Dairy Manure Nutrient Management

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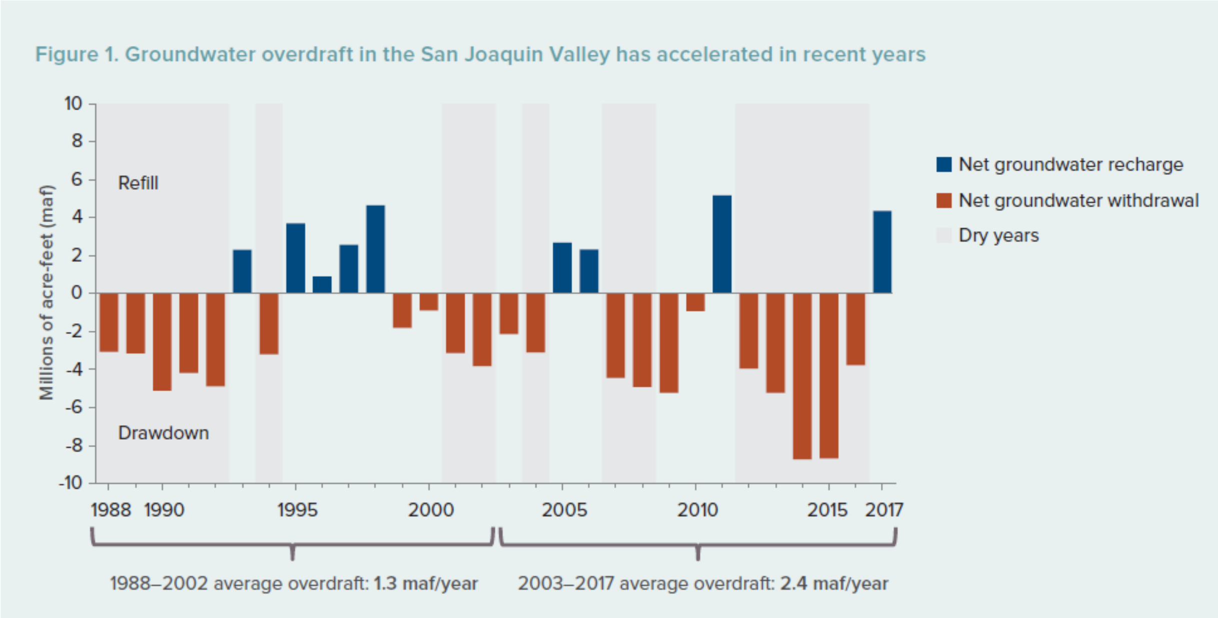
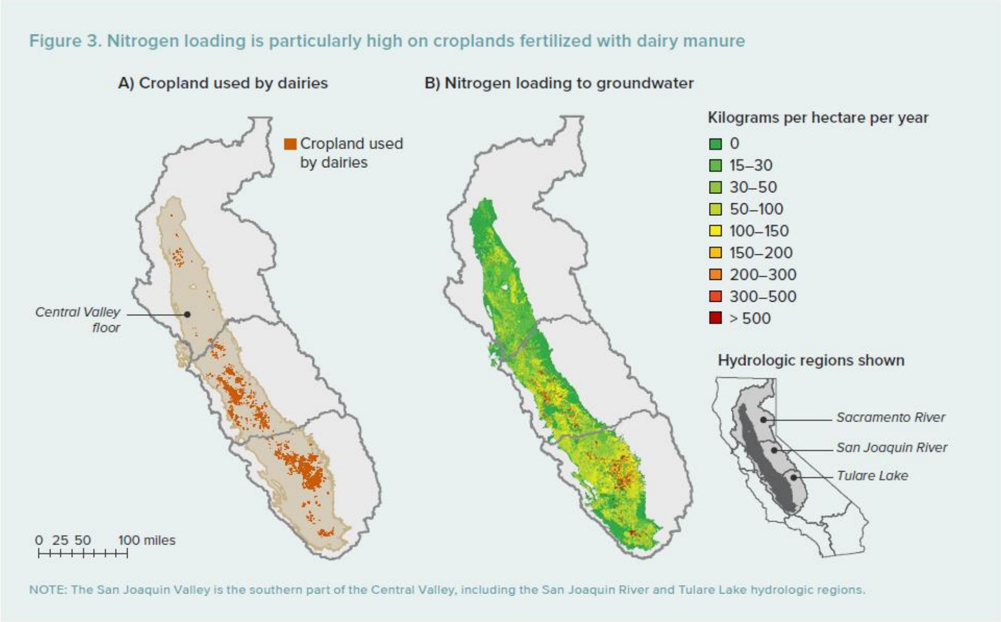
California Bioresources Alliance_17th Annual Forum

(1) The Regulatory Problem

The state's dairy industry and farming in general are faced with two difficult regulatory challenges: **Groundwater overdraft**, especially in the San Joaquin Valley, that will limit available irrigation water, and **nitrate pollution of groundwater**. This presentation focuses on nutrient management on diaries, but results are affected by restrictions on water availability for irrigation (SGMA).



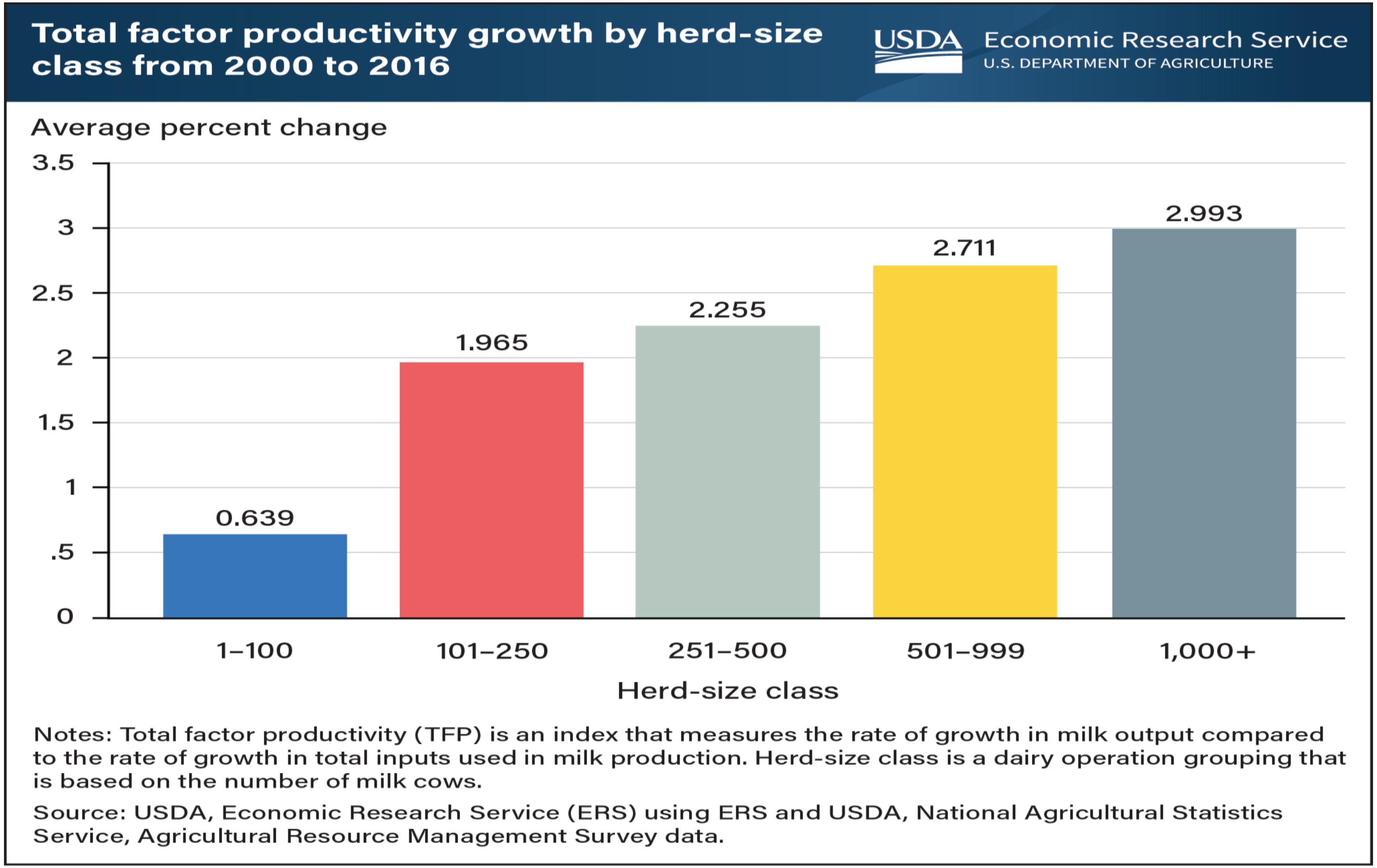
Ground water overdraft: SGMA



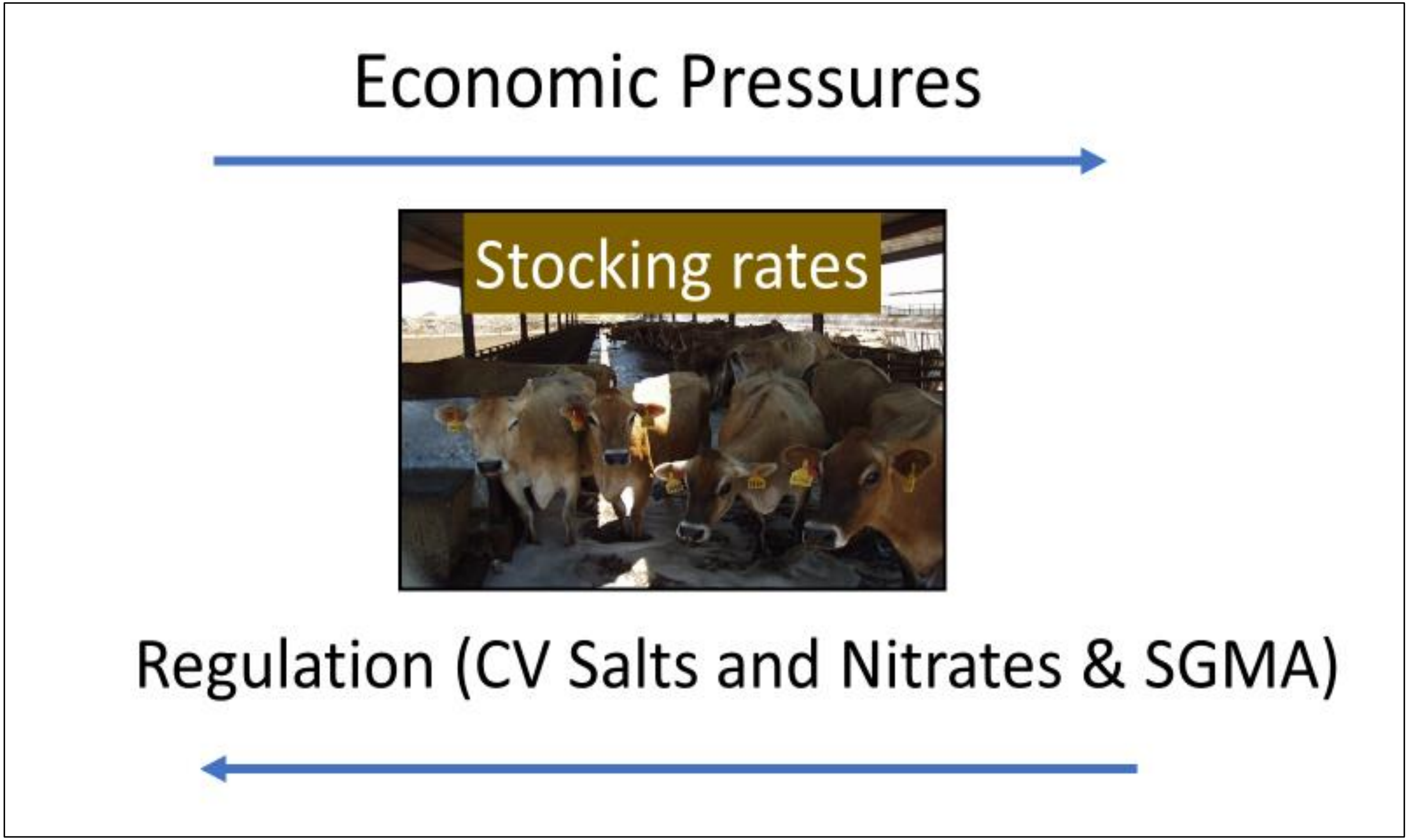
Studies estimate that SGMA will idle 500K to 1M acres in the SJV

Nitrate pollution of groundwater

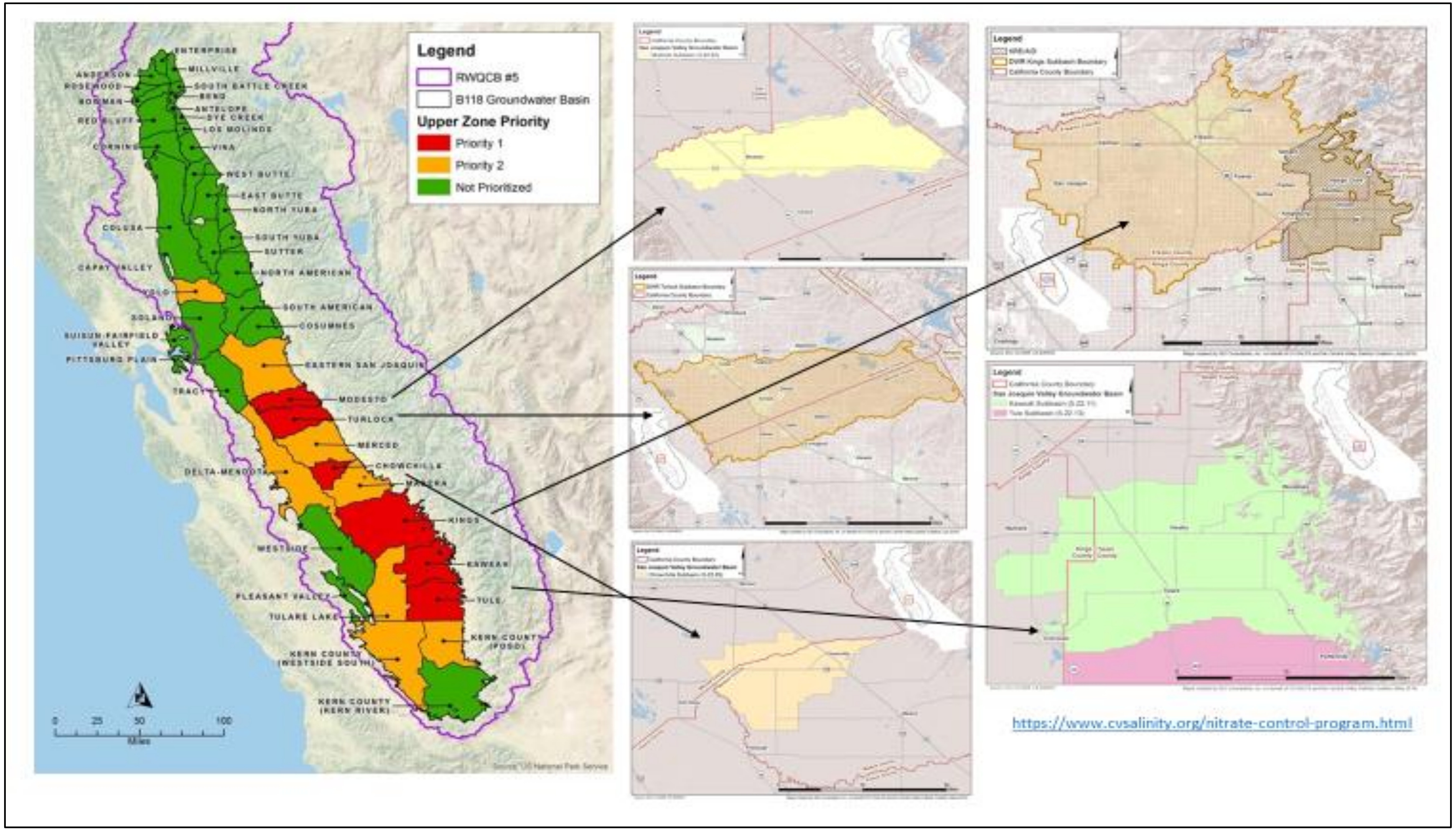
SOURCE: Public Policy Institute of California_ https://www.ppic.org/publication/water-and-the-future-of-the-san-joaquin-valley/



Milk productivity growth by herd-size class from 2000 to 2016. Economic and agroecological efficiency have increased with herd size in the dairy sector over time, but intensification may make nutrient management more difficult, especially for farms that have limited land area for crop production and manure use, or limited manure export options.

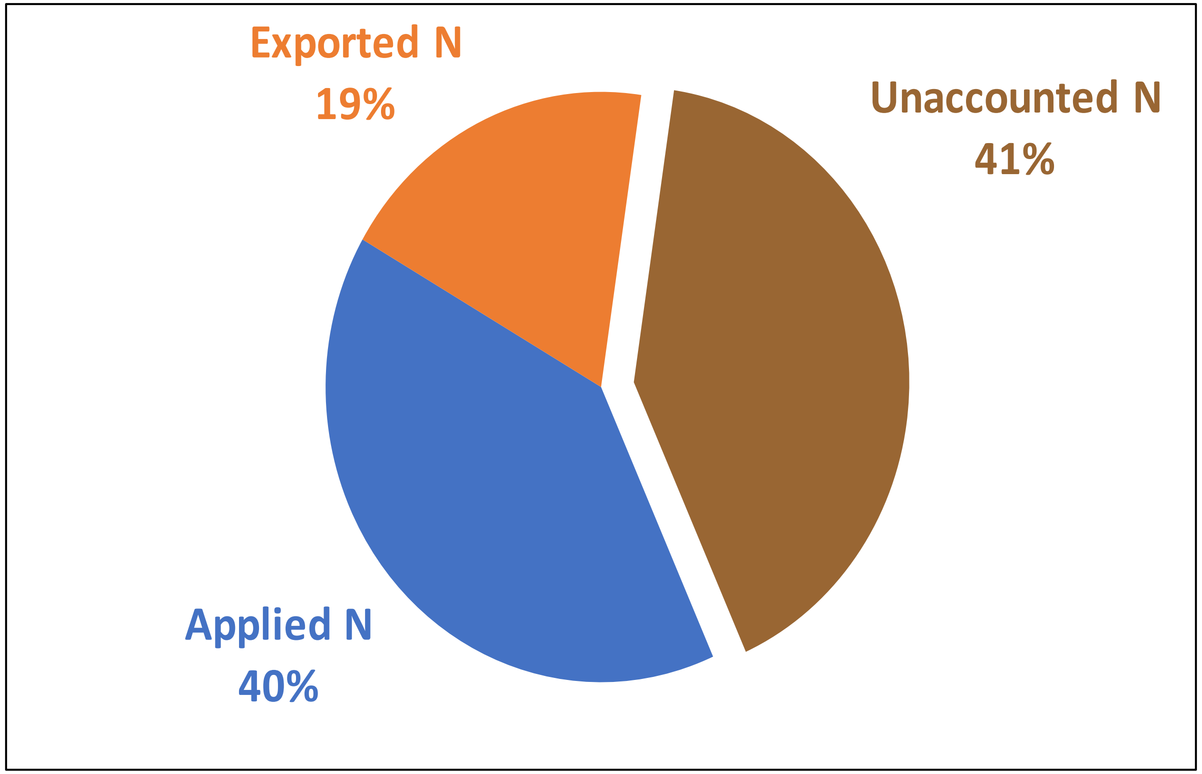


Conflicting pressures affect dairy operators to increase herd size but reduce the effects of increasing manure accumulation that result.

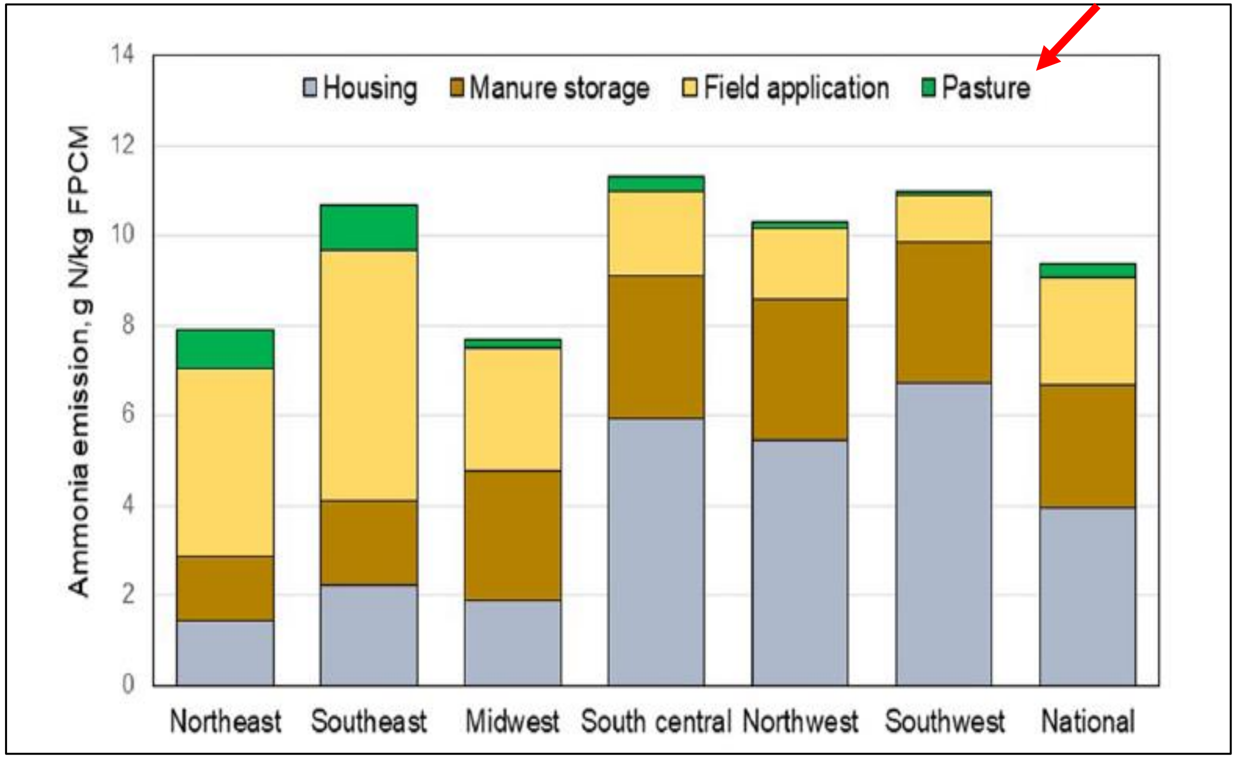


Results from the analysis reported focus on the priority one Groundwater management Zones (GMZs) where surplus nutrient application is thought to be most problematic. Data comes from public records assembled by the Central Valley Representative Dairy Management Coalition to help assess fees for groundwater mitigation. This talk is based on a recent report to CDFA: Kaffka, Williams Marviney and Cole (2022): ***Manure Nutrient Recovery, Removal and Reuse on California Dairies***.

Many previous studies have identified unaccounted N in dairy management systems in CA, potentially available for nutrient recovery, removal and reuse.



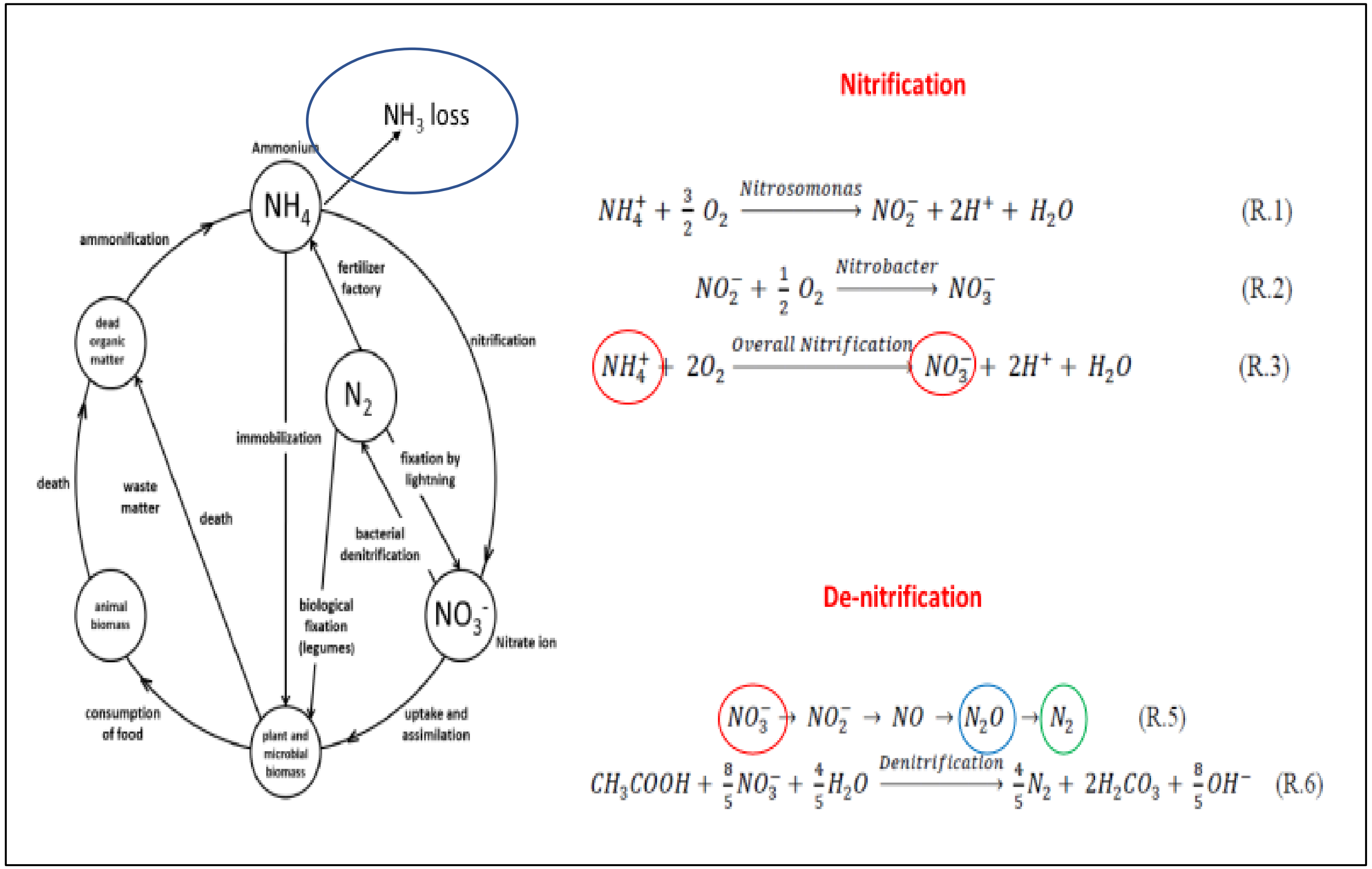
Generalized N balance for central valley dairies. Based on data reported to the CVRWQCB from 2016 to 2017. Till Angermann; CVDRMP. (used with permission). As noted, approximately similar estimates have been reported by others.



Ammonia emissions from major farm sources for each region compared with the weighted average for the US as a whole. Emissions are expressed on fat and protein corrected milk basis (FPCM). NH_3 emissions are largest in the southwest and south-central regions. The southwest region is dominated by California dairies of all sizes. The majority of emissions are from housing and manure storage (From Rotz et al., 2021).

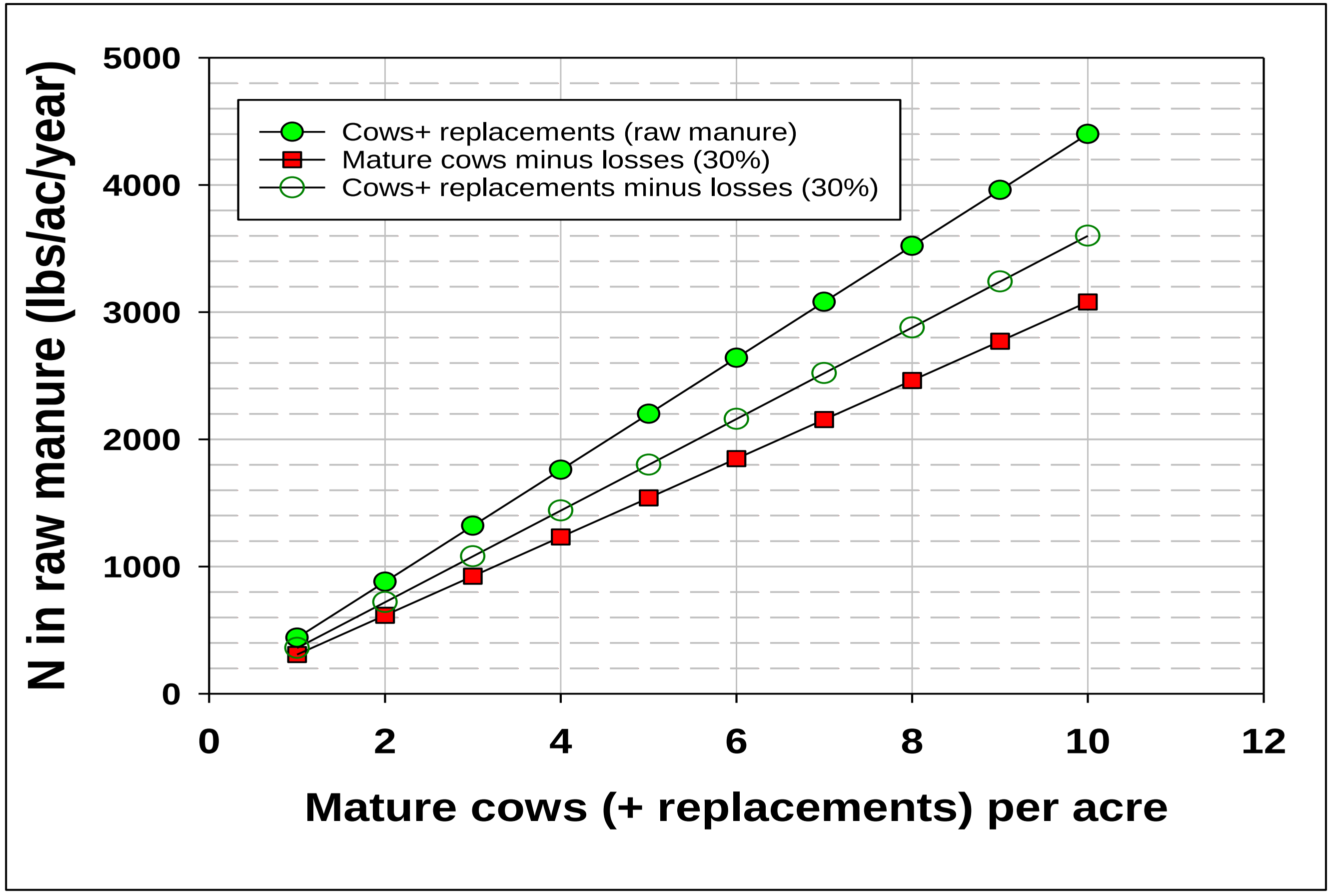
(2) Surplus Nutrients on Dairies in Priority 1 Nutrient Management Zones in the San Joaquin Valley

Manure is a living material undergoing constant transformation. A focus on one type of management and type of emission will result in other types of emissions. **Tradeoffs are unavoidable.**



Nitrogen transformation process in manure, composts, and soils.

Surpluses occur when the nutrients in manure from a large number of cows is applied to a limited number of acres of crop land. **Stocking rates** are the number of cows plus replacement young stock on a dairy relative to the land available for crop production and manure application.



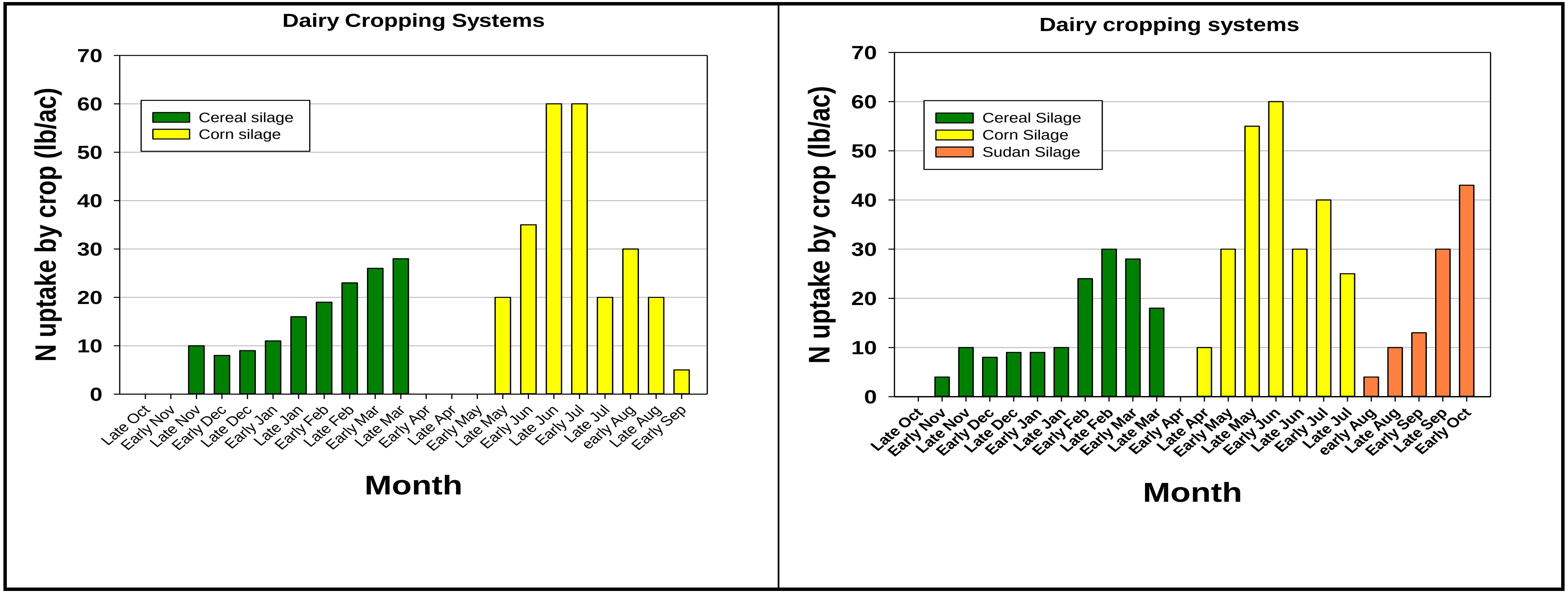
Stocking rate vs manure N supply. It is assumed that mature cows + replacements on average deposit 440 lb of N in manure and urine per year (Harter et al., 2012) and manure cows deposit 360 lbs per year. The value of 30% is used for losses via ammonia volatilization or other pathways.

Table 1.1. Number of mature cows (lactating and dry) for dairies within priortiy 1 and 2 NMZs

Location	# of farms	Mature cows		Acres		Stocking rate	
		AVE	Median	AVE	Median	AVE	Median
All dairies	**948**	**1458**	**1070**	**554**	**312**	**4.67**	**3.3**
Chowchilla	32	1685	1103	910	553	3	1.85
Modesto	53	880	700	265	202	4	3.33
Turlock	182	980	1057	290	295	5	3.79
Kaweah	116	1580	1200	566	462	5	3.3
Kings	119	1730	1379	750	507	5	3.1
Tule	101	2280	1789	775	548	5	3.58
Outside	89	89	865	567	281	5	3

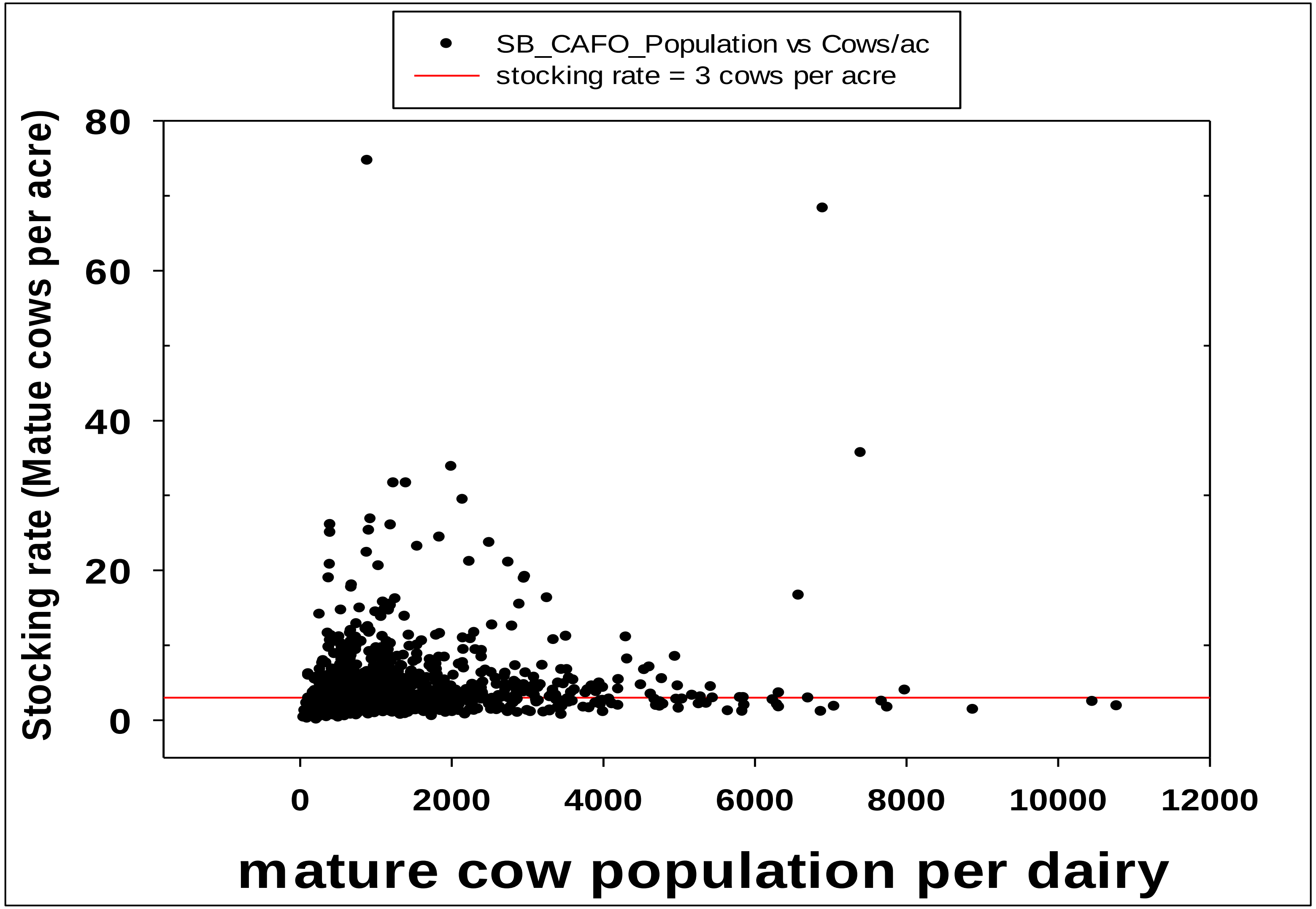
Notes:
Based on CVRWQCB data for 2018-1.
Priority 2 dairies and those outside defined NMZs are included in the all dairies category

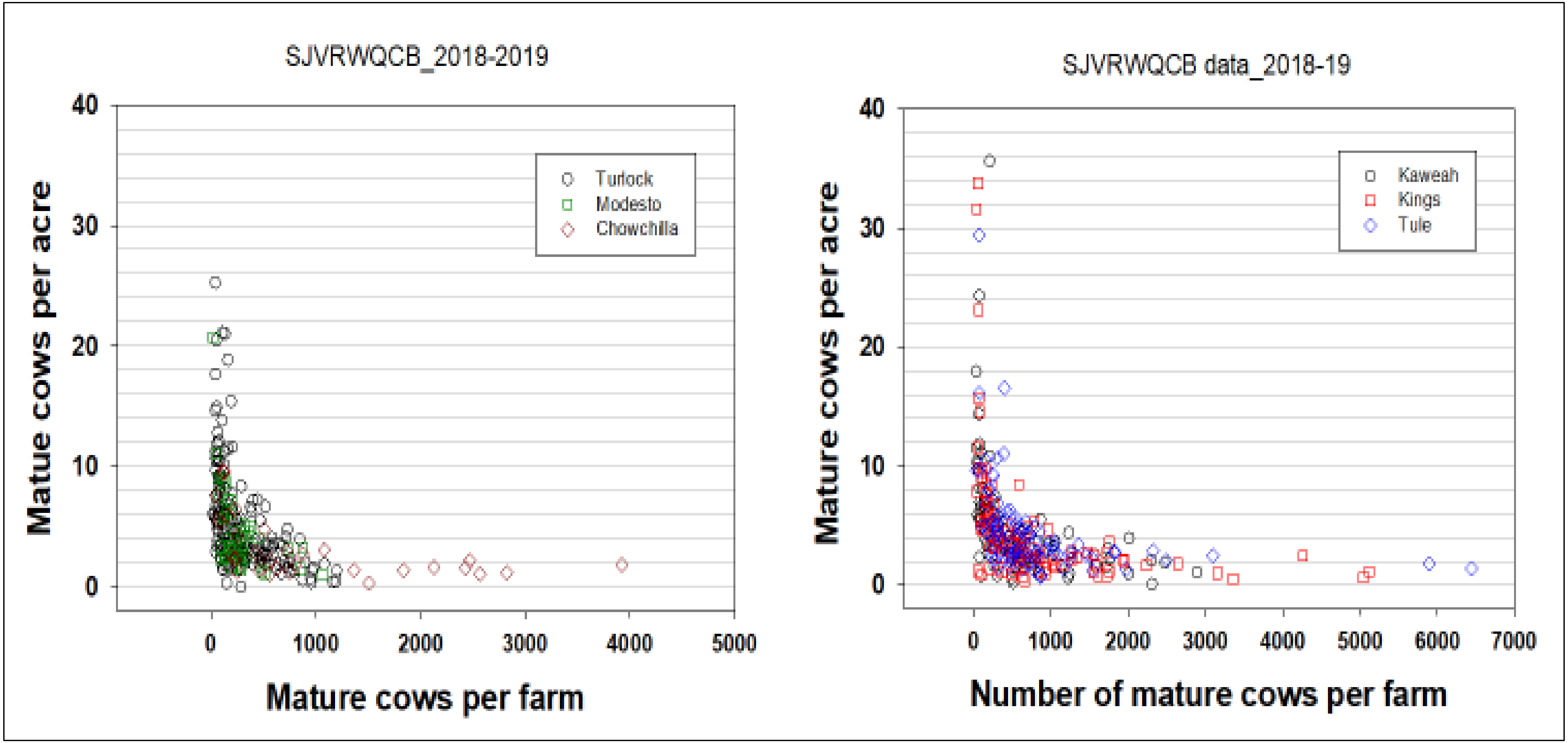
Crop uptake and removal depends on the number and types of crops grown and their yields



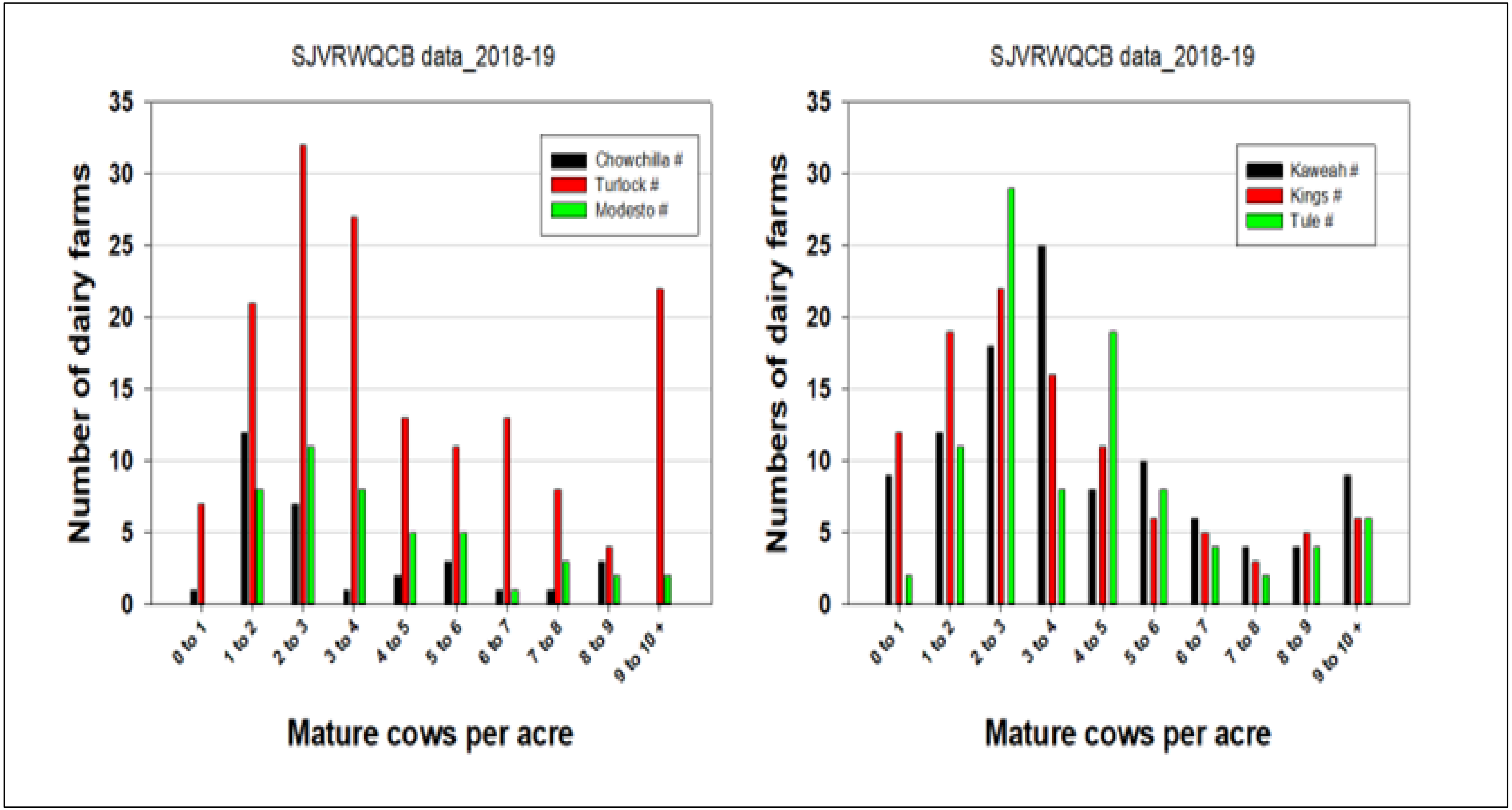
Crop N uptake by month for typical dairy cropping system (excluding alfalfa) in the San Joaquin Valley. Maximum crop uptake for a three-crop system was estimated as 500 lb N $ac^{-1}yr^{-1}$. For a two-crop system, maximum uptake was 400 lb N $ac^{-1}yr^{-1}$. At an application ratio of 1.4, 560 lb of N as manure can be applied for a two-crop system, and approximately 700 lb N $ac^{-1}yr^{-1}$ can be applied for a three-crop system. Adapted from Chang et al. (2006), Figure 5-2. More recent crop yields and N uptake are somewhat higher.

Stocking rate of mature cows per dairy versus total numbers of mature cows. Based on CVRWQCB mature cow data for 2018-2019. The red horizontal line indicates 3 mature cows per acre of land reported receiving manure. Each dot is a single dairy.





Stocking rates in the northern (left panel) and southern (right panel) San Joaquin Valley by farm size within priority 1 NMZs. The highest stocking rates tend to be on the smaller dairy farms in terms of acres.



Numbers of dairies versus mature cows per acre (stocking rates) within Priority 1 NMZs. Data are grouped within the northern and southern portions of the San Joaquin Valley.

We assumed that for stocking rates > 4 cows + replacements per acre (range: 3.5 to 4.4), that surplus nutrients will be present in amounts that cannot be managed over time without changes in the amount removed from farms or through nutrient recovery and reuse technologies. Smaller nutrient surpluses may still exist at lower stocking rates, but are amendable to modest changes in management. **For a nutrient recovery technology provider, it is assumed that farms with larger nutrient surpluses are more likely to be locations for technology deployment.**

Table1. 1. Estimated surplus N in manure based on stocking rates, collection system, estimated crop uptake, AR = 1.4, accounting for manure export of SM and fertilizer use for corn silage

Cows/ac	Manure N (lb/ac/yr/coweq) (excreted)	Forage crops/yr			
		2	3	2	3
		Free stall dairy		Open Lot Dairy	
1	**440**	**-253**	**-393**	**-276**	**-416**
2	**880**	**-17**	**-157**	**-63**	**-203**
3	**1320**	220	80	151	11
4	**1760**	456	316	364	224
5	**2200**	693	553	578	438
6	**2640**	929	789	792	652
7	**3080**	1166	1026	1005	865
8	**3520**	1402	1262	1219	1079
9	**3960**	1639	1499	1433	1293
10	**4400**	1875	1735	1646	1506

Notes: Cows + replacements; Manure per cow equivalent (lactating cows + replacements = 390 lbs N/yr
2 crops/yr: cereal silage and corn silage, N uptake = 400 lb N/ac
3 crops/yr: cereal silage, corn silage, Sudan grass hay; N uptake = 500 lb N /ac
AR = 1.4 times manure N available for application
N application: 2 crop system =490 lb N/ac/yr after adjusting for 50 lb N/ac fertilizer use per acre;
N application: 3 crop system = 650 lb N/ac/yr after adjusting for 50 lbs N fertilizer use per acre
Free stall: 60% on concrete (70% recovery of N); 40 % in corrals (63% recovery of N)
Open lot: 35% on concrete (60 % recovery), 65 % on corrals.
50 lbs fertilizer N per acre per year assumed for corn silage. This reduces the amount applied at an AR of 1.4 to to 490 and 650 lb N equivalent respectively.

Stocking rates of dairies in the priority one NMZs

Table 1.1. Numbers and percent of dairies by different stocking rates and NMZ

	Chowchilla		Turlock		Modesto		Kaweah		Kings		Tule	
Stocking rate (Cows ac^{-1})	Dairies		Dairies		Dairies		Dairies		Dairies		Dairies	
	(n)	%	(n)	%	(n)	%	(n)	%	(n)	%	(n)	%
1	1	3	7	*4*	0	0	9	9	12	11	2	2
2	12	39	21	*13*	8	18	12	11	19	18	11	12
3	7	23	32	*20*	11	24	18	17	22	21	29	31
4 (3.5 to 4.4)	1	3	27	*17*	8	18	25	24	16	15	8	9
5	2	6	13	*8*	5	11	8	8	11	10	19	20
6	3	10	11	*7*	5	11	10	10	6	6	8	9
7	1	3	13	*8*	1	2	6	6	5	5	4	4
8	1	3	8	*5*	3	7	4	4	3	3	2	2
9	3	10	4	*3*	2	4	4	4	5	5	4	4
10	0	0	22	*14*	2	4	9	9	6	6	6	6
SUM	31		158		45		105		105		93	
Dairies with a SR of cows/ac >3	10	*32*	98	62	26	*58*	66	*63*	52	*50*	51	55

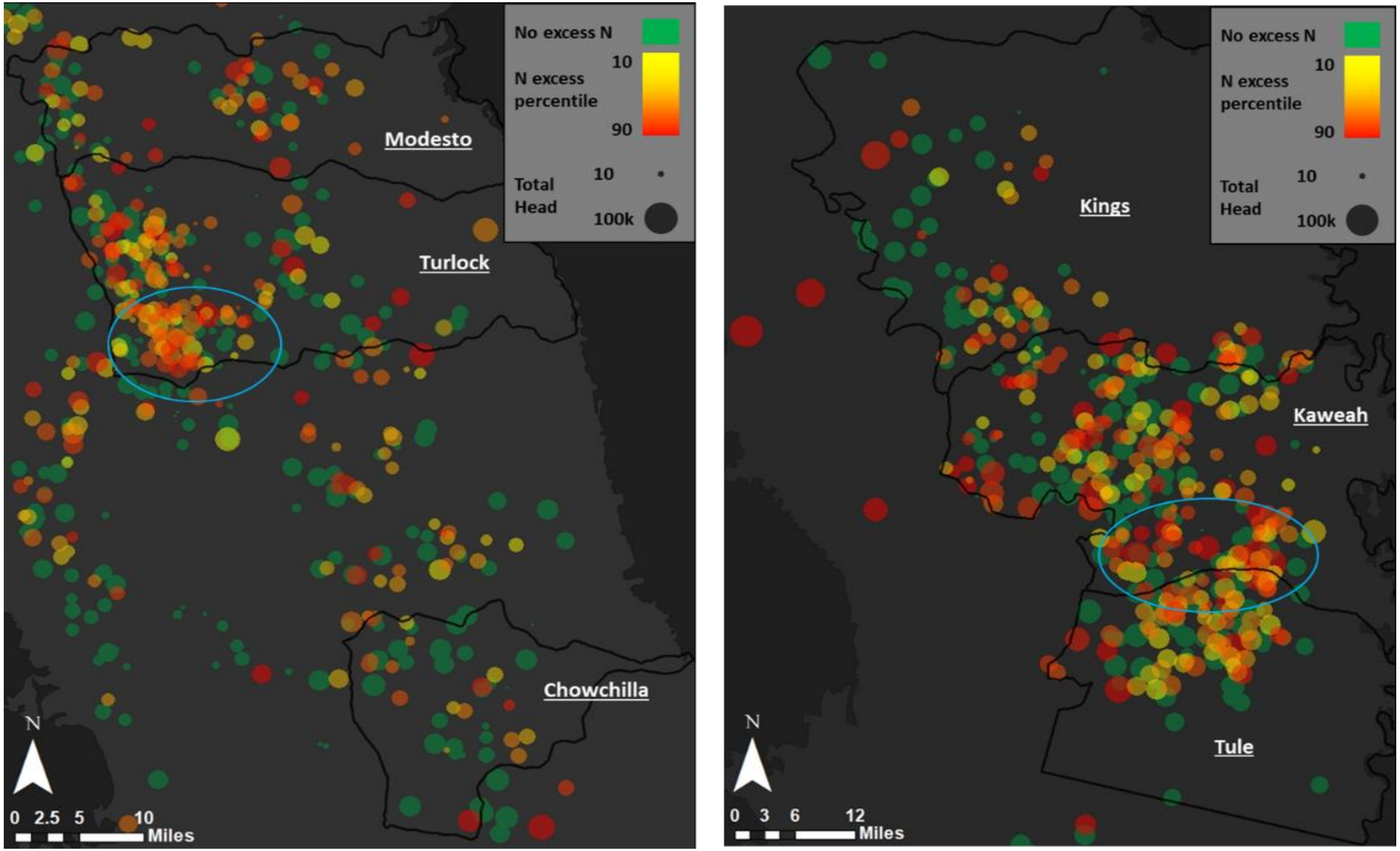
Surplus N

Table 1.1. Dairies reporting a stocking rate ≥ 4 mature cows per acre.

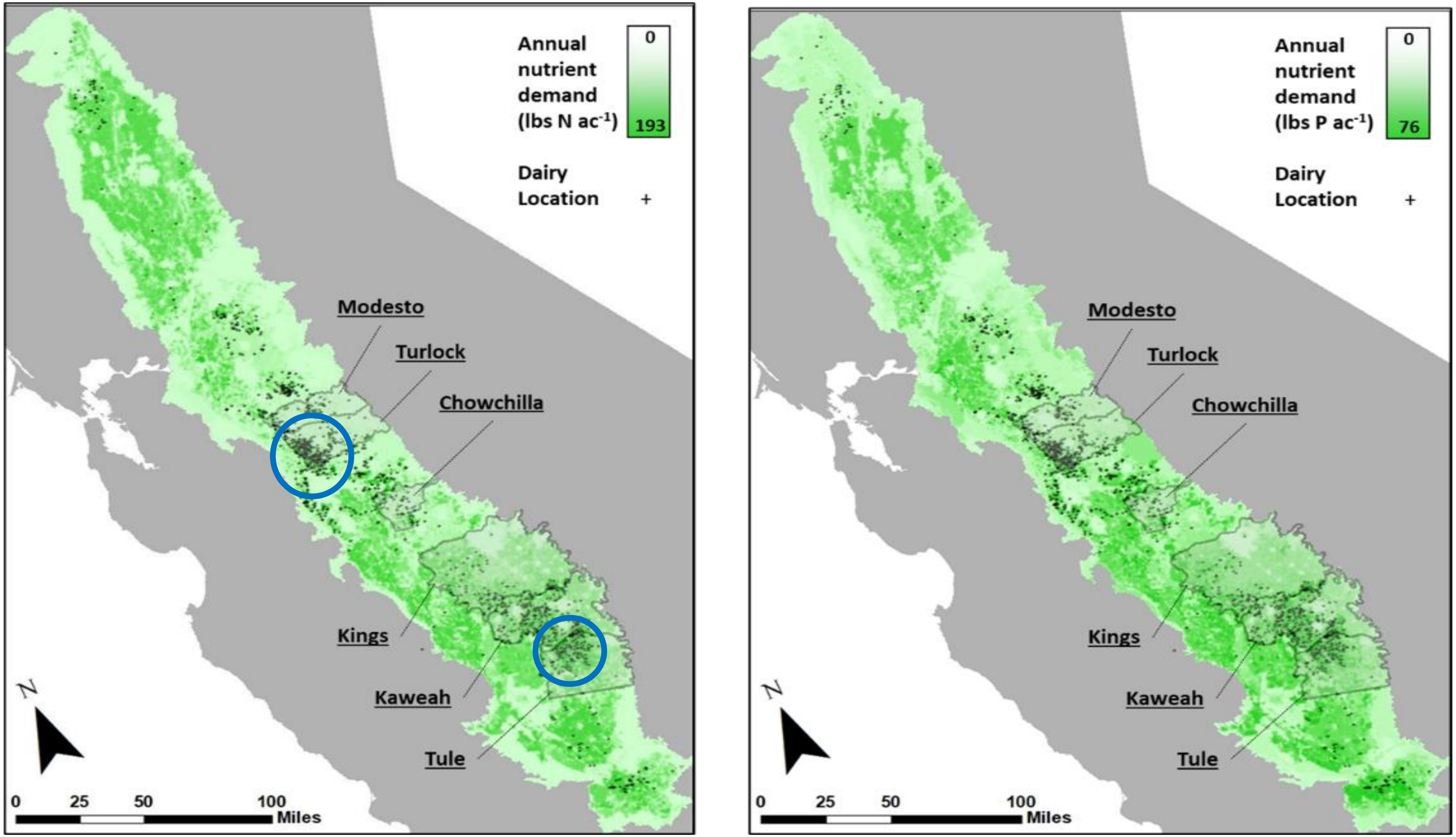
	Chowchilla	Modesto	Turlock	Kaweah	Kings	Tule
Number of dairies	10	20	81	44	43	44
% of dairies	32	52	58	63	50	55
Acres receiving manure (total per NMZ)	1660	4230	13660	10350	10830	16290
Lagoon manure N (t yr^{-1})	330	700	3430	2150	2810	2980
Range by dairy type (FS-OL)	440-160	950-350	4320-1590	2850-915	2780-960	4060-1430
Solid manure N (t yr^{-1})	270	610	2690	980	1810	2580
Range by dairy type (FS-OL)	215-370	670-780	2495-3740	2180-3540	1570-2250	2230-3380

Notes:
FS: Free stall; OL: Open Lot.
Averages are the mean of 2 and 3 crop systems (Manure N application rate of 490 or 630 lb manure N acre respectively at an AR ratio = 1.4.
Lagoon manure (LM) is from FS and OL farms combined. Similarly for Solid Manure (SM).

The dairy industry is very diverse and optimum nutrient management solutions not likely to be the same for all dairies. Creativity in policy and regulation is required to support diverse solutions to surplus nutrient management.



Areas within priority 1 NMZs with dairy manure N surpluses.



Potential crop nutrient demand for surplus dairy farm N and P.

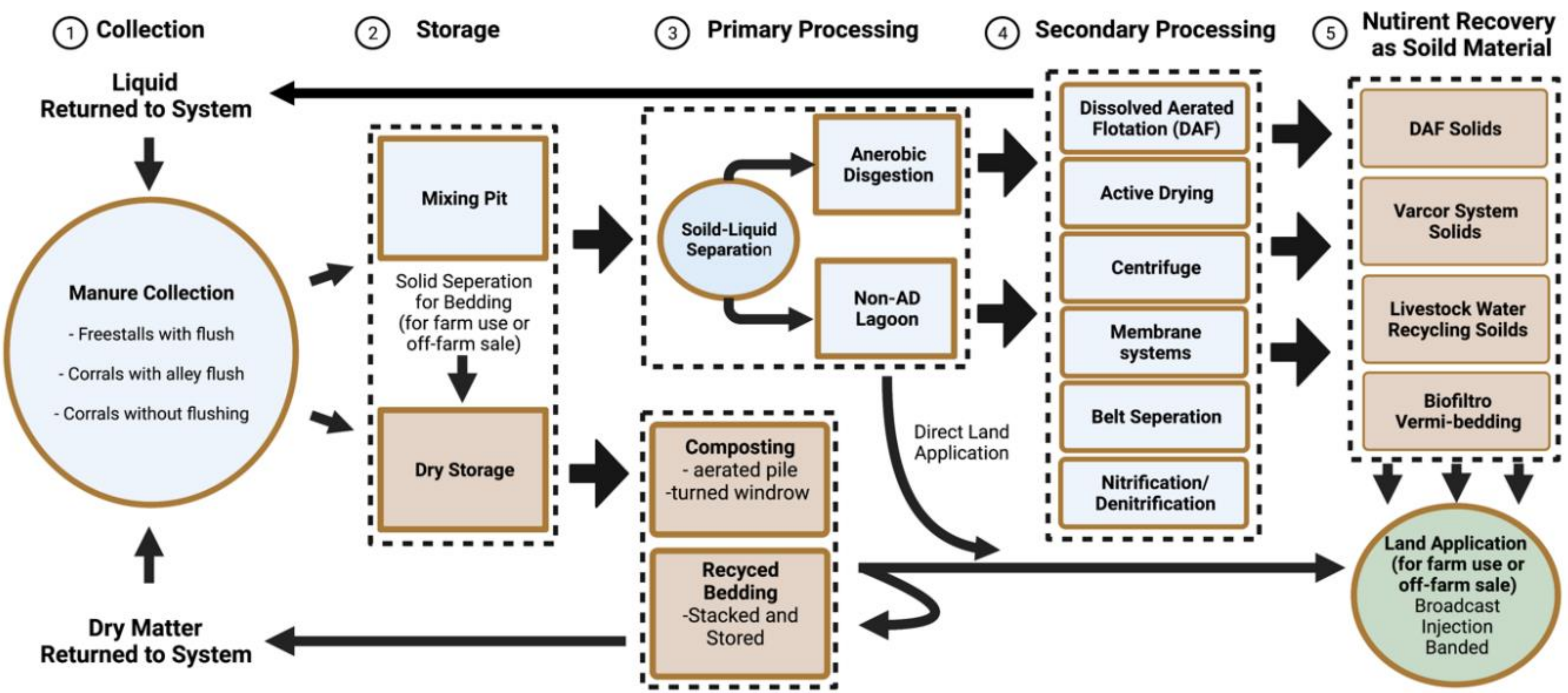
(3) Manure Nutrient Recovery Technologies

Most Manure treatment technologies fall into one of these categories:

Active Solids Drying	AD Support	Aeration
Ammonia Stripping	**Anaerobic Digestion**	Centrifuge
Chemical Flocculation	Clean Water Membrane Systems	**Composting**
Bedding Recovery	**Evaporative Technologies**	Gasification
General Support and Other	Hydrothermal Carbonization	**Nitrification Denitrification**
Pyrolysis	Rotary Screen	Sand Separation
Screw Press	Services	Slope Screen
Struvite Crystallization	Torrefaction	UF Membrane

NEWTRIENT Website: https://www.newtrient.com/Catalog/Dairy-Manure-101

Potential manure management pathways and nutrient recovery systems. Technologies evaluated here focus on the liquid manure fraction primarily.



Manure Treatment Technologies

Solid Manure

Active solids drying
Solids separation: Screens, centrifuges, screw presses, weeping walls, sand separation

Surplus Nutrient Reduction, Recovery and Reuse

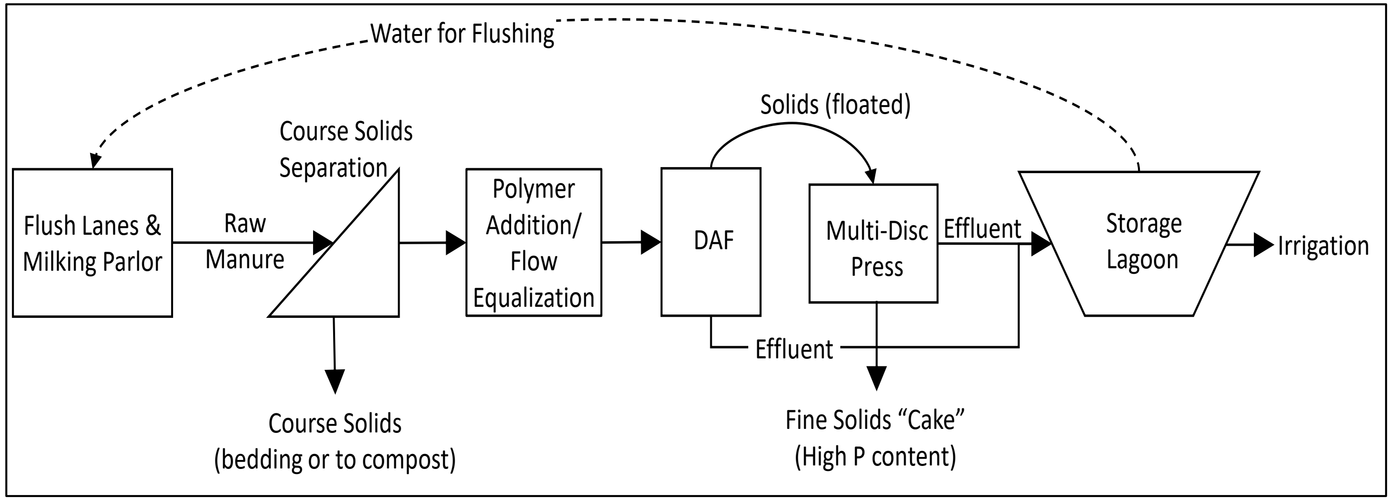
Sale of dry solids
Composting* and sale
Pyrolysis and gasification
Struvite crystalization
Torrefaction

Liquid Manure

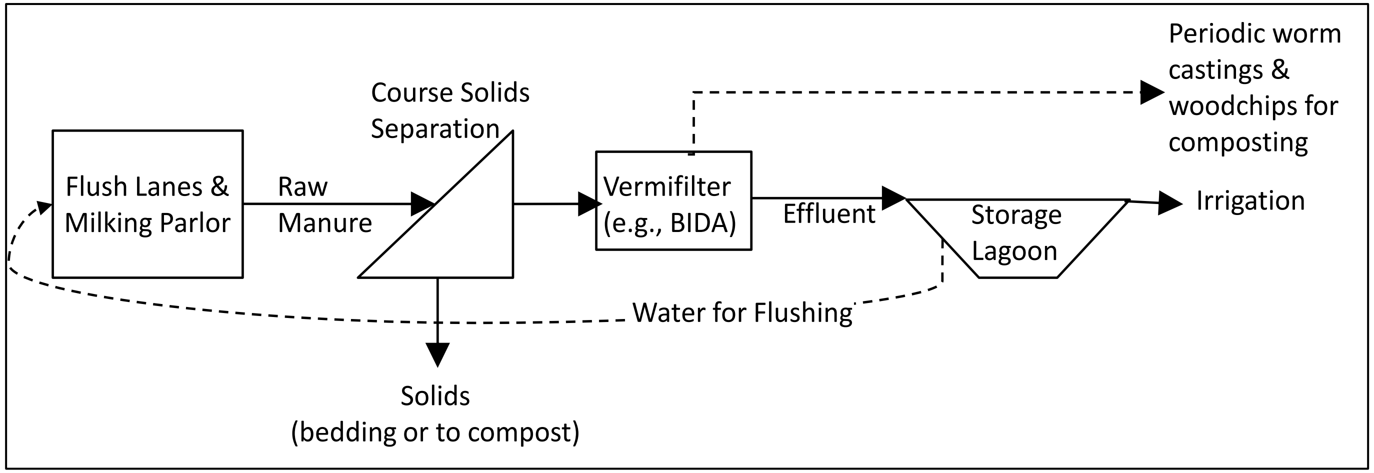
Aeration
Anaerobic Digestion*
Evaporation*

Algal raceways
Duckweed based systems

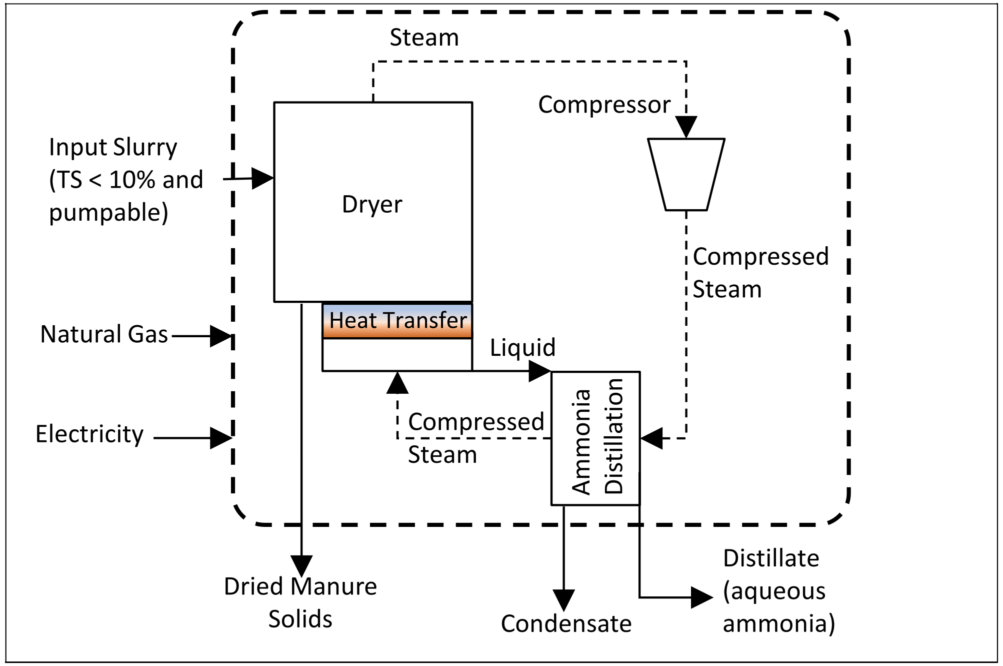
Ammonia stripping*
Chemical flocculation*
Membrane systems
Nitrification/denitrification (vermiculture*)



Typical layout of the Trident system at a flush dairy.



Schematic showing manure flow at a flush dairy with a vermifilter.



Sedron Varcor Schematic

Table 2. 1. Trident Nutrient Recovery System Cost Estimate for a 7000 cow dairy				
Adult Cows	Total Capital ($) [a]	O&M ($/y) [a, b]	Annual Cost ($, 10 year 8% loan) [c]	$/cow/y
7000	2,500,000	390,990	763,563	109

Notes:
[a] Angerman, (2019).
[b] Includes $164,000 (892,000 kWh/y) electricity consumption.
[c] Capital cost is amortized for 10 years at 8% interest.

Table 2. 1. BioFiltro Costs	
Capital Cost ($ cow^{-1})	Operation & Maintenance ($ cow^{-1} $year^{-1}$)
180 - 280	40 - 50

The Sedron-Varcor business model anticipates minimal cost to the dairy producer*

Table 4.1. Chemical characteristics of select manure-derived products						
Parameter	**Unit**	**COM**	**VER**	**DAF**	**LWR**	**SED**
Total C	%	21.6	96.6	22.6	18.3	34.5
Total N	%	2.6	6.6	3.0	2.0	3.3
NH_4^+	mg g^{-1}	0.98	1.89	0.84	1.16	1.35
NO_3^-	mg g^{-1}	0.27	0.39	1.64	0.37	0.25
C / N Ratio		8.5	14.5	7.4	9.4	10.4
NH_4^+ / TN Ratio		0.04	0.03	0.03	0.06	0.04
pH		9.3	8.3	6.8	8.5	8.2
EC	mS/m	7.3	2.1	4.5	0.8	17.9

Notes:

COM – Dairy manure compost; VER – Dairy manure from vermifiltration bedding; DAF – Dissolved aerated flotation solids; LWR – Livestock Water Recycling solids; SED – Varcor system (Sedron) solids

Total short-term mineralized N for the 5 amendments (COM, VER, LWR, DAF, SED) shown as a percentage of added organic N incubated at 3 temperatures (10°C, 20°C, 30°C) in two soil textures (Clay and Sand) for 28 days.

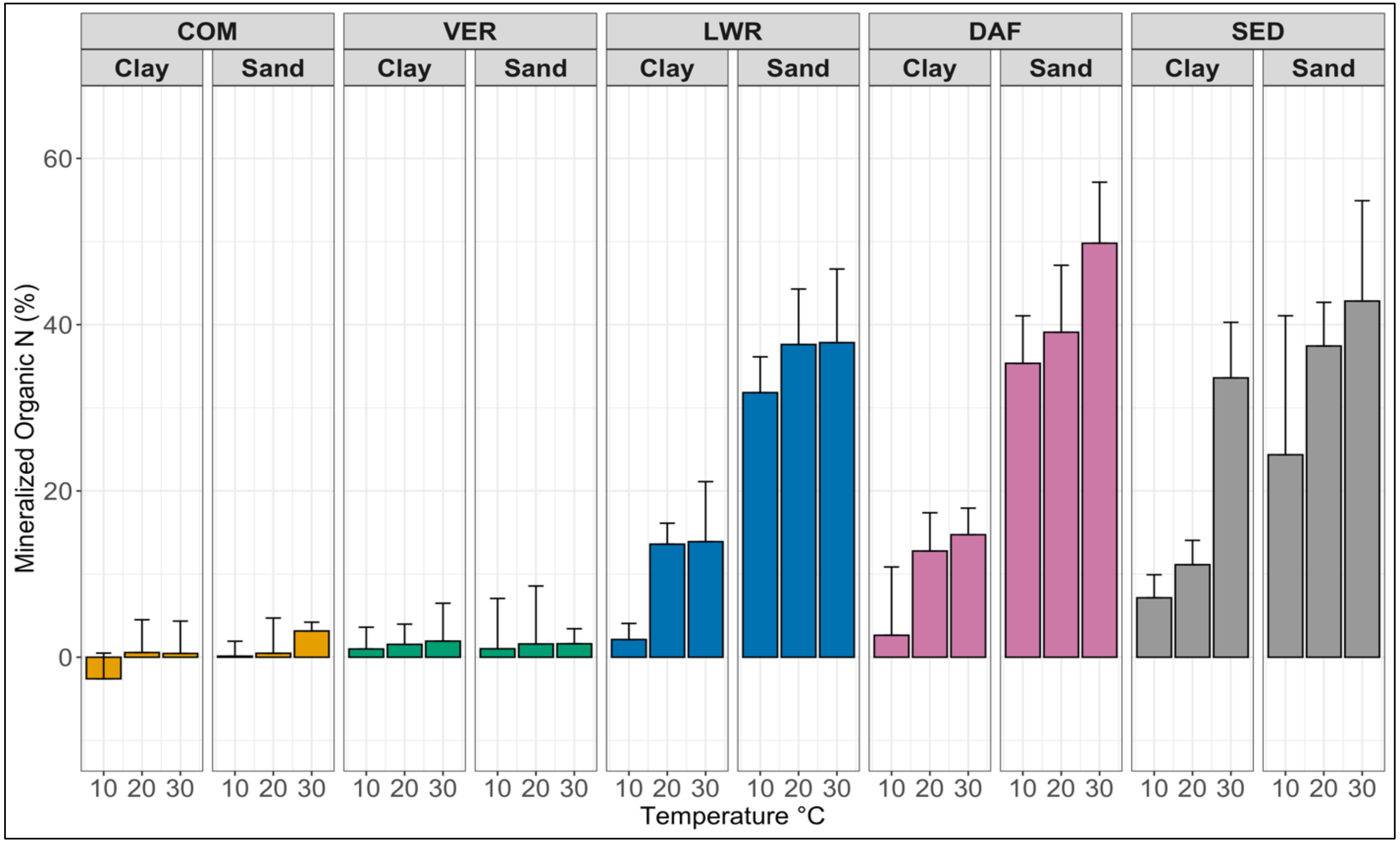


Table 5. 1. Nutrient product mass balance by waste treatment system.

Per kg manure dry matter input (kg)	Trident DAF System	Sedron VarCor System		Biofiltro Vermifiltration System	Anaerobic Digestion	Compost/ Windrow
		Aqueous ammonia distillate	Solid to compost			
Product dry matter (kg)	0.55	0.066*	0.98	1.24**	--	0.618
N output (kg)	0.0043	0.054	0.029	0.019	0.036	0.049
P output (kg)	0.0013	--	0.013	--	0.042	0.023
K output (kg)	0.0009	--	0.028	--	0.255	--
N replacement value	0.62	1	0.62	0.62	--	0.53

Notes:
*Solute mass reported for liquid nutrient product
**Includes addition of woodchips at an assumed 1:1 mass ratio

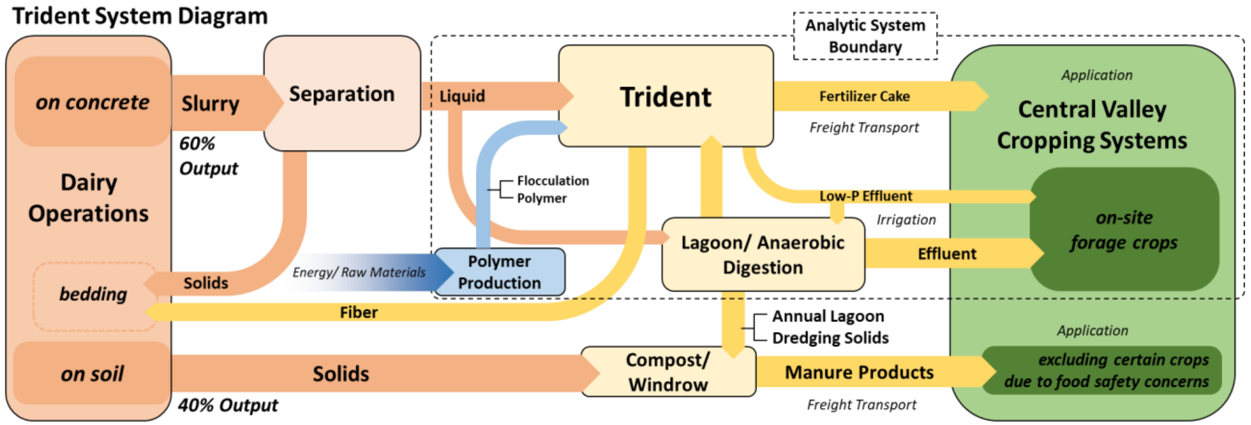
Table 5.1. Emission factors for methane and nitrous oxide for manure treatment processes. (kg per kg DM)

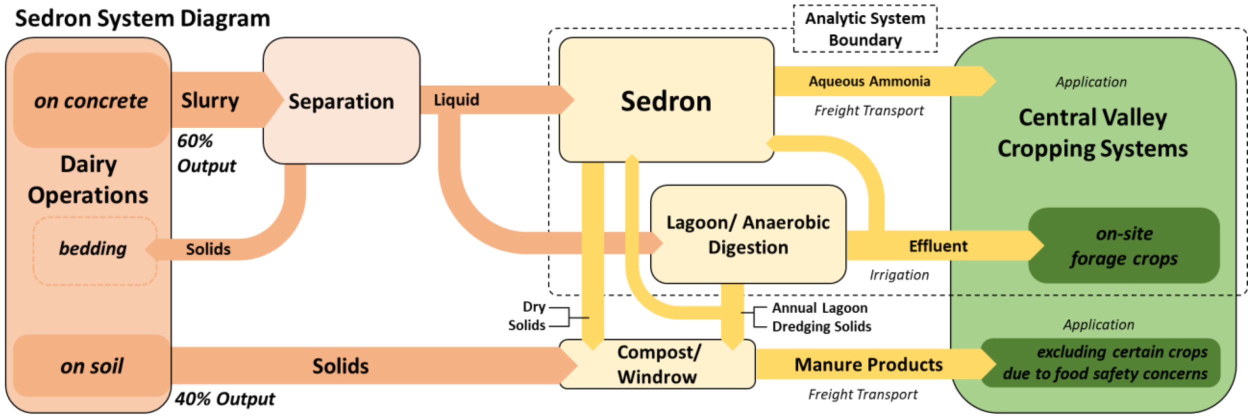
Emission kg per kg manure DM	**Anaerobic Digestion**	**Biofiltro Vermicomposting**	**Lagoon**	**Windrow Composting**
CH_4	0.0019	0.0016	0.101	0.037
N_2O	0.00024	0.00024	0.00028	--
*CH_4 post-Biofiltro**	0.00038	--	0.02	--

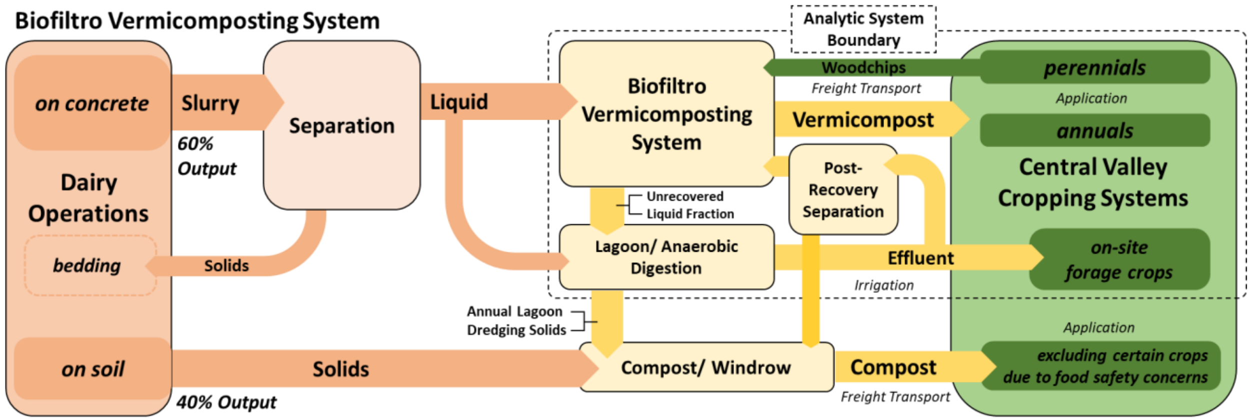
Notes:

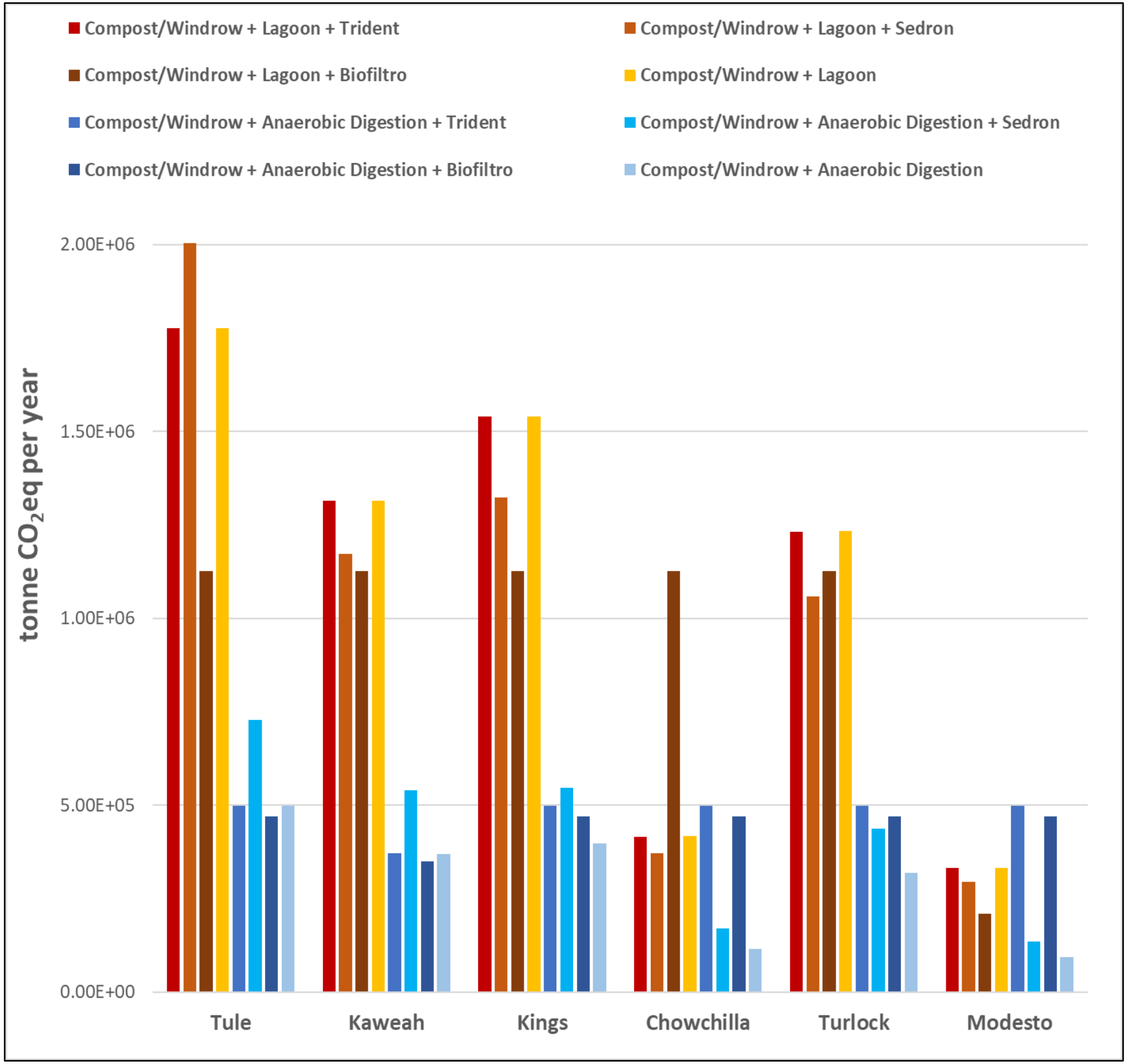
*Based on volatile solids (VS) reduction as described in section 2. These values are used to calculate the direct emissions component of the LCA results, converting input DM to CH_4 and N_2O emissions.

Flow diagrams for Life Cycle Assessment analyses









Total estimated GHG emission as tonnes CO2eq emission under different dairy waste management-nutrient recovery scenarios by nitrogen management zone (NMZ), assuming a distribution of manure dry matter of 48.75% in solid and 51.25% in liquid waste streams. The first 4 columns in each NMZ category represent uncovered lagoon-based processes, while the second 4 columns include anaerobic digestion systems with the treatment technologies.

Regional differences among NMZs are driven primarily by total dairy nutrient surpluses, with variability in nutrient product distribution playing a minor role in the total GHG footprint.

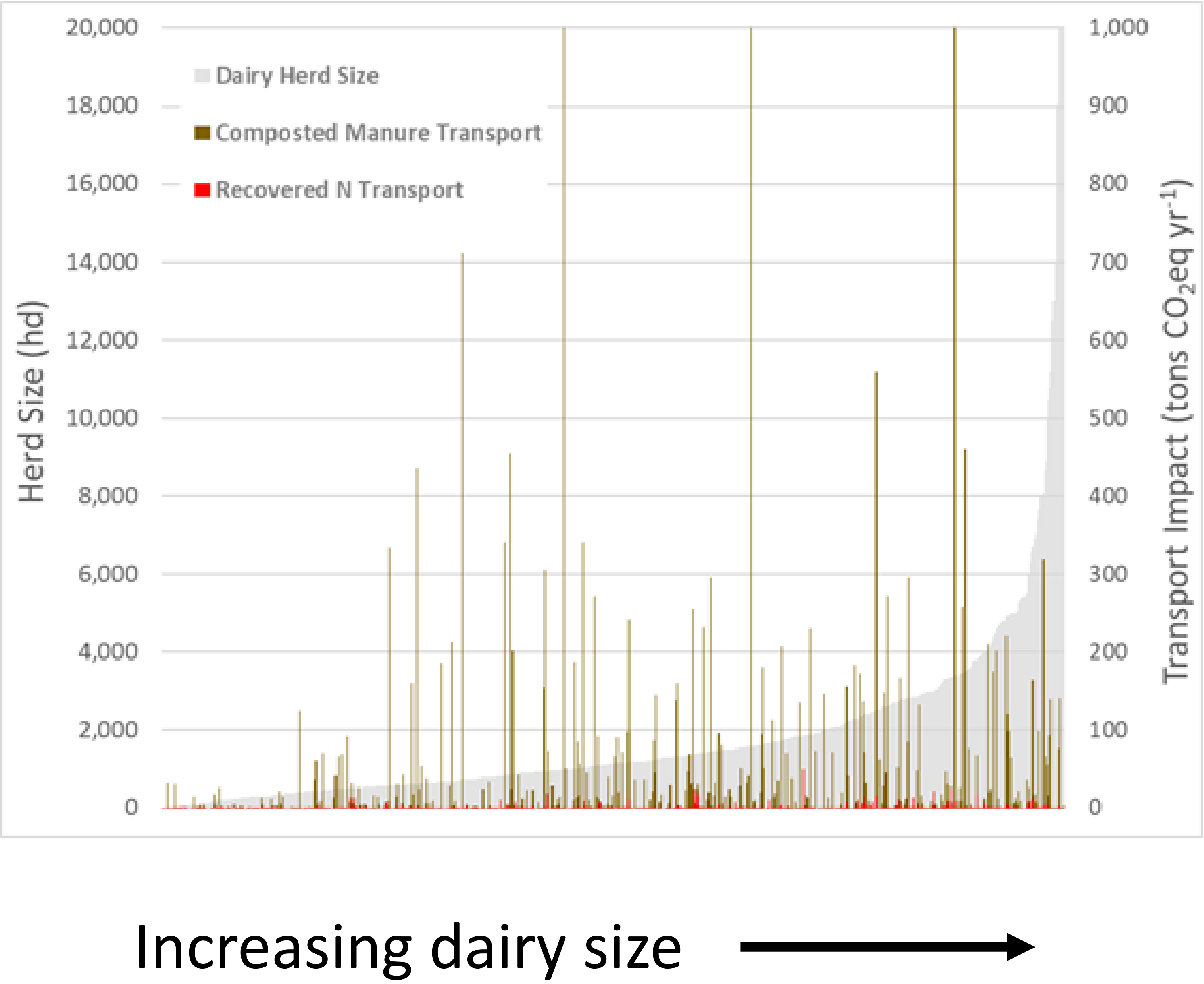
From a GHG emissions standpoint, the addition of Trident and Biofiltro processes to lagoon or AD produces an additional nutrient product while correspondingly reducing potential nutrient loading to fields and aquifers, but with no significant effect on GHG emissions.

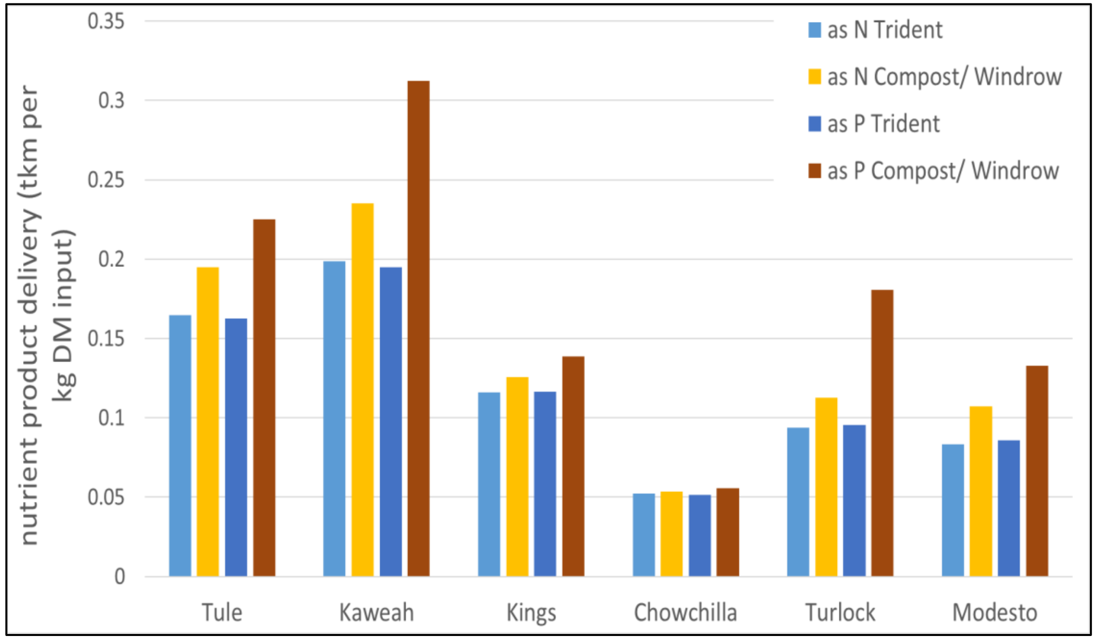
The use of AD systems has the largest effect on GHG emissions, recovery technologies have more modest effects.

Freight transport requirement for delivery of generic recovered N products or composted manure from dairies to non-dairy cropping systems.

Calculated by multiplying annual product mass (I.E., metric tonnes produced at each dairy) by transport distance (kilometers) to produce tonne-kilometer (tkm) freight transport impact values on a per-trip basis. Tkm values are then converted to tons CO_2eq using life cycle inventory data (from EcoInvent LCI database) and GWP_{100} impact characterization factors (from USEPA TRACI 3.1).

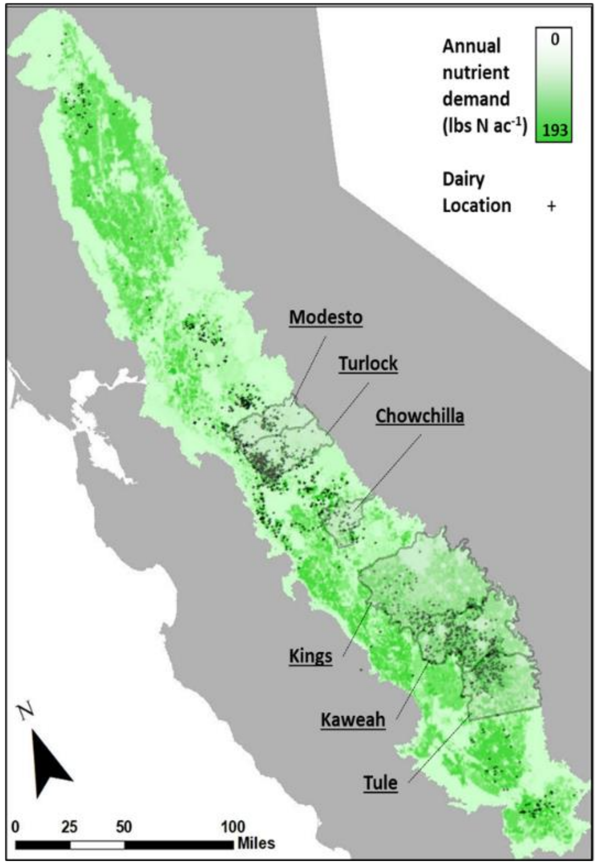
The x-axis is ordered by increasing dairy herd size (grey fill). Red lines indicate GWP_{100} impact of delivery of generic recovered nutrient product to cropland, while brown lines indicate GWP_{100} impact for delivery of composted manure to cropland. Transport requirements are determined by the distances between dairy sources and crop fields available to accept nutrients, specific to crop type and annual nutrient demand

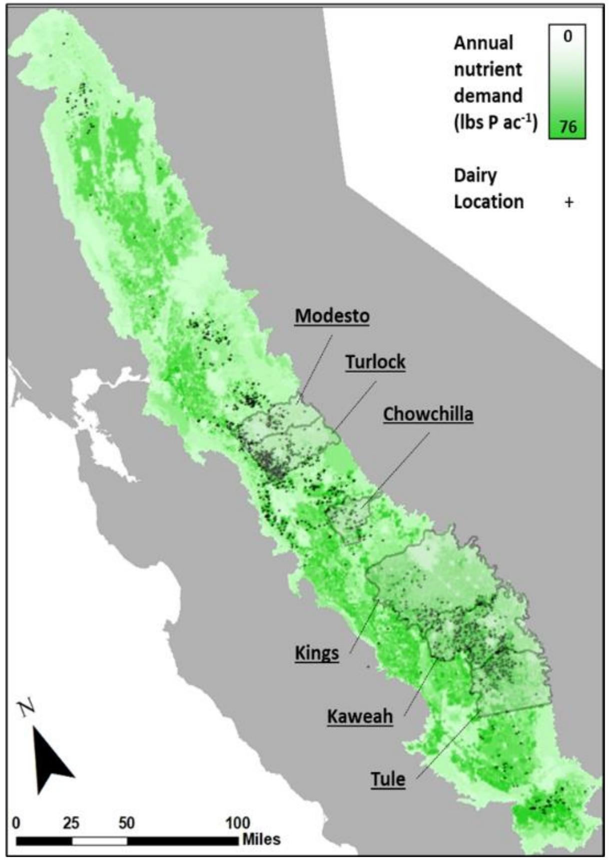




Freight transport requirement by nitrogen management zone, nutrient (N or P), and technology, using the Trident technology and composting as examples**.**

Compost has lower nutrient density and requires greater transport than more concentrated manure solids.





Potential crop nutrient demand for surplus dairy farm N and P

Conclusions:

This analysis is focused on the potential for surplus nutrient recovery and removal on dairy farms and its potential reuse on non-dairy farms in California. Data on the highest priority nutrient management zones was evaluated.

The dairy industry in CA is not monolithic. Dairy farms in CA are very diverse in structure, cow numbers and manure management systems employed. There are large regional differences.

Farms with larger stocking rates (> 4 cows + replacements per acre), have larger amounts of nutrients on average than can be recovered by annual forage crops, based on the data used here and assumptions made about the amounts of nutrients conserved in manures and available for application to fields.

Conclusions:

Several nutrient recovery technologies available for the treatment of liquid manures on dairies were evaluated. Each have benefits and disadvantages, and involve tradeoffs among costs, amounts and types of nutrients recovered, and potential for non-dairy farm reuse.

Most of these technologies reduce GHG emissions, but less than the use of anaerobic digestion systems to treat liquid manure fractions. To maximize GHG benefits, they are best deployed in sequence with AD systems.

Surpluses also exist in the form of solid manures. There are fewer ways to treat solid manure, and wide spread distribution commonly comes with large GHG costs for transport and application.

Creative policy and regulatory incentives are need to optimally address improved management of surplus manure nutrients on California’s dairy farms.

(4) Supplemental slides

Assumptions and Calculations used to estimate nutrient surpluses

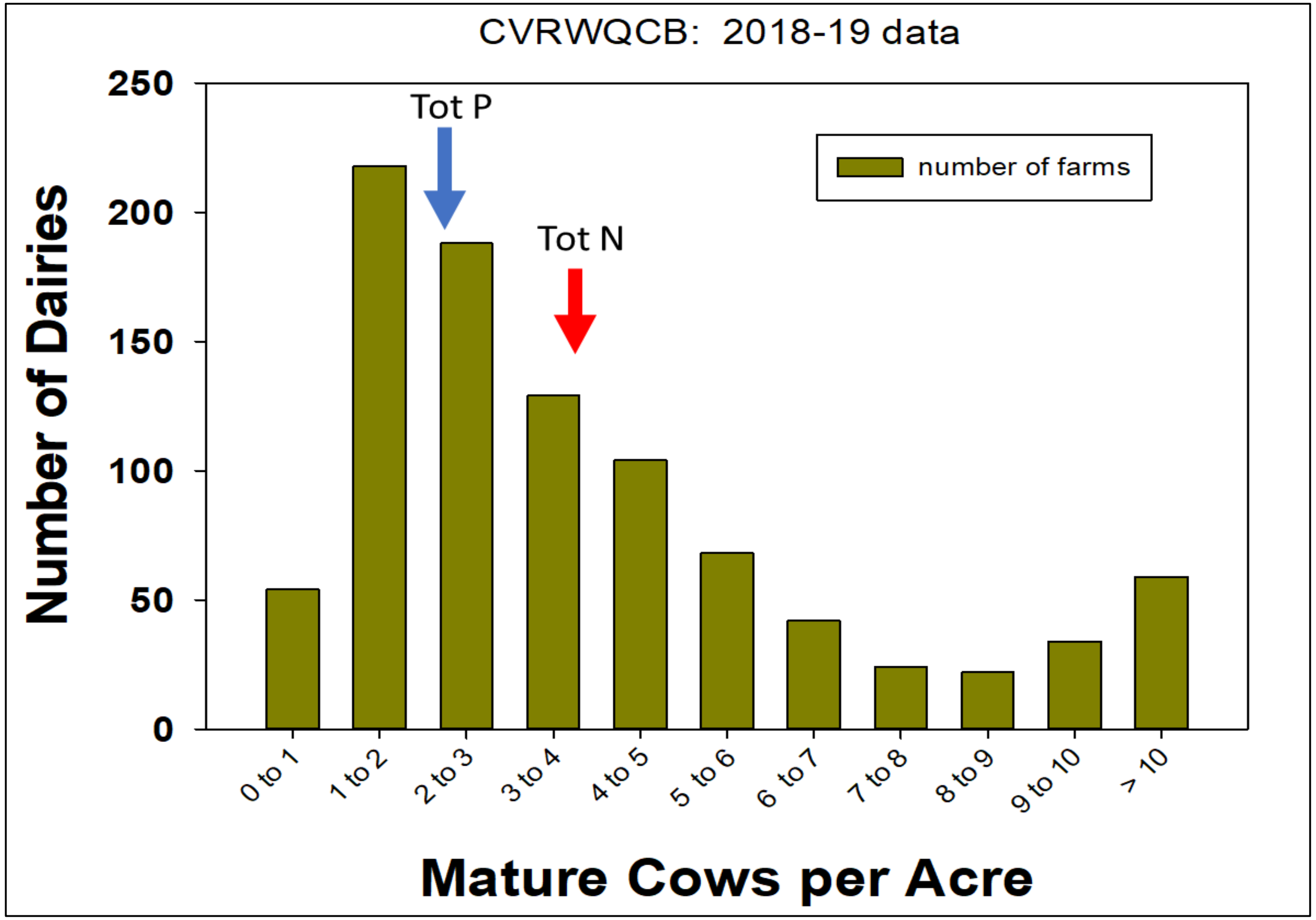
Table1. 1.A. Variables, units, and values used for calculating manure N surpluses

Variable	Units	Symbol	value	Source(s)
Manure N excreted per matue cow + replacements	lb N/yr	MN	440	Harter et al, 2012; Pettygrove et al, 2009; Chang et al.,2006; others
Stocking rate	# of mature cows per farm per acre receiving manure	SR	1 to 36	Calculated from data from CVRWQCB
Free stall farm (FS): fraction of MN falling on concrete (= liquid manure (LM))	unitless	FS_{LM}	0.6	Meyer et al., 2019; Davidyan, 2021, Harter et al., 2017; Lorimor,et al., 2005, other sources
Fraction of LM conserved	unitless	LMcon	0.7	Meyer et al., 2019; Davidyan, 2021, Harter et al., 2017; Lorimor,et al., 2005 other sources
FS fraction of manue N falling in corrals as solid manure (SM)	unitless	FS_{sm}	0.4	by difference and similar to above
Open lot farm (OL): fraction of LM	unitless	OL_{LM}	0.35	Meyer et al., 2019; Davidyan, 2021, Harter et al., 2017; Lorimor,et al., 2005 other sources
OL: fraction falling in corrals as solid manure	unitless	OL_{SM}	0.65	Meyer et al., 2019; Davidyan, 2021, Harter et al., 2017; Lorimor,et al., 2005 other sources
MN sold off farm	unitless	MN_{sold}	0.2	Parsons and Harter , 2018
Acres receiving MN per farm	acres	ac	from data	CVRWQCB data
N removed by crops (cereal+corn silage)	lb N/ac/yr	CR_{2crop}	400	Chang et al., 2006, Miller etal., 2017
N removed by crops (cereal+corn silage+ sudan grass hay)	lb N/ac/yr	CR_{3crop}	560	Chang et al., 2006, Miller etal., 2017
Application ratio of MN to crop uptake	unitless	AR	1.4	Chang et al, 2006; CVRWQCB
Fertilizer N applied to fields (corn silage)	lb N/ac/yr	Fert N	50	Diverse sources

Table 1.9.B. Calculations for surplus manure N per dairy farm

Variable	Equation	Purpose
MN	440*SR	Total raw manure N per acre for cows + replacements (lbs) based on the stocking rate on each farm in the data base
FS_MN_{cons}	$MN*(FS_{LM} * LM_{cons}) + MN*(FS_{SM} * SM_{cons})$	Calculates MN available (conserved) after volatilization losses on a free stall (FS) dairy, per cow equivalent
OL_MN_{cons}	$MN*(OL_{LM} * LM_{cons}) + MN*(OL_{SM} * SM_{cons})$	Calculates MN available after volatilization losses on an open lot dairy, per cow equivalent
FS_MN_{sold}	$FS\_MN_{cons} *0.2$	Assumes 20 % of total manure N (after volatilization losses) is sold
OL_MN_{sold}	$OL\_MN_{cons} *0.2$	Assumes 20 % of total manure N (after volatilization losses) on an open lot dairy is sold
FS_MN_{net}	$FS_{LM} *LM_{cons} + (FS_{SM} * SM_{cons} – FS\_MN_{sold})$	Assumes only SM is sold. Deducts total MN_{sold} only from the SM fraction on a free stall farm.
OL_MN_{net}	$OL_{LM} *LM_{cons} + (FS_{SM} * SM_{cons} – FS\_MN_{sold})$	Assumes only solid manure is sold on an open lot dairy. Deducts total MN_{sold} only from the SM fraction on an open lot farm.
CROP_N	$CR_{xcrops} *AR$	MN recovered by crops (x = either a 2 or 3 crop system)
$FS\_MN_{surplus}$	$(FS\_MN_{net} + FertN – CROP\_N)*ac$	MN left after volatilizations losses, sales and crop removal based on the number of cows per acre and the number of acres per farm on a free stall dairy.
$OL\_MN_{surplus}$	$(OL\_MN_{net} + FertN – CROP\_N)*ac$	MN left on an open lot dairy after volatilizations losses, sales and crop removal based on the number of cows per acre and the number of acres per farm on an open lot dairy.

The stocking rate threshold for whole farm nutrient balance depends on the regulatory basis used to judge balance. Results differ if N or P is used.



Approximate stocking rate thresholds associated with P or N based standards for manure applications (Tot N is based on this study; Tot P based on Pettygrove et al, 2009**)**. A commonly recommended N:P ratio for corn crops is five to one. But manure is enriched in P relative to N compared to common fertilizers. Samples in California collected and analyzed by Pettygrove et al., (2009) reported N:P ratios of 2.3 to 3.0. Using these values, the allowable N amount applied as manure would decline to ≈ 60 % or less than the amount that can be applied using a N basis for application, and reduce threshold stocking rates as calculated here by approximately that amount.