Manure Technical Guide Series
University of California Cooperative Extension

Dairy Manure Nutrient Content and Forms

Introduction

Due to public concerns related to water quality impacts of livestock operations, dairy farmers in California are increasingly required to monitor and control manure discharges to land, including traditional use of manure as a fertilizer. Manure contains important nutrients for plant growth, most notably nitrogen (N), phosphorus (P), and potassium (K). Regulations and good stewardship require that manure be applied to crop fields in a manner consistent with crop nutrient needs. By monitoring and adjusting manure applications and utilizing the manure nutrients as a valuable resource, dairy producers can realize significant fertilizer cost savings.

A key practice that makes it possible to apply manure at agronomic rates is manure sampling and analysis. Due to variations in animal diet and manure handling and storage procedure, nutrient concentrations in both liquid and solid manure vary significantly between dairies and over time within the same dairy. Frequent sampling and analysis of manure is needed to avoid under- and over-fertilization of crops -- and in the Central Valley is required under waste discharge regulations.

This bulletin discusses estimation of manure nutrients excreted per cow and also presents examples of nutrient content and other chemical characteristics of different types of dairy manure. Examples are presented from several recent studies of manure conducted on dairies in the Central Valley of California.

Estimating Quantity of Nutrients Excreted per Cow

The quantity of manure and nutrients in the manure excreted by an animal can be estimated using a procedure developed and published by the American Society of Biological and Agricultural Engineers (ASAE Standard D384.2, ASABE 2005). This procedure bases estimates of N and P excretion of lactating cows on the level of milk production. This is an improvement over earlier procedures based on animal weight (Harter et al., 2007). Calculating the amounts of N, P, and K excreted in manure will give the dairy farmer an idea of the amount of N and other nutrients that can be used in crop production or must be exported off-farm in order to avoid excessive losses to the environment.

Table 1 shows the total annual excreted (urine plus feces) N and P for a hypothetical Holstein cow and its associated replacement animals. The daily excretion factors and equations used are from ASAE Standard D384.2. This procedure is also the one recommended by the Central Valley Regional Water Quality Control Board in estimating herd manure nutrients during the first stage (2007 Preliminary Dairy Facility Assessment) of compliance with dairy waste discharge requirements. A detailed description of this procedure is available at the following website:

https://apps.co.merced.ca.us/EnvironmentalHealthWM/pages/help/Links.aspx

The quantity of nutrients estimated by this method depends on assumptions regarding replacement animals and the length of the lactation cycle, as well as other factors not reflected in the ASAE excretion factors. Actual quantities of N and P excreted may vary considerably from the hypothetical example shown here.

Table 1. Hypothetical amounts of manure N and P produced by a mature Holstein cow and associated replacement stock.

	Manure N, lb/year			Manure P, lb P_2O_5/year		
Annual milk production, lb/cow	*Milk cow*	*Associated replacement animals*	*Total*	*Milk cow*	*Associated replacement animals*	*Total*
20,000	**305**	**56**	**361**	**54**	**9**	**63**
25,000	**326**	**56**	**382**	**54**	**9**	**63**

1. Manure (feces plus urine) N and P estimated with ASAE D384.2 MAR2005, Sections 5.3.7 (eq. 16) and 5.3.10 (eq.22) for milk cow N and P.
2. Assumes mature cows are milked 305 days/year, dry 60 days/year
3. Assumes replacement animals per mature cow: 0.5 heifers, age 6-24 months, and 0.17 calves, age 0-6 months.
4. $P=P_2O_5/2.29$

The values in Table 1 are prior to any loss of N during manure handling and storage. Roughly half of excreted N is in feces and half is in urine. Urine N is especially subject to rapid volatilization loss when urea in the urine is enzymatically hydrolyzed to ammonia (NH_3). Volatilization of NH_3 is highly specific to site conditions, but an estimated range for confinement style dairies in the Central Valley of California is 20-40% of the total excreted manure N (feces + urine N) (Harter et al., 2007). The quantity of excreted N/cow remaining is shown in Table 2, assuming a median loss value of 30%.

Dairy manure is relatively rich in P, and when it is used as the sole fertilizer nutrient source and applied at an appropriate rate based on its N content, inevitably P will accumulate in the soil. As shown in Table 2, the N:P ratio for excreted manure after NH_3 volatilization loss is already well below the N:P ratio of harvested crop material. Losses of manure N following application to land will further increase the imbalance between manure and crop harvest nutrient removal. To capture more of the economic value of manure phosphorus as a fertilizer, farmers should apply manure at a rate closer to the amount required for crop P nutrition and make up the N shortage with commercial N fertilizer. In some locations, tailwater or runoff to surface waters and pollution with P bound to sediment is a concern, and in such situations, growers should not allow P to accumulate to high levels in the soil.

Table 2. Dairy manure vs. harvested forage N:P ratios.

Annual milk production, lb/cow	Annual manure N, lb/mature cow	Annual manure P, lb P_2O_5/mature cow	$N:P_2O_5$
20,000	361	63	**2.5**
25,000	382	63	**2.7**
	After 30% N loss by NH_3 *volatilization*		
20,000	253	63	**1.8**
25,000	267	63	**1.9**
	Typical $N:P_2O_5$ *ratio of harvested material*		
		Various non-legumes	**2.3-3.0**
		Alfalfa	**4.9**

1. N and P manure totals for mature (milk and dry) cows are from Table 1 and include amounts excreted by associated replacement animals.
2. $P=P_2O_5/2.29$
3. Forage N:P from Pettygrove (2009)

Types of Dairy Manure in California

Dairy cow manure in the Central Valley of California is collected, stored, and applied to crops both in liquid and solid form. Dairy manure in California can be classified as follows:

Corral scrapings: Solid manure scraped from dirt-floored corrals and usually stockpiled before fall or spring application to crop fields. Corral manure also may be transferred to other crop farms, to commercial compost facilities or for use in landscape soil amendments.

Lagoon water: Wastewater resulting from flushing of manure from concrete feed lanes, free stalls, and the milking facilities and stored in anaerobic lagoons. It is also referred to as process wastewater, manure water, liquid manure, and nutrient water. Freestalls/feedlanes are typically flushed by recirculating top water from the lagoons. In some instances, process wastewater from flushing of concrete lanes is applied to cropland directly without first being stored in a lagoon.

Settling basin solids: Many dairies have basins or ponds that serve to retain a portion of the solids, with the liquid fraction (still containing suspended material) decanted into the main storage lagoon. The main purpose is to remove material that could plug pumps, pipes, and gates during irrigation or that might smother crops. Settling basins on many dairies are cleaned out annually or more often.

Lagoon sludge or slurry: This is fine particle material in the liquid waste stream that is not removed by settling basins or mechanical screens. Over time, it settles in storage lagoons. Depending on design and operation of the lagoon, some portion of it will be transferred to fields during lagoon water irrigations, but in most dairy lagoons, some sludge accumulates and eventually must be removed by hydraulic dredging or excavation.

Mechanical screen solids: Material filtered out of the liquid waste stream by a screen [insert – size of holes?] before it enters the storage pond. It consists primarily of coarse or fibrous manure particles, spent bedding (e.g., rice hulls) and spilled/waste forage and feed. This material is often stacked and then reused within the dairy for bedding; occasionally it is applied to cropland.

Composted materials: Mechanical screen solids and/or corral manure – occasionally with crop residues added – may be stacked in piles or windrows, then turned one or more times to stimulate self-heating by aerobic, thermophilic microbes. Maximum temperatures of 55 to 70° C are achieved, thus killing most pathogens and weed seeds present while producing a relatively biologically stable, homogenous material. This material is typically recycled within the dairy for use as animal bedding, but in some dairies is applied to crops or transferred off the dairy for use as a soil amendment.

Dairy Manure Characteristics -- Examples

In the following tables and figures, examples are provided of solid and liquid dairy manure characteristics. While there is a very wide range of nutrient contents within each type of manure, some differences between types can be seen.

In addition to livestock excreta, manure and process wastewater collected on dairy farms may contain other materials, for example, soil, animal bedding, waste feed, waste milk, weed seeds, pathogens, and cleaning and foot bath compounds.

Solid Manure (Table 3 and Fig 1).

Examples of the median and ranges of nutrient properties of solid manures (including storage pond sludge) are shown in Table 3.

Table 3. Summary of properties of 29 solid manure samples (4 corral, 8 pond solids, 14 mechanical screen solids, 3 composts) from 11 dairies in the Central Valley.

Property	Unit	Median	Minimum	Maximum
Moisture content	% wet wt.	68	1	83
Volatile solids	% dry wt.	72	35	89
Total carbon	% dry wt.	35.6	18.1	43.9
Total N	% dry wt.	2.1	1.2	3.5
C:N	--	16.1	9.3	33.4
NH_4-N	mg/kg dry wt.	1346	13	6282
NO_3-N	mg/kg dry wt.	9	<1	312
Total P	% dry wt.	0.41	0.18	1.99
Total K	% dry wt.	0.57	0.15	4.37
pH (sat'd paste)	--	7.8	6.6	9.0
EC (sat'd paste extract)	mS/cm	4.1	1.7	36

Fig. 1 gives a better idea of the range of values for different types of solid manure.

Organic Matter Content of Manure

The value of manure organic matter (organic carbon) as a soil amendment is overlooked. The value of organic amendments in improving soil tilth is well established. Organic amendments such as manure help build soil organic matter levels and nourish a diverse soil microflora, which in turn helps the soil retain nutrients. Even under California's Mediterranean climate regime, regular manure additions will improve soil aggregation and structure. Organic C content of manures can be estimated with adequate accuracy by measuring the loss of weight (volatile solids content) following combustion of a sample at 550° C. As shown in Fig. 3, manure carbon content is approximately equal to half of VS content; in other words, manure organic matter is about half C by weight.

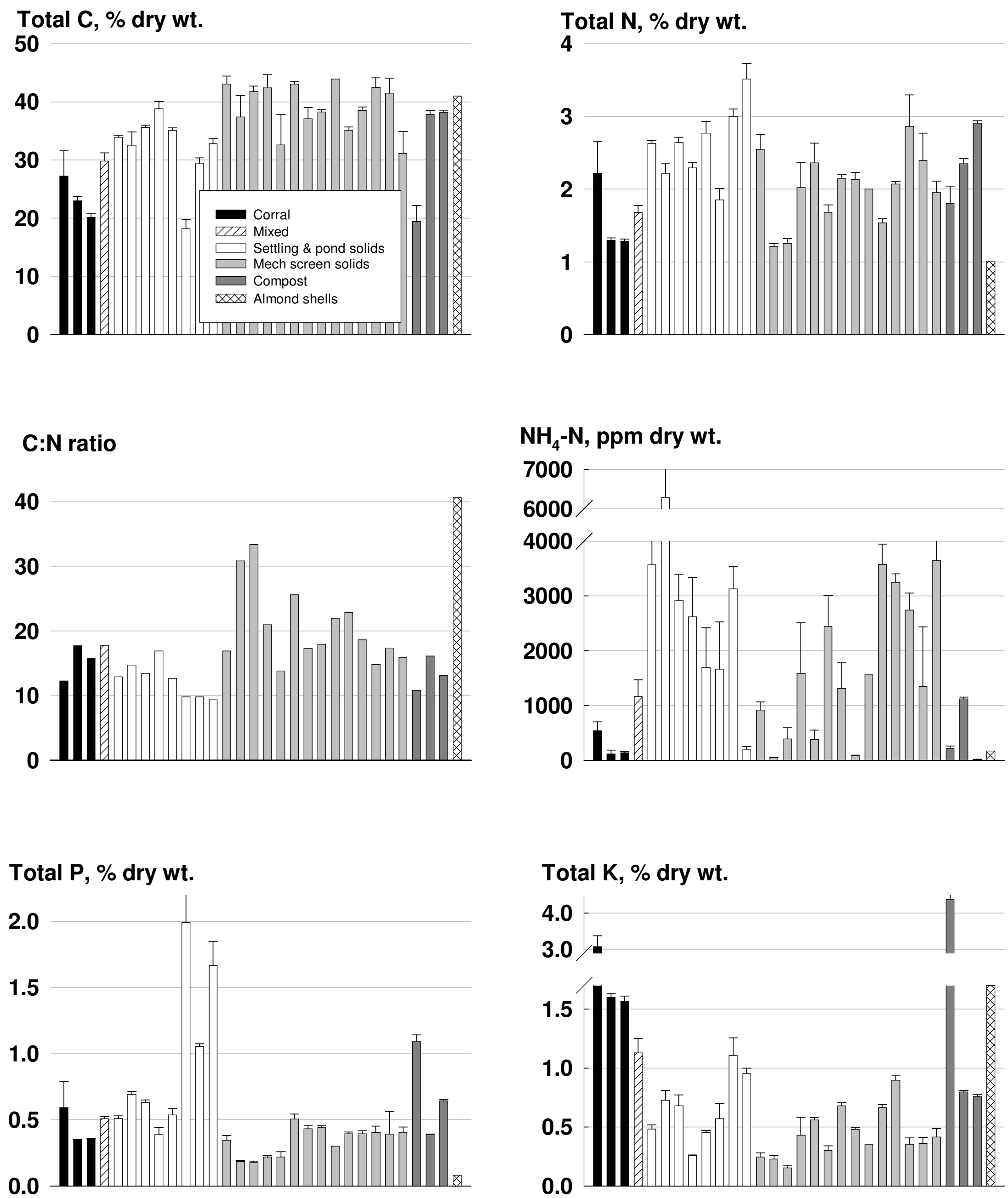

Fig. 1. Distribution of properties of 29 solid manure samples (4 corral, 8 pond solids, 14 mechanical screen solids, 3 composts) from 11 dairies in the Central Valley. Error bars represent standard deviation of three samples.

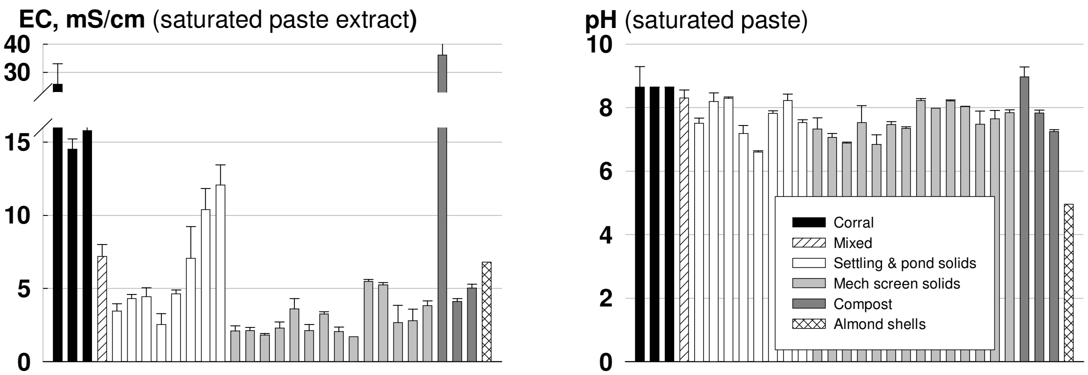

Fig. 1. (continued)

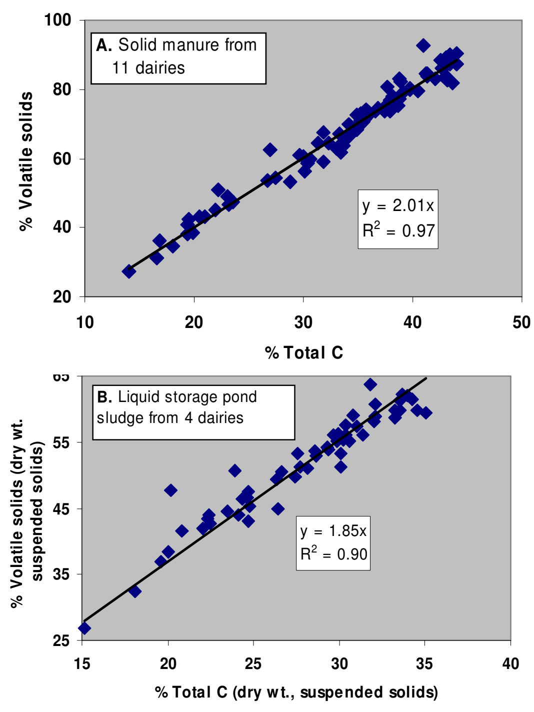

Fig. 2. Relationship of carbon and volatile solids content of (A) solid dairy manure and (B) retention pond liquid sludge.

Dairy solid manure properties from a recent UC study are shown in Table 4. Several types of manure were collected from each dairy. These data suggest some consistent differences among types of manure. For example, pH of fresh manure is lower than for other types. Corral manure has a higher pH. Anaerobic lagoon sludge organic matter is enriched in N, as indicated by a higher N content when expressed on a volatile solids basis.

Table 4. Characteristics of solid manures collected from eight San Joaquin Valley dairies in 2006-08 (Heinrich, 2009).

Material	n	**pH**	**EC** *dS/m*	**DM** *%*	**VS** *% of DM*	**Total C** *g C/kg DM*	**Total C** *g C/kg DM*
FM	8	7.1c	3.2b	15b	83a	423a	507ab
SM	4	8.3ab	2.1b	19b	88a	424ab	482b
CS	8	8.9a	7.6a	60a	46b	238c	527ab
Compost	7	8.2ab	3.0b	61a	57b	306bc	530ab
SL	11	7.9b	2.4b	16b	51b	270c	540a

Material	n	**Total N** *g N/kg DM*	**Inorg N** *g N/kg DM*	**Org N** *g N/kg DM*	**Org N** *g N/kg VS*	**C:N**	**C:Org N**
FM	8	25ab	2ab	23a	28c	17b	18b
SM	4	17b	2ab	15a	18c	26a	30a
CS	8	19b	1b	18a	41b	12c	13cd
Compost	7	22ab	1b	22a	39b	14bc	14c
SL	11	30a	5a	25a	50a	9d	11d

Values with same letter within a column are not significantly different using Tukey-Kramer HSD ($p>0.05$)
FM = Fresh manure collected from concrete flush lanes
SM = Mechanical screen solids
CS = Corral scrapings
Compost = Aerobic windrow composted corral/screen solids
SL = Anaerobic dairy lagoon sludge (fine material near bottom of anaerobic retention ponds)

Dairy Lagoon Water (Tables 5 and 6)

Table 5. Physical and chemical characteristics for lagoon water collected from same dairies as samples in Table 4 (Heinrich, 2009)

Dairy	9	3-2	10	11	12	8-2	13	Mean
pH	7.6	7.9	7.5	7.3	8.2	8.2	7.2	**7.7**
EC (mS/cm)	10.9	4.2	7.8	7.8	5.7	6.9	0.0	**6.2**
TS (g/L)	10.2	3.0	7.7	6.1	4.0	5.8	22.9	**8.5**
TSS (g/L)	3.4	0.8	2.8	1.6	0.7	2.2	21.1	**4.7**
TKN (mg N/L)	1010	320	770	730	410	630	810	**670**
NH_4-N (mg N/L)	600	200	440	480	270	360	170	**360**
Dissolved Org N (mg N/L)	150	20	120	90	60	120	50	**90**
TSS-N (mg N/L)	230	70	180	120	50	140	580	**200**
Total C (mg C/L)*	3580	1080	2660	2250	1200	1950	8430	**3020**
Dissolved Org C (mg C/L)	540	160	290	430	220	270	250	**310**
TSS-C (mg C/L)	1820	440	1340	900	390	950	7630	**1920**
Total C:TKN	3.5	3.4	3.5	3.1	2.9	3.1	10.4	**4.5**
Total C:Org N	8.8	9.1	8.2	9.1	8.9	7.0	13.1	**9.8**
TSS-C:TSS-N	8.0	6.0	7.3	7.5	7.1	6.7	13.2	**8.0**
TSS <28 µm and >0.3 µm (%)	87	98	82	94	100	98	43	**86**

*Total C = Total suspended solid C + dissolved organic C + dissolved inorganic C
Abbreviations in Table 6. TS=total solids, TSS=total suspended solids, TKN=total Kjeldahl N,

Table 6. Lagoon water characteristics at Central Valley dairies prior to dilution with fresh irrigation water. Samples collected from March 2000 through August 2002. [1](Source Final Report to UC SAREP for Dairy BIFS study)

	Total N	NH_4-N	P	K	Total Solids	pH	EC
	----------------------μg/g------------------------				--%--		mmho/cm
Dairy 1							
median	645	434	141	846	1.1	7.1	7.5
range	424-1200	260-540	53-290	480-1040	0.4-2.5	7.1-7.4	4.5-9.5
Dairy 2							
median	284	185	64	323	nes[3]	7.3	2.2
range	171-1633	109-268	30-263	168-379	nes	7.0-7.6	2.1-3.4
Dairy 5							
median	353	202	80	429	0.5	7.3	4.1
range	110-637	70-320	28-254	169-722	0.2-2.5	6.8-7.5	2.1-5.7
Dairy 6							
median	164	124	43	213	0.2	7.2	2.6
range	51-332	10-203	9-63	35-408	0.1-0.8	6.8-7.8	0.7-4.2
Dairy 7							
median	397	321	75	521	0.4	7.2	5.0
range	222-513	168-433	43-122	282-705	0.3-0.6	6.8-7.5	3.1-6.4
Dairy 8[2]							
median	325	258	52	652	nes	7.0	4.7
range	240-345	220-267	45-58	486-773	nes	6.6-8.0	4.2-5.5
Dairy 9							
median	214	175	48	245	0.3	7.2	3.7
range	36-390	27-229	10-86	37-470	0.1-0.9	6.7-7.6	1.1-5.1
Dairy 10							
median	391	272	70	602	0.4	7.2	4.9
range	198-2420	158-370	26-380	280-880	0.2-2.0	6.9-7.5	3.0-6.1
Dairy 11							
median	468	334	79	640	0.8	7.3	6.9
range	249-953	135-554	39-283	258-992	0.3-2.0	6.8-8.1	3.6-9.6

[1] All samples collected from the same dairy within 5 days where ammonium N was within 10% value were averaged together. Median value was calculated based on these composite samples. Samples from Dairy 3 are not included because all samples at that location were of mixed water (manure water diluted with fresh irrigation water) All values for N, P, K are based on lab analyses, except Dairy 8, where N is based on the Nessler quick test method.

[2] Samples for Dairy 8 are from main storage lagoon; samples analyzed from settling basin are excluded

[3] nes = not enough samples to analyze (5 or fewer samples with this analysis).

Dairy Anaerobic Lagoon Sludge

Table 7. Properties of anaerobic lagoon sludge (54 samples collected during hydraulic dredging at four dairies).

Property	Unit	Median	Min	Max
Total solids	g/L	74.9	10.6	127
Suspended solids (SS)	g/L	73.4	9.5	125
Total dissolved solids	g/L	3.15	0.91	4.83
Volatile solids	% dry wt.	53.3	26.9	63.8
Total C of SS	% dry wt.	29	15.1	35
Total N of SS	% dry wt.	2.72	1.79	3.31
C:N of SS	--	10	6.8	13.1
Total Kjeldahl N	mg/L	2565	556	4420
NH_4-N	mg/L	434	135	658
NO_3-N	mg/L	0.5	0.1	1.3
N - organic	mg/L	2246	298	3762
Total P	mg/L	972	141	3263
Total K	mg/L	1001	223	1385
Electrical conductivity	mS/cm	4.31	1.67	7.64

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