	**-0.35**	**-0.20**	**-0.33**	0.08	1	-	-	-
TKN	**0.94**	**0.83**	**0.88**	**0.92**	**0.65**	**-0.42**	1	-	-
K	0.18	**0.51**	**0.80**	**0.61**	**0.82**	**0.21**	**0.45**	1	-
P	**0.46**	**0.67**	**0.82**	**0.73**	**0.79**	-0.02	**0.67**	**0.72**	1

tration or specific gravity, which would enable farmers to use the information in their nutrient management plans.

MANURE PHYSICOCHEMICAL CHARACTERISTICS IN RELATION TO THE PRESENCE OF PSB

Of the 33 dairies monitored, 12 had lagoon water with distinct pink coloring, indicating the presence of PSB. All of these lagoons were on farms that used scraping for manure management and therefore would have a lower solids load into the lagoon than dairies that use flush or vacuum systems. All but one of these dairies was a dry-lot dairy. Chen et al. (2003) reported that swine lagoons with PSB had lower concentrations of NH_3, pH, COD, alkalinity, and electrical conductivity. In the present study, we found a main effect of PSB (within those dairies that used scraping) on TAN, TKN, and COD. Dairies with PSB had 70% less TAN (152 vs. 511 mg L^{-1}), 65% less TKN (314 vs. 893 mg L^{-1}), and 65% less COD (5,033 vs. 14,362 mg L^{-1}) than dairies without PSB. This could indicate that either PSB are using N and COD in the lagoons, and therefore decreasing these concentrations, or they are more prolific at lower nutrient and COD concentrations. Additional research would be needed to determine the actual causal relationships. Previous work on dairies in southern Idaho found the presence of PSB in both purple and non-purple lagoons. However, PSB only proliferated in certain ponds (Dungan and Leytem, 2015). In that particular study, the pigment concentrations (used as an indirect measure of PSB) were positively correlated with salinity, N, TS, VS, and COD.

USE OF LAGOON NUTRIENTS IN CROP PRODUCTION

It is evident from the data that lagoon water can contain significant quantities of plant nutrients and can therefore be a valuable source of nutrients for plant growth when land-applied. Using an average of 130 L cow^{-1} d^{-1} of lagoon water generated by a typical dairy in south-central Idaho (Bjorneberg and King, 2014), the ranges of total N, P, and K applied with lagoon water each year would be 4 to 108 kg cow^{-1}, 1 to 3 kg cow^{-1}, and 24 to 81 kg cow^{-1}, respectively. Using the value of 520 L cow^{-1} d^{-1} estimated for California dairies, there could be as much as 433, 13, and 325 kg of N, P, and K generated per cow each year. This does not account for losses of N due to ammonia volatilization during land application of the wastewater, which can be substantial. Dairy lagoon water in Idaho is typically applied to silage corn or alfalfa crops. An average silage corn crop may remove an average of 229 kg N ha^{-1}, 56 kg P ha^{-1}, and 200 kg K ha^{-1}, and an alfalfa crop may remove 228 kg N ha^{-1}, 22 kg P ha^{-1}, and 200 kg K ha^{-1} (estimates based on field data from the region). The nutrients contained in lagoon water may provide a substantial amount of these crop nutrients and should be accounted for in nutrient management planning. For example, using wastewater alone would require 3.3 cows to supply the K requirements for 1 ha of corn (assuming an average of 60 kg K cow^{-1} $year^{-1}$), 6.2 cows to supply the N (assuming an average of 37 kg N cow^{-1} $year^{-1}$), and 22 cows to supply the P (assuming an average of 2.6 kg P cow^{-1} $year^{-1}$).

In Idaho, manure applications are typically based on P levels, as dairies are regulated by the state based on soil test P thresholds set in Idaho NRCS code 590 (NRCS, 2007). The N:P ratio needed for silage corn production in the region is close to 4. However, the average N:P ratio of lagoon water in the present study (only including the data for the six lagoons monitored seasonally) was 8 for TKN. Therefore, application of wastewater to meet P needs may over-apply N, resulting in potential leaching of excess N, which is a threat to groundwater quality in the region. Also of concern is that the K:P ratio needed for forage production is 3.6 to 9 and the K:N ratio is 0.9, while the average K:P ratio of lagoon water in the present study was 23 and the K:N ratio was 3.0. The continual application of this wastewater to the same field could lead to over-application of K and result in high-K forages that are a health concern for cattle, as excessive K in forage can lead to milk fever and grass tetany (Cherney et al., 2002; Tyler and Ensminger, 2006).

CONCLUSIONS

The results of the study suggest that lagoon water contains significant quantities of N, P, and K and, when applied to agricultural fields, can be a valuable source of nutrients with potential to replace some of the synthetic fertilizers used on farms. The large variation in the physicochemical properties of the lagoons indicated that sampling lagoons to determine nutrient contents, instead of using book values, is important in order to obtain accurate information on nutrient loading to manage potential N losses as well as forage quality, as the N:P and N:K ratios were high compared to typical crop needs in the region. In addition, as the physicochemical properties of the lagoons varied greatly over time, it is important that lagoons be sampled as close to the date of land application as possible in order to accurately account for the amounts of nutrients applied when calculating nutrient budgets.

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