Utilizing Dairy Manure as Biofertilizer and Organic Matter Amendments

Abdolhossein Edalati
Ph.D. Student
Department of Biological and Agricultural Engineering
University of California, Davis

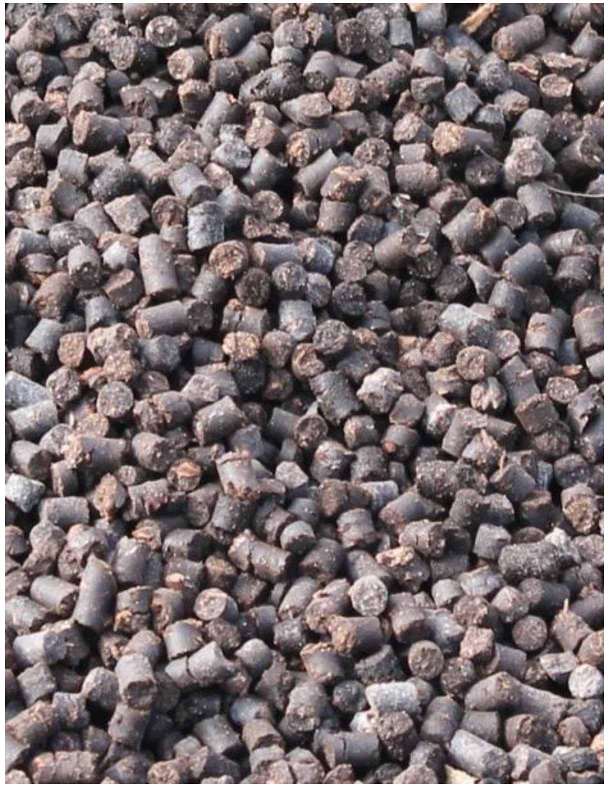
2022 California Biomass Alliance Symposium (Virtual)
Wednesday, November 9th, 2022

Biofertilizer Production from Dairy Manure

- Created pathogen free and easy-to-use pelletized products from anaerobically digested manure and composted manure
- Tested the biofertilizer products for producing corn and almonds.

CALIFORNIA DAIRY RESEARCH FOUNDATION
Science for a Sustainable Future





Manure Solids – Compost – Pellets

Manure Solids Compost Composition and Properties

- Organic Matter (%):37.5
- NPK (%): 1.25-0.35-0.90
- Pelletization reduced volume and increased the stability of compost.

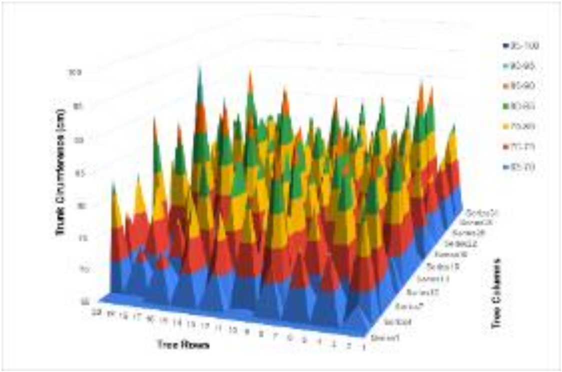
Manure Solids Compost Composition

Parameter	Units	Compost	Compost Pellets
Bulk Density	lb/cu ft	26	50
Total Nitrogen (TN)	% db	1.20	1.33
Total Phosphorus (TP)	% db	0.31	0.39
Potassium (K)	% db	0.76	1.00
Organic Matter (OM)	% db	36.3	39.2
C:N Ratio (C:N)	Ratio	17:1	17:1
Sodium (Na)	% db	0.25	0.29
Sulfur (S)	% db	0.35	0.32
Calcium (Ca)	% db	1.50	1.70
Magnesium (Mg)	% db	0.440	0.480

Field Measurements

- **Compost & soil quality/safety**
  - Physicochemical properties
  - Pathogens: *E.coli* and *Salmonella*

- **Tree health & almond quality/safety**
  - Trunk circumference
  - Almond yield
  - Pathogens: *E.coli* and *Salmonella*



- **Soil emission (CO_2, CH_4 and N_2O)**
  - Static chambers were used to measure soil emission fluxes

Acknowledgements

Project Sponsors

- California Dept. of Food and Agriculture
    - Health Soils Program
    - Alternative Manure Mgmt. Program
- Almond Board of California
- California Dairy Research Foundation
- UC Davis BAE Department

cdfa
CALIFORNIA DEPARTMENT OF FOOD & AGRICULTURE

CALIFORNIA DAIRY RESEARCH FOUNDATION
Science for a Sustainable Future

california almonds
Almond Board of California

CALIFORNIA CLIMATE INVESTMENTS
Cap and Trade Dollars at Work

100 YEARS 1915 - 2015
UCDAVIS
BIOLOGICAL AND AGRICULTURAL ENGINEERING

Research Collaborators

Dairy and Almond Farmers
The Farm Personnel
Members of the UC Davis Zhang Lab
Members of the UC Davis Pandey Lab
Dan Rivers, UC Cooperative Extension
Guangwei Huang, Almond Board CA
John Faria, JPT Composting and Spreading
Kyle Nichols, Nichols Custom Ag Services
Frank Silva, Silva & Sons Custom Spreading
Dave Thiel, Cortez Almond Grower's Assn
Manager at Almond Tree Huller
Jonathan Cloward, Kamps Hulling
McKennan Buckner, RDO Equipment Co.

Research Goal and Objectives

Goal: Recycle dairy manure on almond orchards as nutrient rich, safe, organic matter amendments, while sequestering carbon and providing economical and sustainable benefits to the soil, crop, and environment.

Objectives:

1. Evaluate the performance of an advanced, mechanical solid-liquid separations system with centrifuge to separate solid manure from flush manure on a California Dairy;
2. Investigate the on-farm composting of dairy manure and produce pelletized amendments from the compost;
3. Apply the loose and pelletized amendments using a conventional orchard applicator, and study/compare pelletized manure and manure-sticks compost;
4. Study the affect of these organic amendments on the soil and the trees as it relates to: carbon sequestration, soil physicochemical properties, pathogens, and soil GHG emissions; and tree health, almond yield, and consumer safety.

Research Goal and Objectives

Goal: Recycle dairy manure on almond orchards as nutrient rich, safe, organic matter amendments, while sequestering carbon and providing economical and sustainable benefits to the soil, crop, and environment.

Objectives:

1. Evaluate the performance of an advanced, mechanical solid-liquid separations system with centrifuge to separate solid manure from flush manure on a California Dairy;
2. Investigate the on-farm composting of dairy manure and produce pelletized amendments from the compost;
3. Apply the loose and pelletized amendments using a conventional orchard applicator, and study/compare pelletized manure and manure-sticks compost;
4. Study the affect of these organic amendments on the soil and the trees as it relates to: carbon sequestration, soil physicochemical properties, pathogens, and soil GHG emissions; and tree health, almond yield, and consumer safety.

The California Dairy Industry and Challenges

Dairy Industry

- #1 commodity at $6.4B in sales
- ~19% US milk/cheese production
- #3 Agricultural Export: $1.7B
- 2.5 (1.7 milking) out of 5.2M cattle

Challenges

- Increased herd concentration
- Impact our air and water quality
- Tough regulatory/business environment
- Generate tons of manure

CA Agricultural Statistics Review, 2018-2019

Challenges: Herd Concentration and Manure Management

Challenges of Manure Management

- 120 lb manure/day/cow wet basis
- Manure = to CA human population
- ~50% of CA methane emissions
- N leaching, impact on water and air quality
- Industry consolidating over time

Illustration by Susie Cagle

Dairy Concentration (NASS, 2016, CDFA 2015)

- Dairy have consolidated dramatically in the last 4 decades (table below):

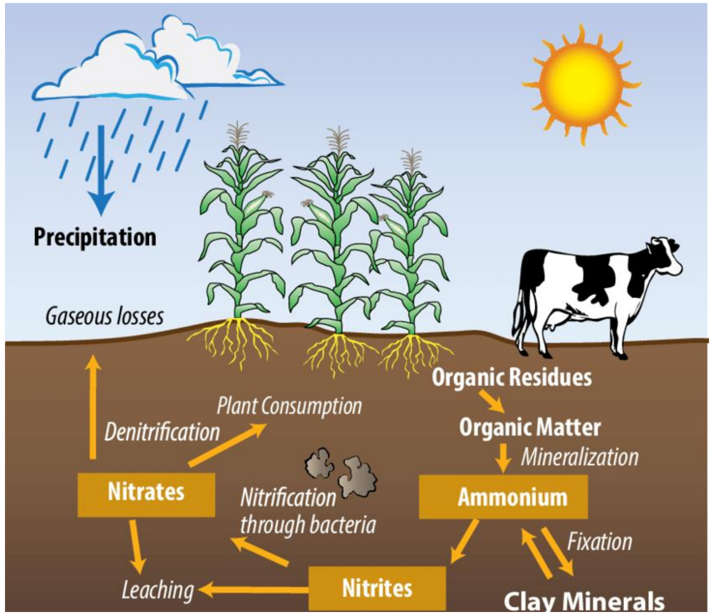
California Dairy Farm inventory 1982-2016 (NASS)

						Not adjusted for coverage		
	2016	**2012**	**2007**	**2002**	**1997**	**1992**	**1987**	**1982**
Milk cows (farms)	1,392	1,548	2,165	2,793	2,922	3,124	3,631	4,638
Milk cows (number)	1,738,090	1,815,655	1,840,730	1,644,692	1,406,884	1,249,038	1,070,366	946,201
Average Dairy Size (#/F)	1,249	1,173	850	589	481	400	295	204

CA Agricultural Statistics Review, 2015, 2018-2019

USDA National Agricultural Statistics Service, 2016

California Dairies: Herd Concentration



The Nitrogen Cycle *(Verhulst, 2014)*

Challenges of Manure Management

- 120 lb manure/day/cow wet basis
- Manure = to CA human population
- ~50% of CA methane emissions
- N leaching, impact on water and air quality
- Industry consolidating over time

Dairy Concentration (NASS, 2016, CDFA 2015)

- Dairy have consolidated dramatically in the last 4 decades (table below):

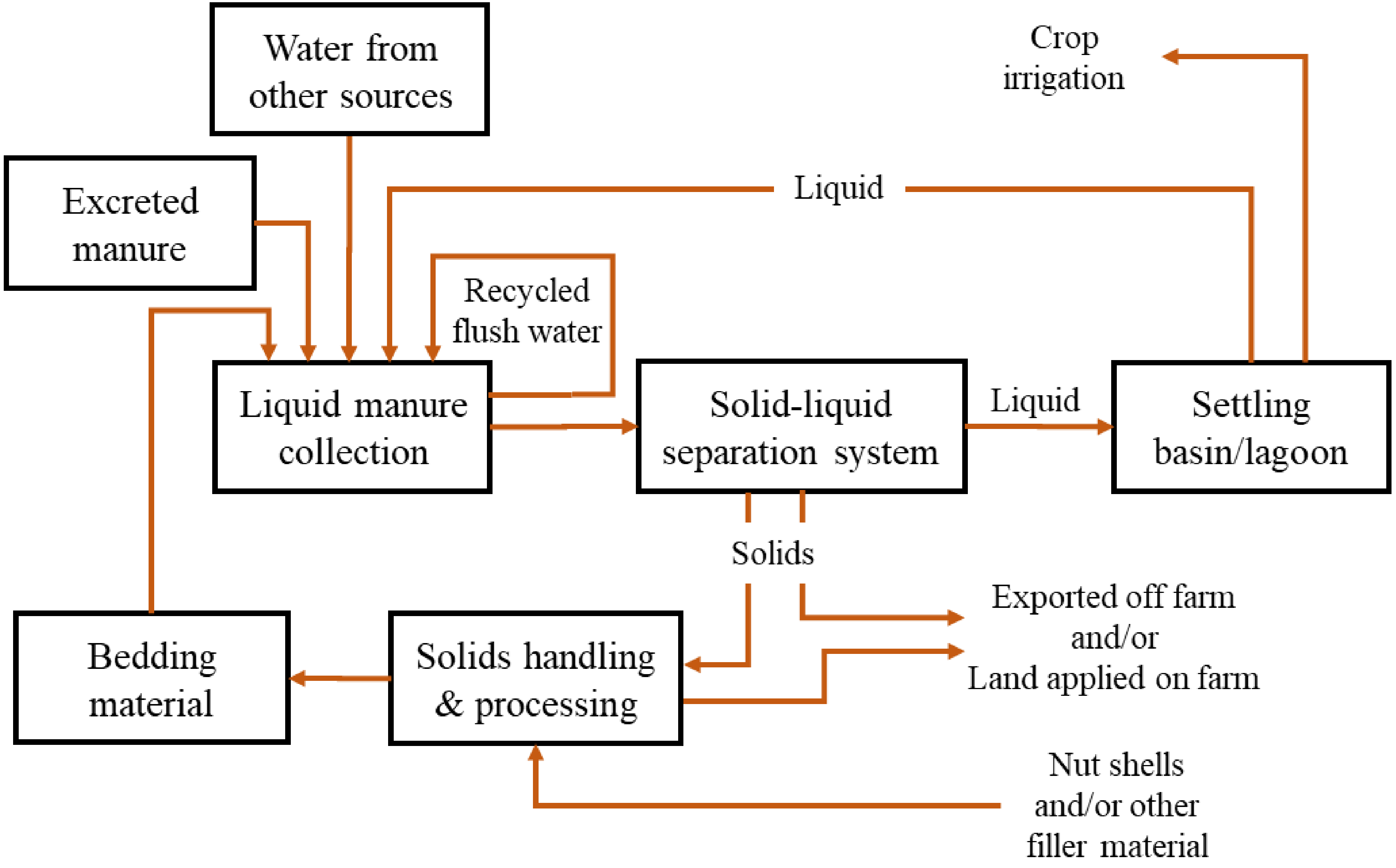
California Dairy Farm inventory 1982-2016 (NASS)

						Not adjusted for coverage		
	2016	2012	2007	2002	1997	1992	1987	1982
Milk cows (farms)	1,392	1,548	2,165	2,793	2,922	3,124	3,631	4,638
Milk cows (number)	1,738,090	1,815,655	1,840,730	1,644,692	1,406,884	1,249,038	1,070,366	946,201
Average Dairy Size (#/F)	1,249	1,173	850	589	481	400	295	204

CA Agricultural Statistics Review, 2015, 2018-2019

USDA National Agricultural Statistics Service, 2016

Flush Manure Management System on a California Dairy



Background: Solid-liquid separators, research motivation, and questions

Solid-liquid separators

- Generate solids for bedding and compost
- $\downarrow$ organic loading to lagoons → $\downarrow$ CH_4 emissions
- Mostly sloped/scraped screens in CA (Flaherty, 2017)
- Other tech (weeping walls, advanced systems)
- Good alternative to digesters because:
  (1) digesters expensive,
  (2) methane is cheap, and
  (3) digester management is complicated

From 2017-21 we studied an advanced, multistage separator system in the California Central Valley and evaluated its solids removal efficiency and composted solids from the separator. In 2021, the farmer had a centrifuge installed on that system.

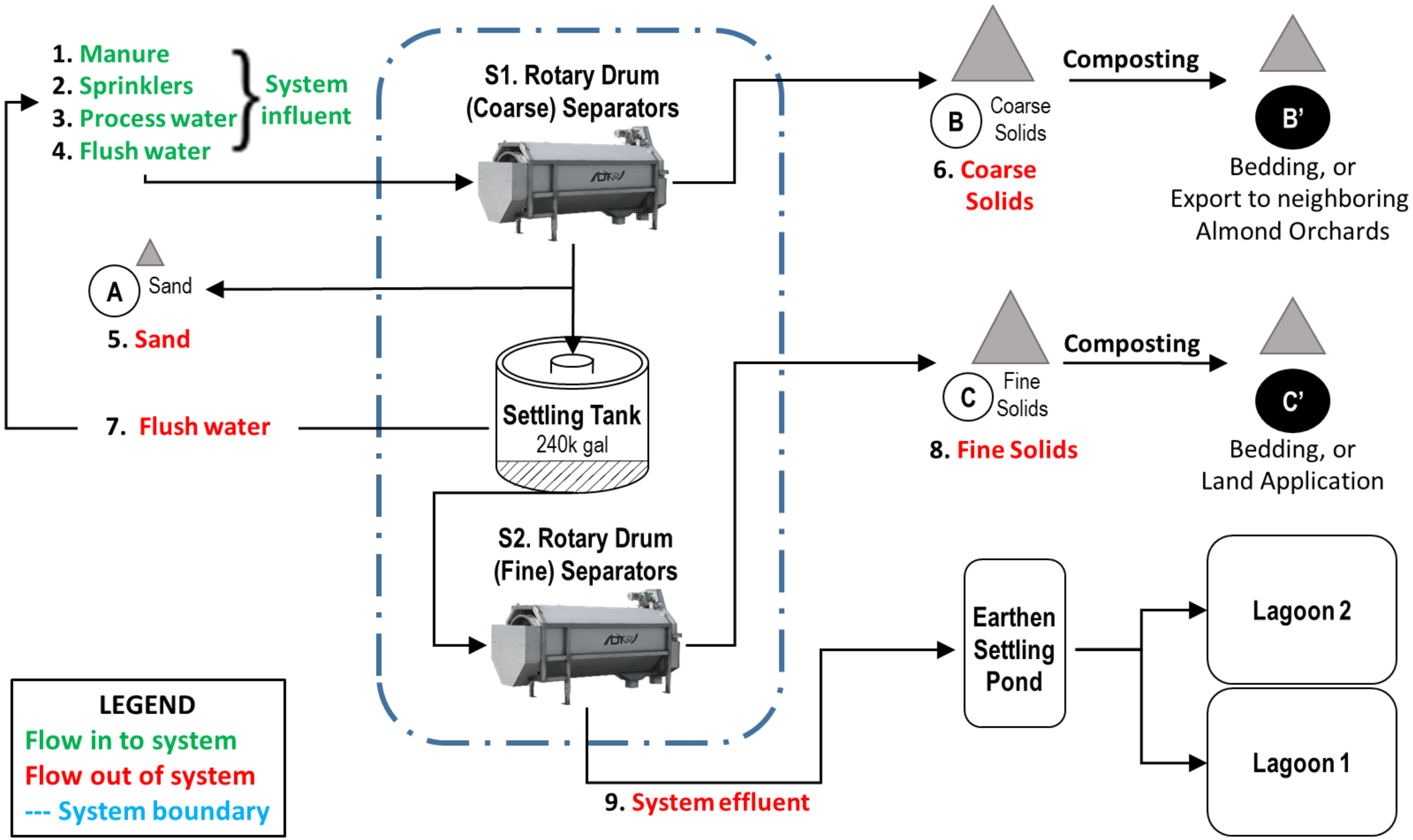
Background: Solid-liquid separators, research motivation, and questions

Solid-liquid separators

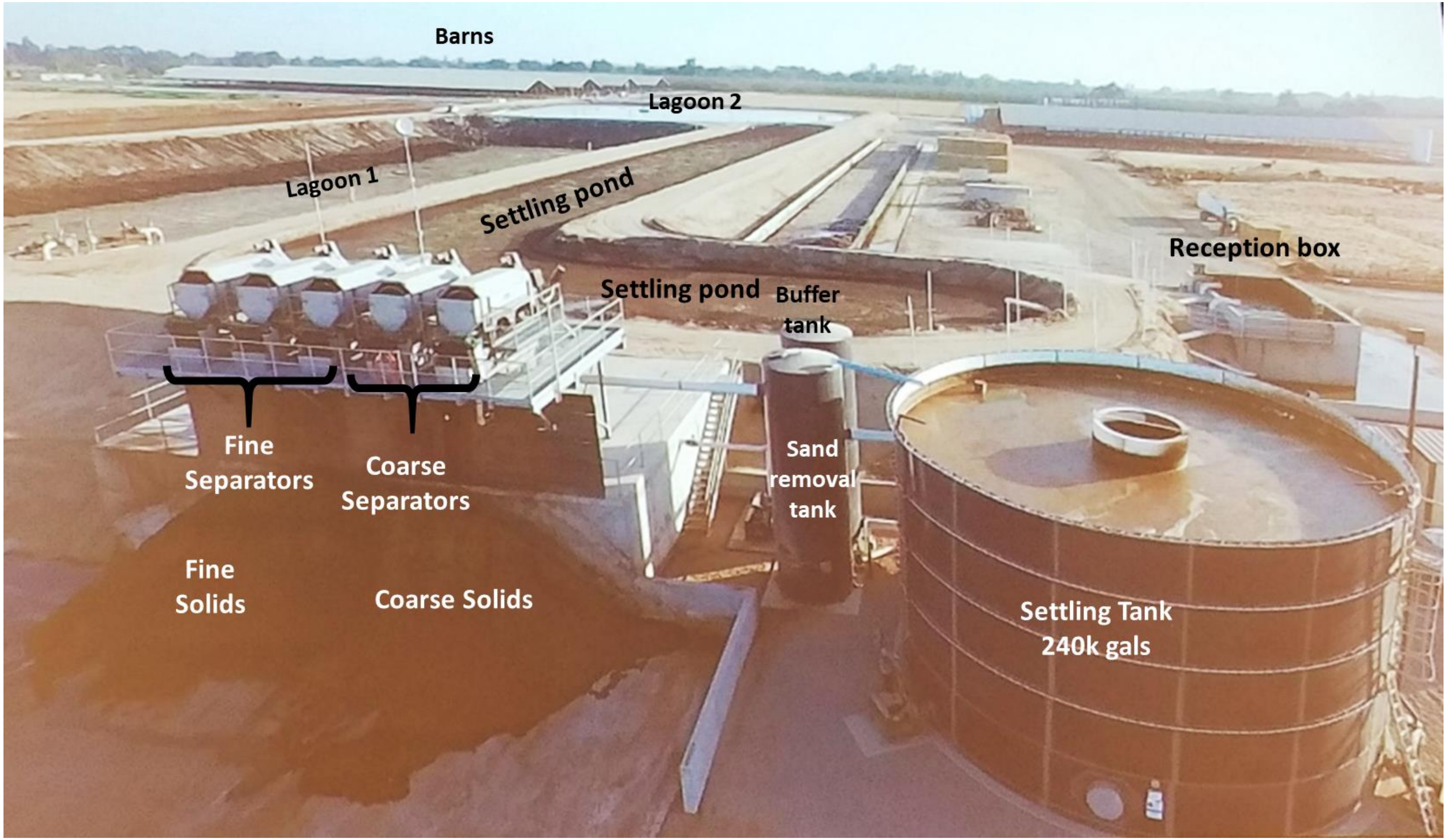
- Generate solids for bedding and compost
- ⬇ organic loading to lagoons → ⬇ CH_4 emissions
- Mostly sloped/scraped screens in CA (Flaherty, 2017)
- Other tech (weeping walls, advanced systems)
- Good alternative to digesters because:
    (1) digesters expensive,
    (2) methane is cheap, and
    (3) digester management is complicated

From 2017-21 we studied an advanced, multistage separator system in the California Central Valley and evaluated its solids removal efficiency and composted solids from the separator. In 2021, the farmer had a centrifuge installed on that system.

Advanced Multistage Separator System



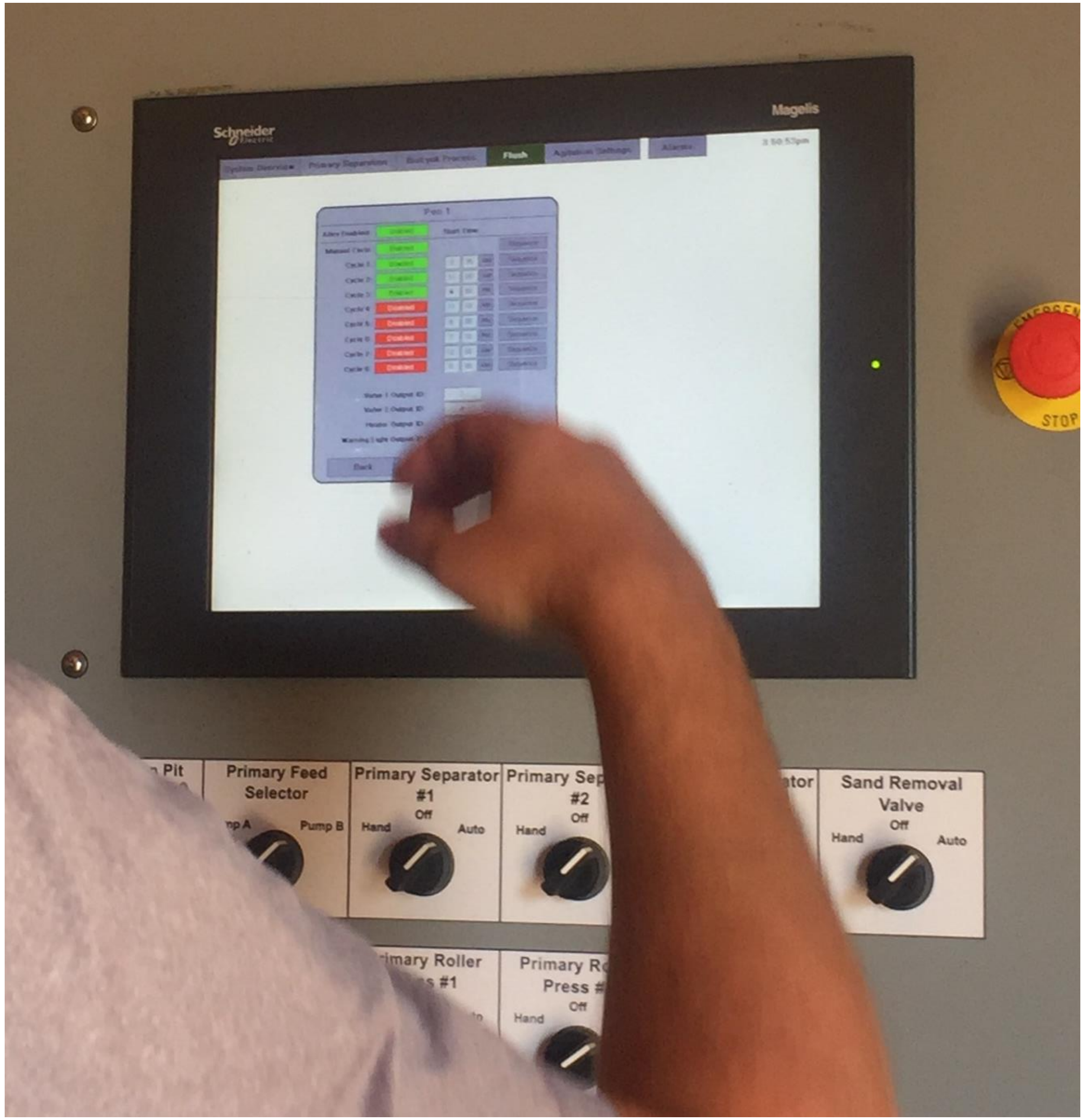
Advanced Multistage Separator System

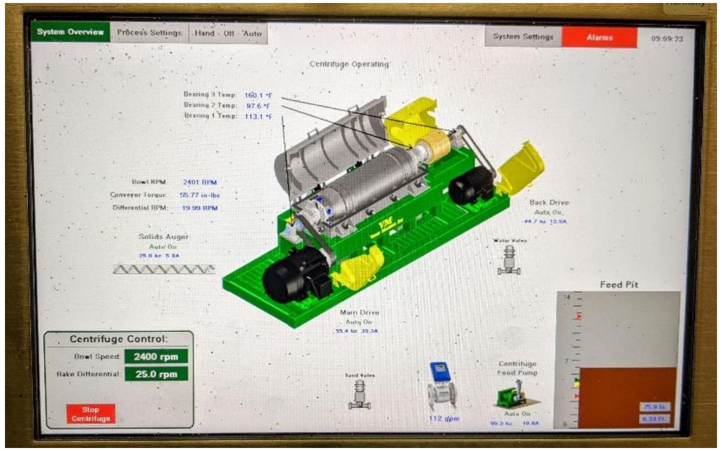


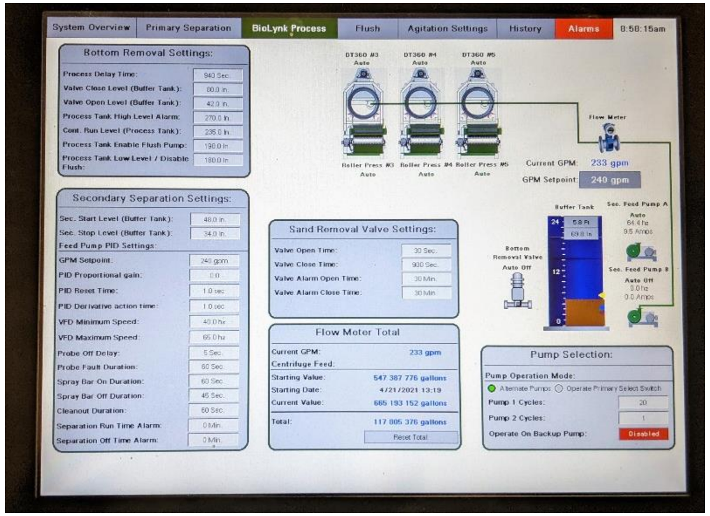
Description of Advanced Multistage Separator System

- Milking cows: 2,600; Dry cows and heifers: 700; Breed: Jersey cow
- Sand removal limited, lots of sand in the flush
- Separators and Screen Size
    - 1st stage: 2 units coarse rotary drum separators (3.175 mm)
    - 2nd stage: 3 units fine rotary drum separators (533 µm)
    - Settling tank in between 1st and 2nd stage separators
    - Recent addition: Centrifuge System
- Flush water: Settling tank and process water

Description of Advanced Multistage Separator System







System Control and Automation

Description of Advanced Multistage Separator System

Rotary drum separator

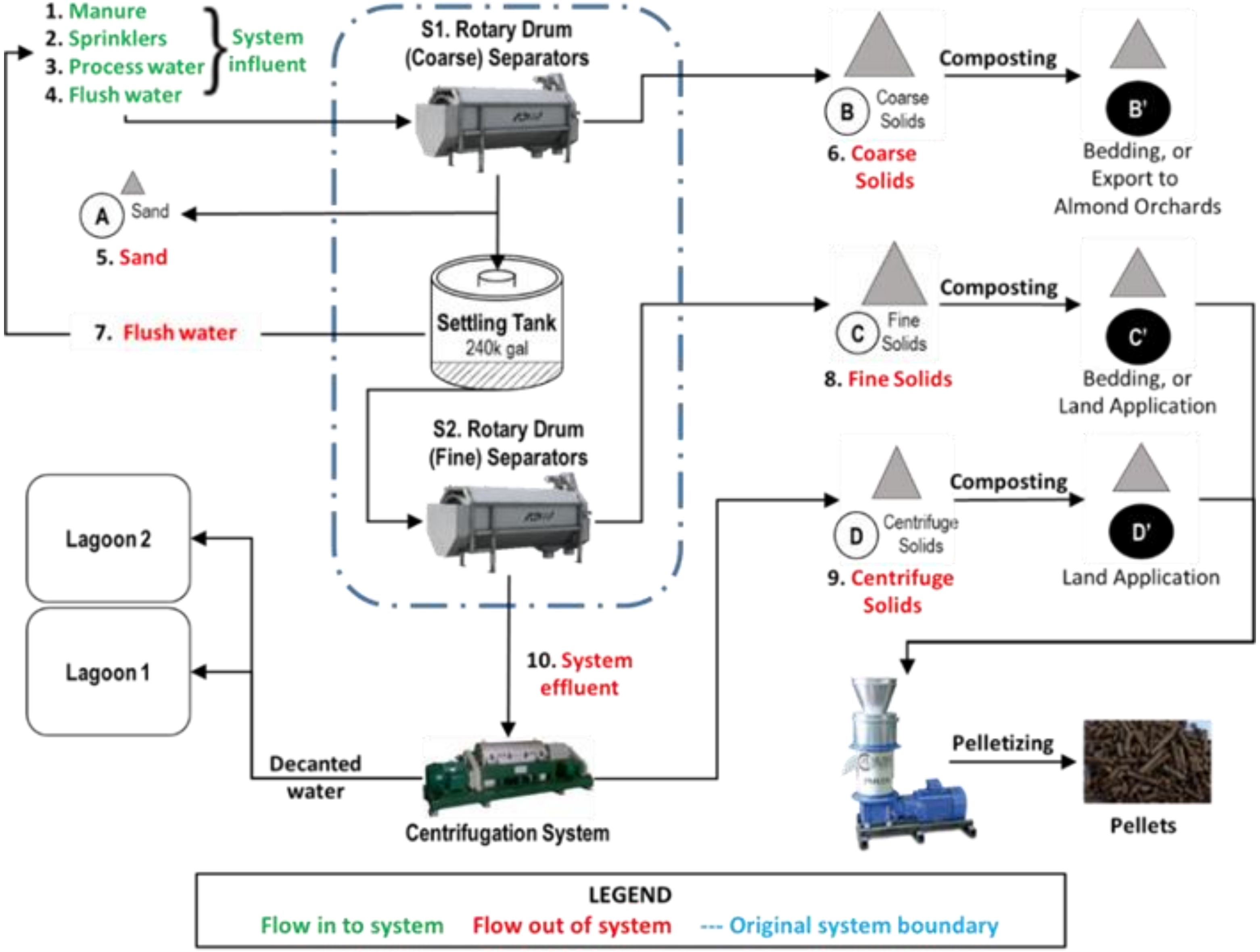
Description of Advanced Multistage Separator System

Fate of Separator Solids on the Dairy

Coarse Solids > 3.175 mm
- Composted or
- Subjected to advance solar drying
- Used for bedding
- Fall 2017 (1 day):
    - ~60,000 lb wet (~MC 75%)

Fine Solids > 0.533 mm
- Composted or
- Subjected to advance solar drying
- Some used for bedding
- Also land applied
- Fall 2017 (1 day):
    - 105,000 lb wet (~MC 75%)

Advanced Multistage Separator System with Centrifuge



Centrifuge Addition to Advanced Separator System

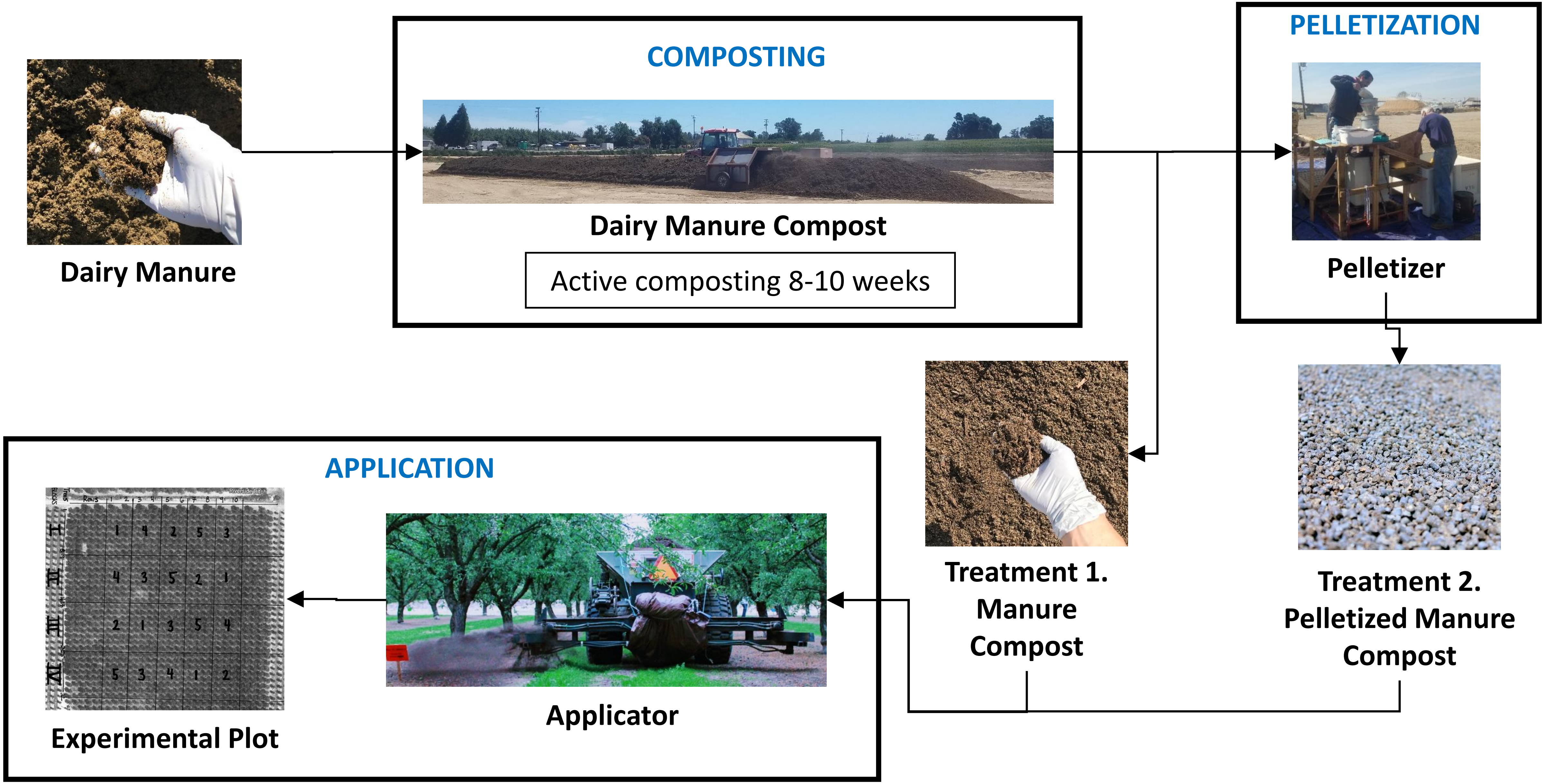
Centrifuge

Results: Total Solids removal efficiency

Stage	August 2017	March 2018	June 2018	June 2022
1st stage	9.1%	5.8%	8.7%	8.7%
Settling Tank	40.5%	62.8%	43.5%	49.9%
2nd Stage	15.5% (30.8%)	10.2% (32.5)	10.6% (23.1%)	14.6% (39.4%)
Biolynk System	65.1%	78.8%	62.8%	73.2%
Centrifuge	n/a	n/a	n/a	11.3% (47.4%)
Biolynk + Centrifuge	n/a	n/a	n/a	84.5%

- n/a: not applicable
- Total Solid Removal efficiency values were calculated based on the inlet of the 1st stage, except those in ()
- Values in () represent removal efficiency calculated based on the inlet of the unit operation itself

Process Overview



Orchard Application: Experimental Design

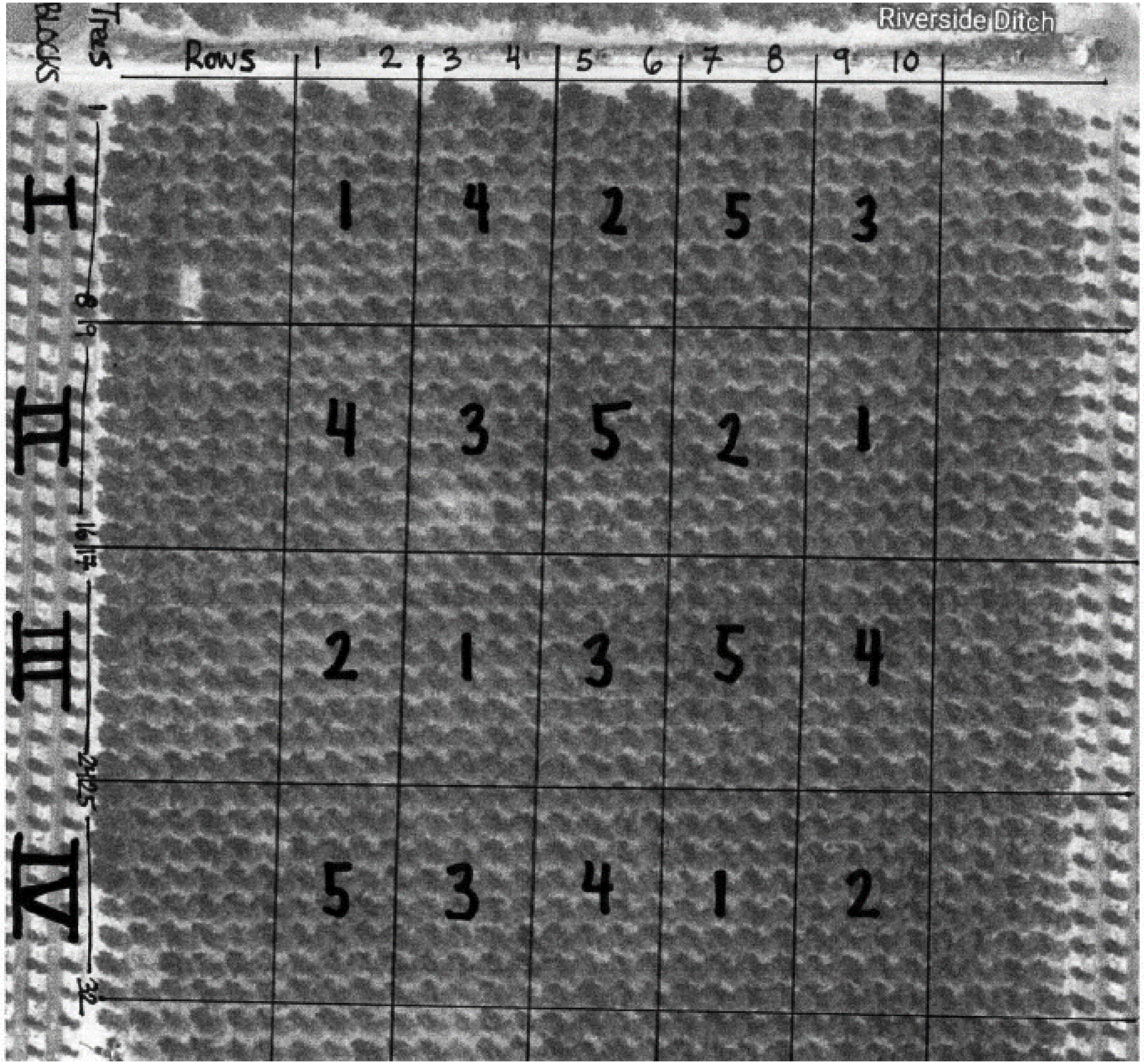
Design: Randomized
Complete Block Design
-16 experimental trees/block

Treatments:

1. Unamended
2. Dairy Manure Compost
3. Pelletized DMC

Tree Variety: Independence

Application Rate: 4 dry tons/acre



Experimental Layout

Composting: Setting Up Piles

1. Loading raw materials into side dump and weighing on a scale

Composting: Setting Up Piles

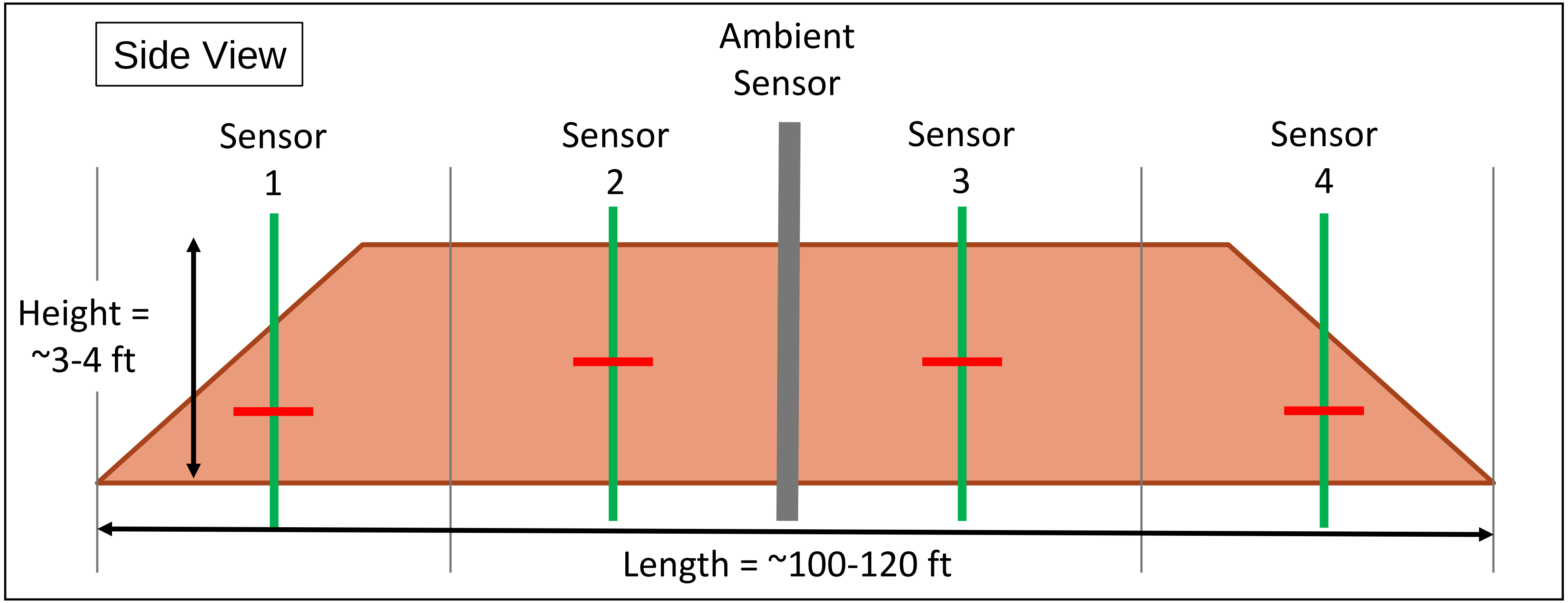
2. Creating piles with a side dump

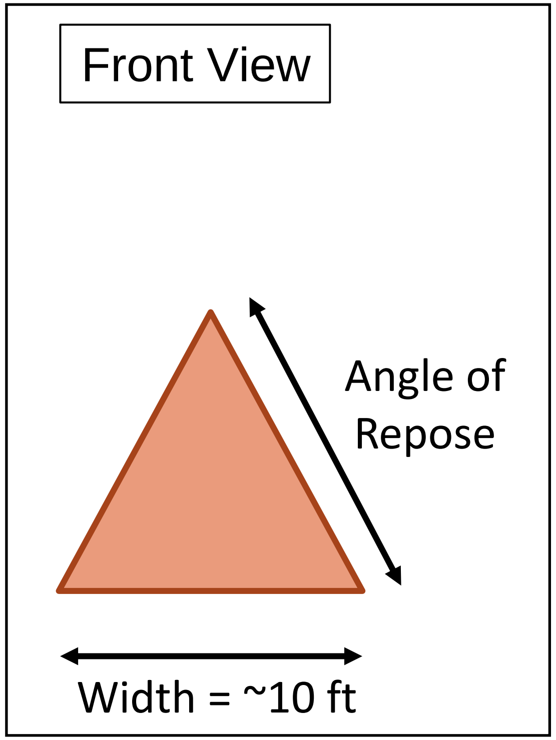
Composting: Setting Up Piles

3. Turning compost piles to shape, aerate, and mix them

4. Return weekly to turn piles, take measurements, and samples

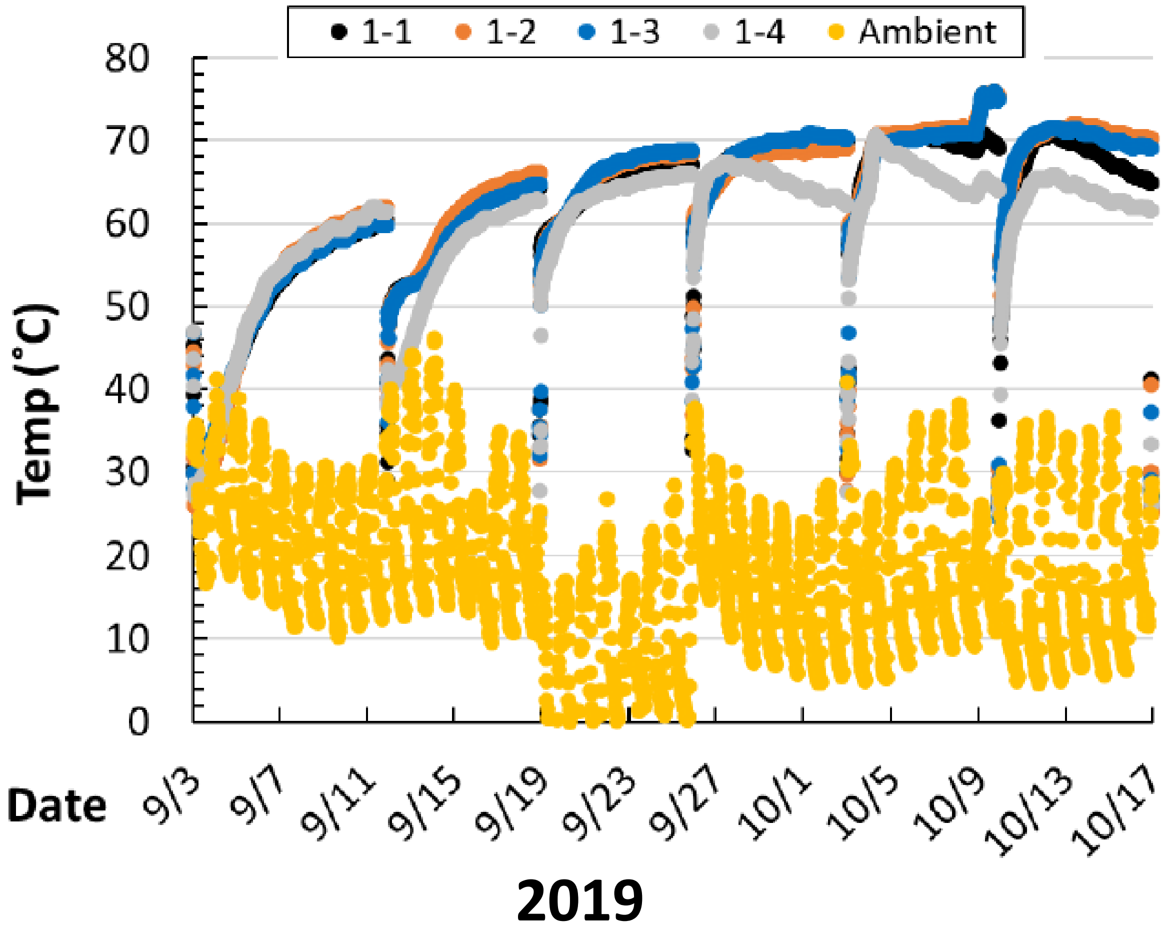
On Farm Measurements

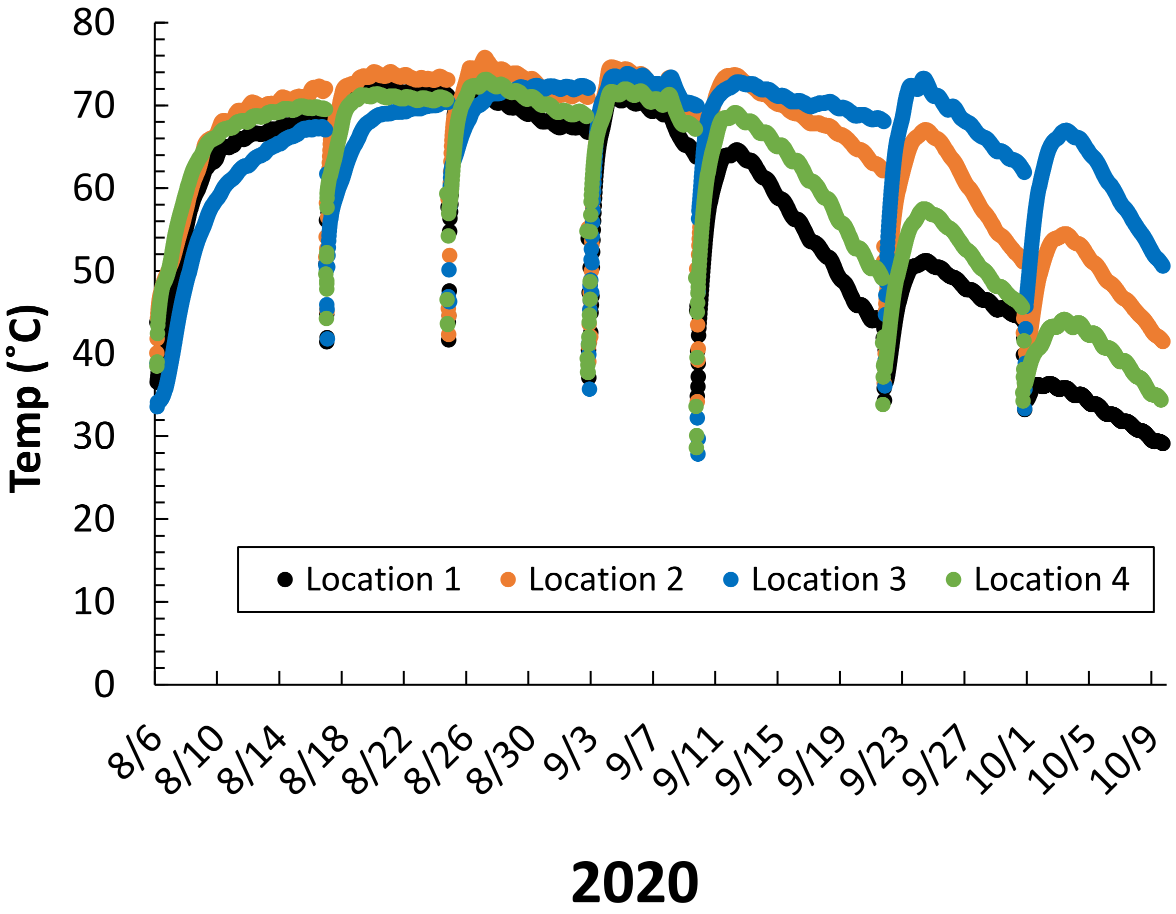




- Compost pile divided into 4 sections. Green lines are the midpoint of each section.
- Temp sensors inserted halfway into the piles at the intersection of the red-green lines.
- Ambient sensor mounted on pole just above the compost pile
- Weekly measurements: length, width, height, angle of repose, and bulk density as well as sampling for laboratory analysis after the windrows were turned

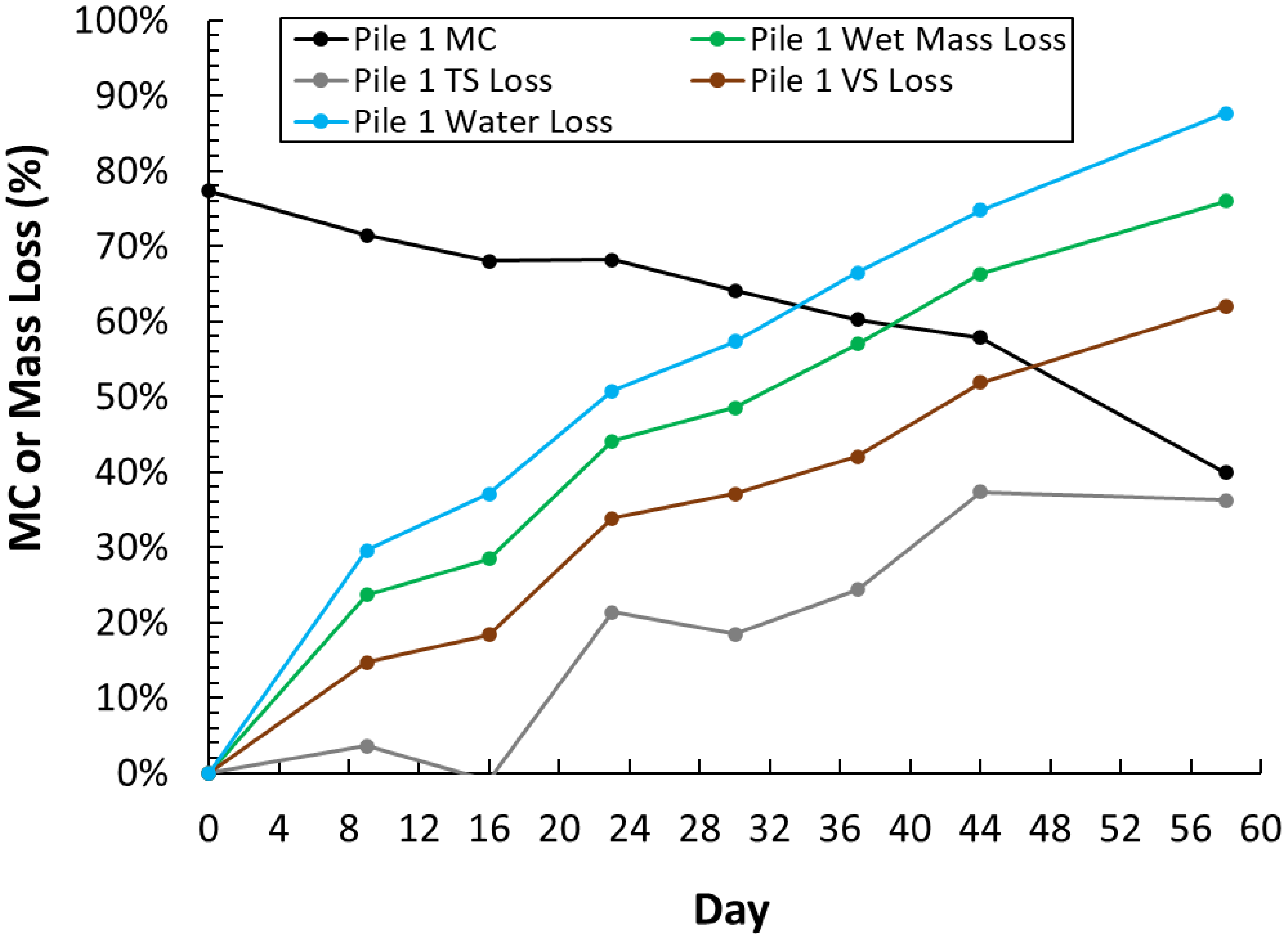
2019 and 2020 Composting: Temperature Data





- Windrow Ends take longer to heat up and lose heat more quickly at the end of the exp
- Sudden temperature drops due to weekly pile turning
- Achieved up to 75°C in the first 4 weeks, begin to drop off at week 5 as moisture drops

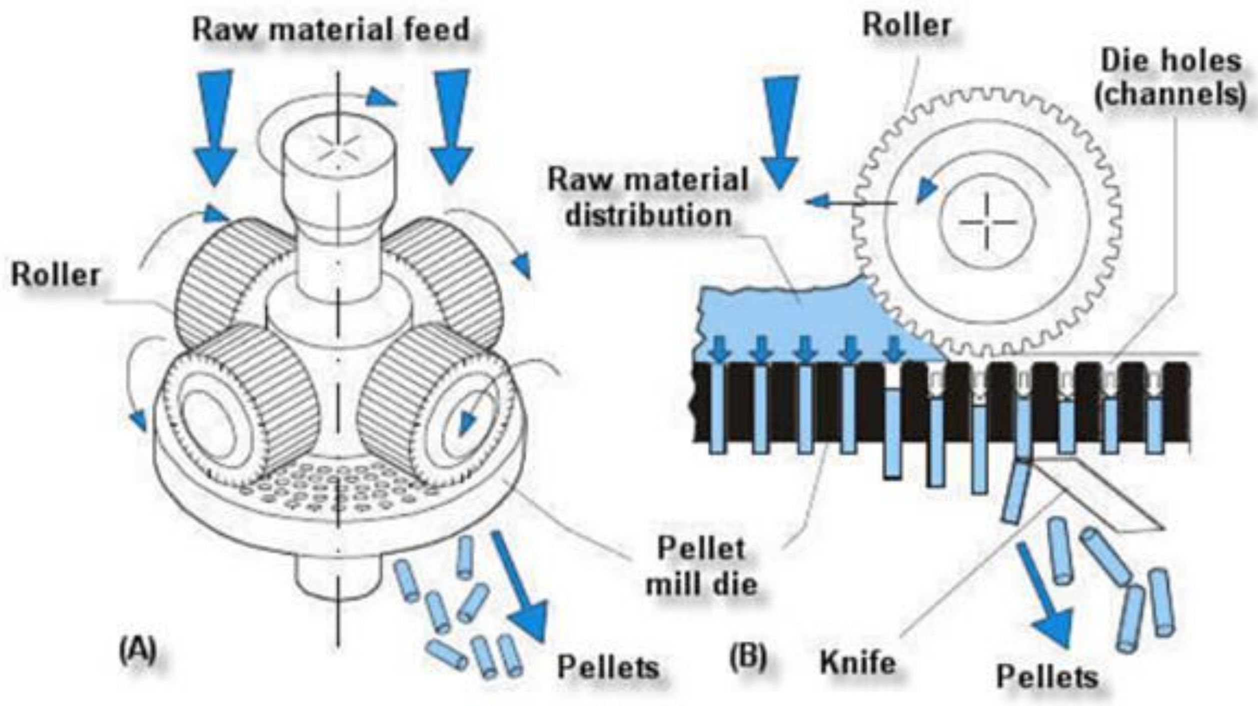
2019 Composting: MC, and Wet, Dry, and Volatile Solids Changes



- Initial Moisture content: 77.4%
- Final Moisture content: 39.9%.
- 76.0% drop in mass on a wet basis
- 36.2% drop in Total solids conc.
- 62.1% drop in Volatile solids conc.
- 87.6% drop in moisture

Pelletization and Application of Dairy Manure and Almond Processing By-products

- What is pelletization/pelleting?
  - A process where smaller particles are formed into larger pellets
  - Accomplished by various methods – flat die pellet mill used in this work
- Why pelletize?
  - Increases bulk density
  - Improves storage, handling, and application
  - Reduces dust generation
  - Attractive to higher value markets



Designs and operating principles of pellet mills-Flat die pellet mill

Image: http://www.biofuelmachines.com/

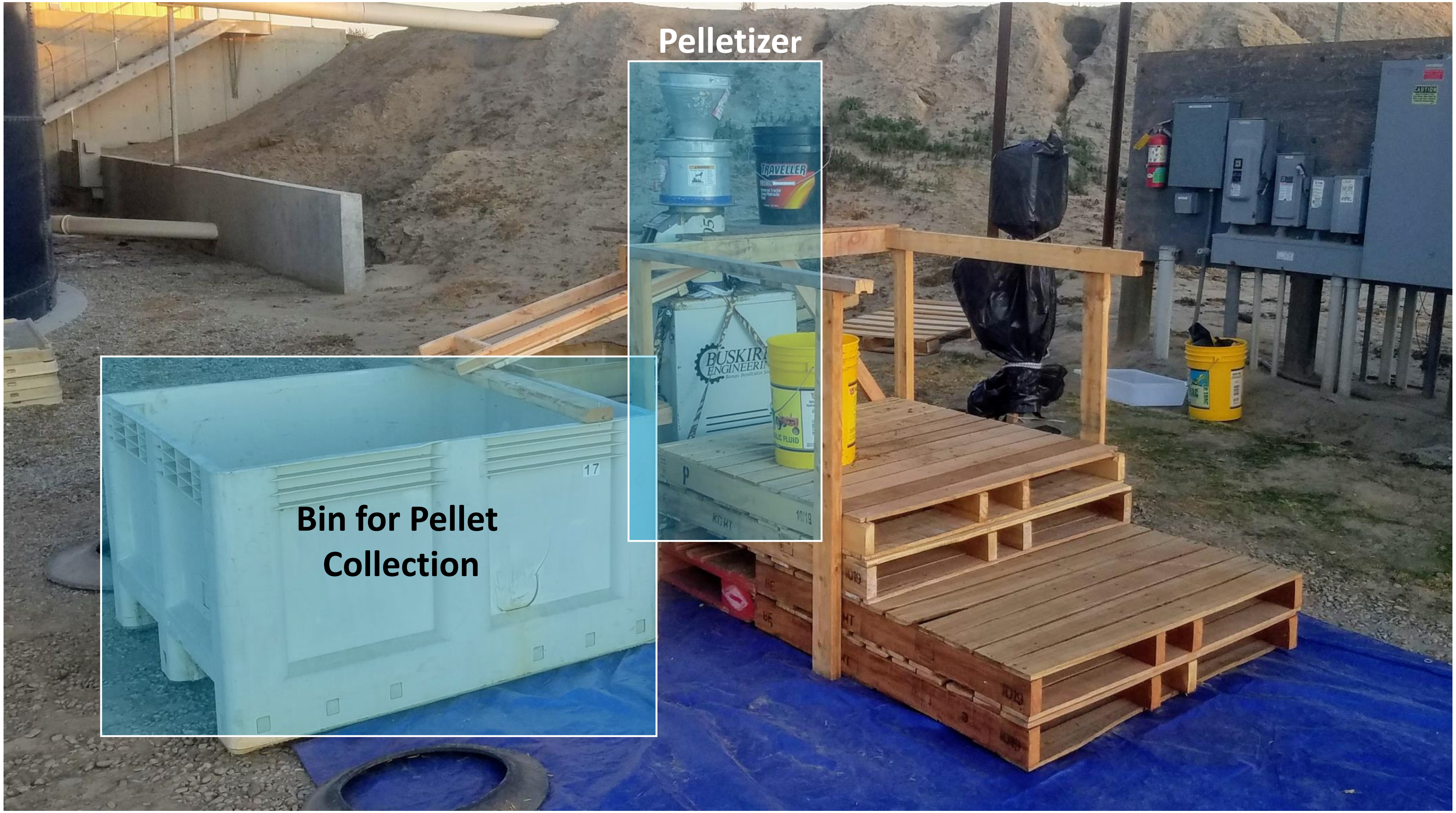
Pelletization: Pellet Mill Specs, Setup, and Operation

- Used a Buskirk PM605 Laboratory Scale Pelletizer
- Driven by 5 HP motor
- Processes 100-150 lb/hr
- Recommend input material be between 10-15% MC
- Operating temperature depends on input material:
  - 90-220°C

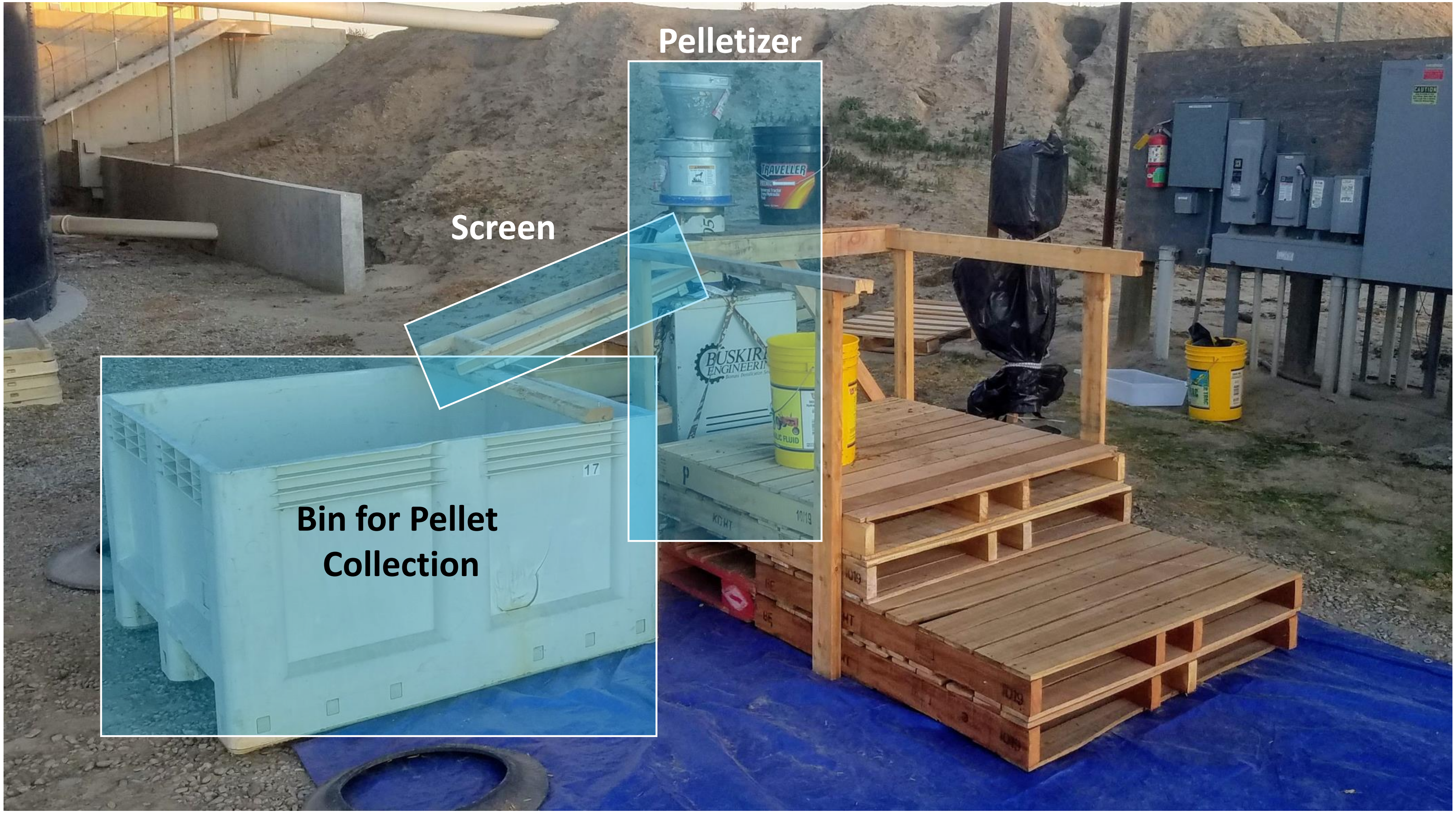
Pelletization: Pellet Mill Specs, Setup, and Operation

Pelletization: Pellet Mill Specs, Setup, and Operation

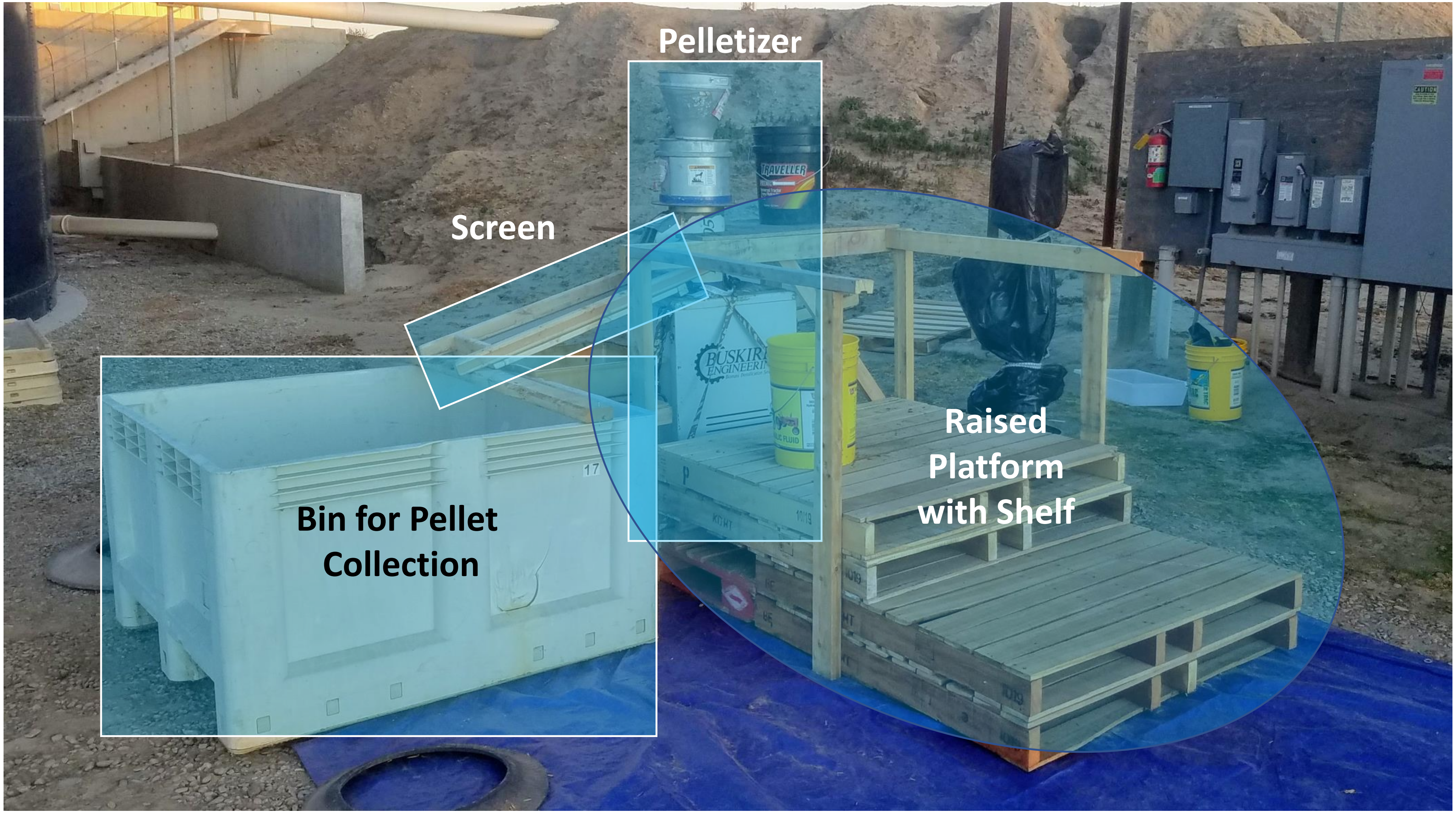
Pelletization: Pellet Mill Specs, Setup, and Operation



Pelletization: Pellet Mill Specs, Setup, and Operation



Pelletization: Pellet Mill Specs, Setup, and Operation



Amendment Composition

Parameter	Units	MC	PMC
Bulk Density	lb/cu ft	26	50
Moisture (H_2O)	%	31.9	23.8
pH	pH units	7.0	7.2
Electrical Conductivity	mmhos/cm	6.15	8.43
Total Nitrogen (TN)	% db	1.20	1.33
Total Phosphorus (TP)	% db	0.310	0.390
Potassium (K)	% db	0.760	1.00
Organic Matter (OM)	% db	36.3	39.2
C:N Ratio (C:N)	Ratio	17:1	17:1
Sodium (Na)	% db	0.250	0.290
Sulfur (S)	% db	0.350	0.320
Calcium (Ca)	% db	1.50	1.70
Magnesium (Mg)	% db	0.440	0.480
Zinc (Zn)	mg/L	103	112
Boron (B)	mg/L	26.0	31.0
Manganese (Mn)	mg/L	142	165
Iron (Fe)	mg/L	4,910	5,420
Copper (Cu)	mg/L	31.0	32.0

- Amendments abbreviations
  - MC: Manure Compost
  - PMC: Pelletized MC
- Bulk Density
  - Pelletizing MC ↑ BD by 1.9x
- C:N Ratio
  - No change
- Electrical Conductivity
  - Pelletizing ↑ EC by 1.3-1.4x
- NPK (%)
  - MC/PMC: 1.25-0.35-0.90
- NPK (per acre at 4 dry tons/acre)
  - MC/PMC: 100-28-72

Pathogen Study (2020): Method and Results

Method:

- 1: qPCR by the Veterinary Diagnostic Lab at Kansas State Univ.
- 2: Culture method (XLD agar plates) at Pandey Lab at UC Davis

Tested: Manure compost (MC) and pelletized manure compost (PMC) for *E. coli* + *Salmonella*

***Salmonella* and pathogenic *E. coli* test results**

OMA	*Salmonella*[2]	*E. coli O26*[1]	*E. coli O45*[1]	*E. coli O103*[1]	*E. coli O111*[1]	*E. coli O121*[1]	*E. coli O145*[1]	*E. coli O157*[1]
MC	-	-	-	-	-	-	-	-
PMC	-	-	-	-	-	-	-	-

Pelletization: Pellet Mill Specs, Setup, and Operation

(Top) Fresh pellets
(Bottom) Pellets in the applicator

Pellets up close

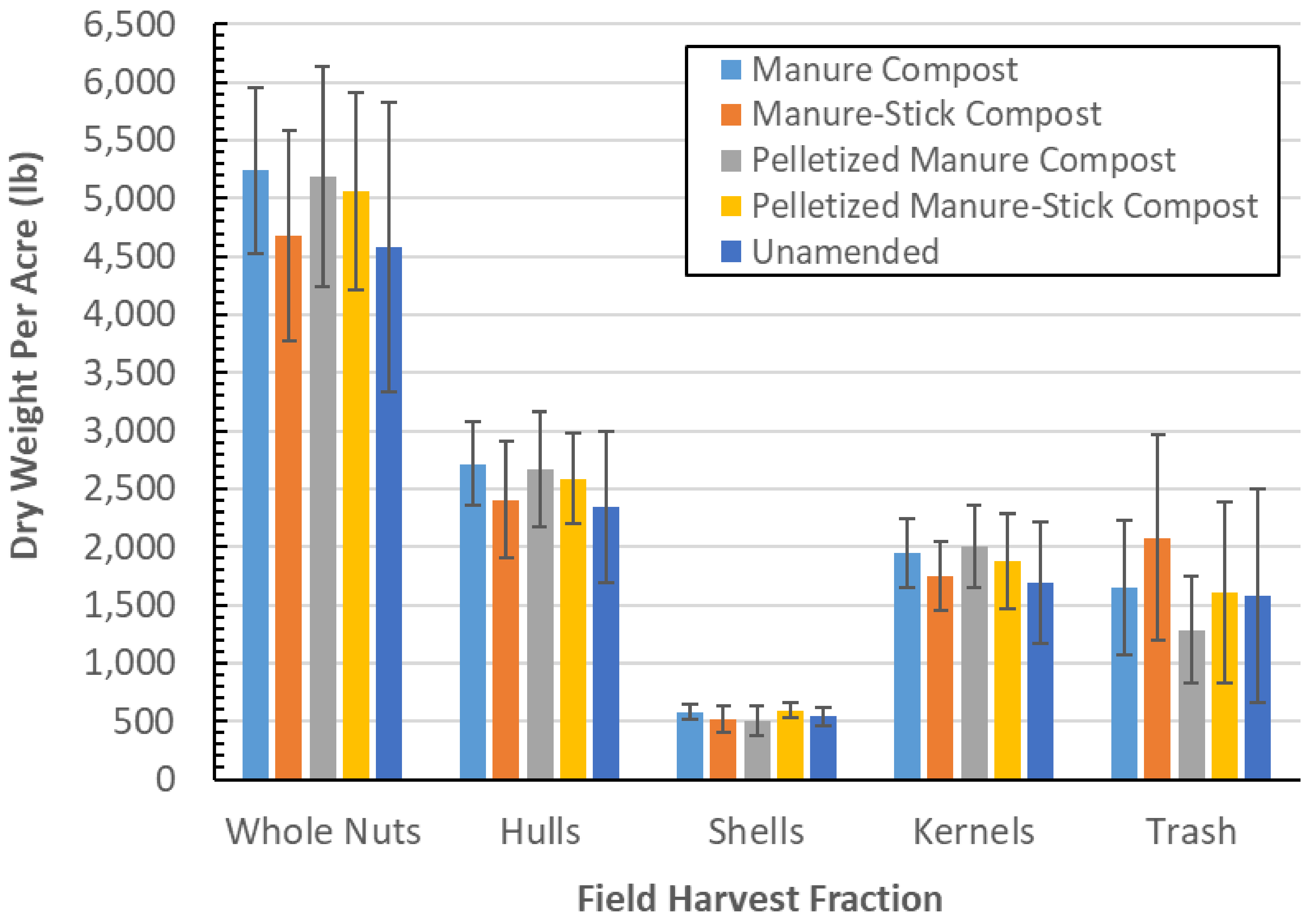
Orchard Application: Applicator Calibration

Orchard Application: February 2021

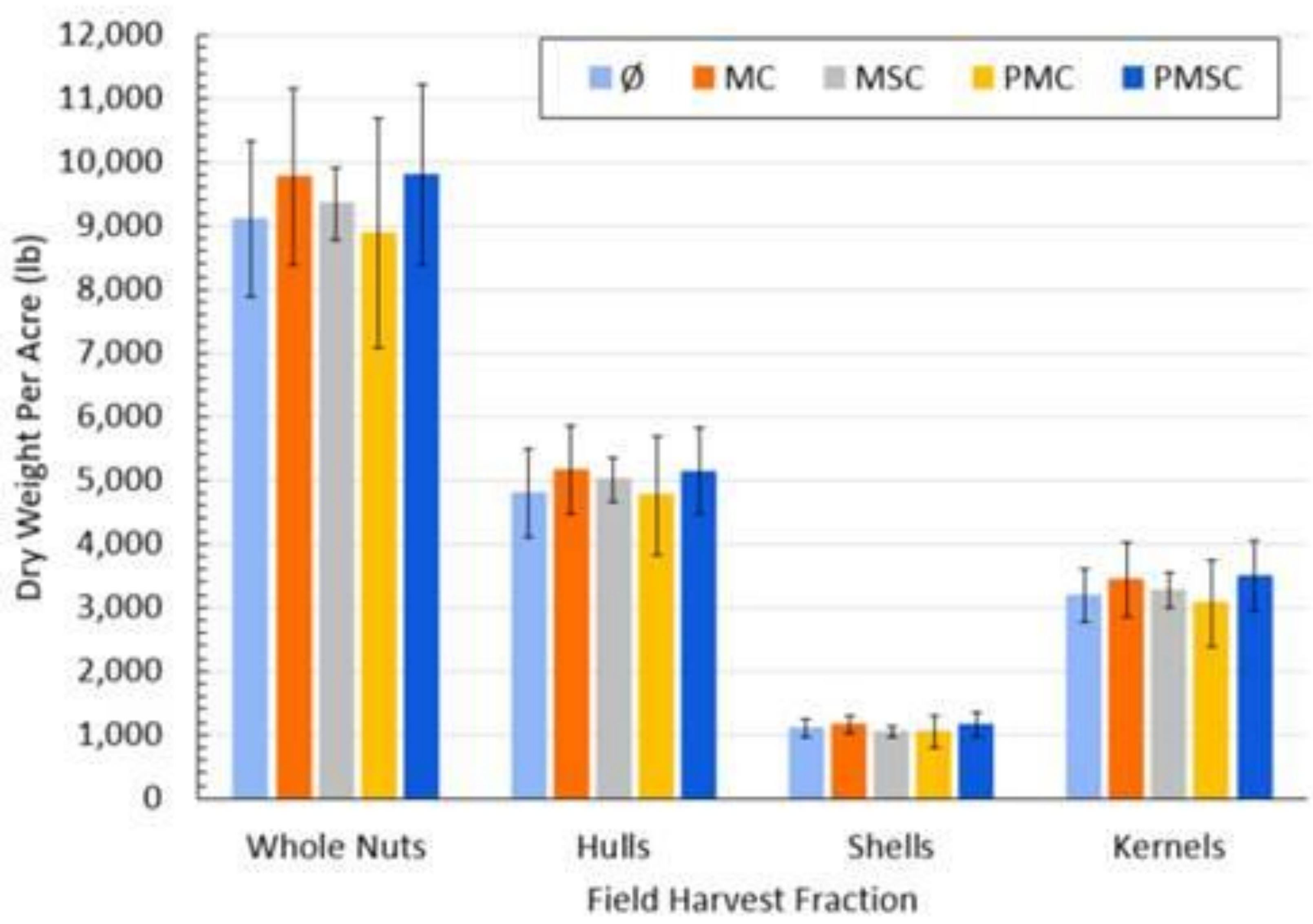
Composted Manure Application

Pelletized Composted Manure Application

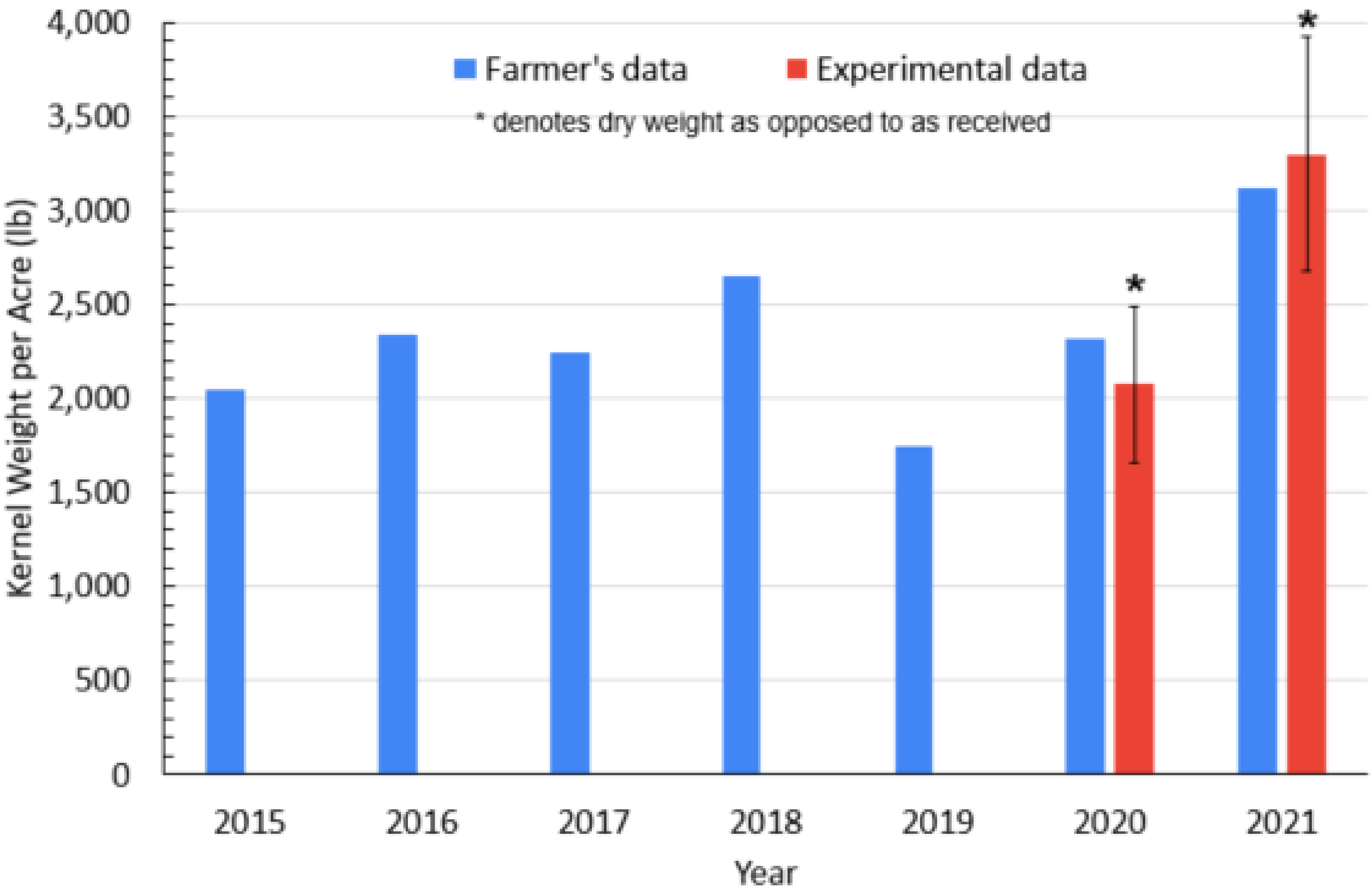
2020 Harvest Yield Data



2021 Harvest Yield Data



Historic Yield Data: Experimental Plot vs Farmer's data



Conclusions (Separator Work)

- This project is follow-up work to a project in 2017-18 where we studied 4 different types of solid-liquid separation technologies on 6 different California Dairy Farms.
- The Farmer added a centrifuge to his existing advanced multistage separator system. The original studied determined total solids removal efficiencies of 62-80% for the Biolynk system (1^{st} stage, settling tank, + 2^{nd} stage).
- A study in June 2022, resulted in similar TS removal efficiency of 73% for the Biolynk system and an additional 11.3% removal achieved by the centrifuge. The centrifuge removed nearly 50% of the total solids it received.
- Further work includes:
    - Studying the system during 1 more seasons;
    - Co-composting fine separator + centrifuge solids, monitoring the process, analyzing the quality;
    - Demonstrating year-round composting on the farm; and
    - Pelletizing compost using a full-scale pellet mill that is currently being installed on the farm.

Conclusions (cont'd)

- **Composting**, after 8 weeks of active composting:
  - Initial MC: 77.4%, Final MC: 39.9% at the end of active composting
  - 76.0% drop in mass on wet basis; 87.6% drop in moisture content
  - 36.2% drop in TS concentration; 62.1% drop in VS concentration

- **Pelletization:**
  - <20% MC too dry while >35% is too high, target range: 25-35% on this dairy
  - Suspect the high levels of sand in the manure to be the cause
  - Higher MC for pelletization means less need for drying after composting

- **Application:**
  - Higher bulk density → more pellets can be loaded into the applicator
  - Successfully applied both compost + pellets a rate of 4 dry tons per acre

- **Harvest Yield:**
  - No differences in 2020 + 2021 harvest yield between treatments

Acknowledgements

Project Sponsors

- California Dept. of Food and Agriculture
  - Health Soils Program
  - Alternative Manure Mgmt. Program
- Almond Board of California
- California Dairy Research Foundation
- UC Davis BAE Department

Research Collaborators

Dairy and Almond Farmers

The Farm Personnel

Members of the UC Davis Zhang Lab

Members of the UC Davis Pandey Lab

Dan Rivers, UC Cooperative Extension

Guangwei Huang, Almond Board CA

John Faria, JPT Composting and Spreading

Kyle Nichols, Nichols Custom Ag Services

Frank Silva, Silva & Sons Custom Spreading

Dave Thiel, Cortez Almond Grower's Assn

Manager at Almond Tree Huller

Jonathan Cloward, Kamps Hulling

McKennan Buckner, RDO Equipment Co.

Questions?

Supplemental Slides

Materials & Methods: Field Work

1. Sampling frequency and period
   1.1. Goal for a full year, 1 day in each season
   1.2. Each sampling event spans a period of 6-24 hours

2. Measure flow rate and total flow into the system using a flow meter
   2.1. Doppler ultrasonic insert velocity sensor installed on inlet pipe
   2.2. Meter connected to MACE Agriflow Xci data logger and controller
   2.3. Validate flowmeter and start sampling
   2.4. This data combined with TS, VS data from individually collected samples was used to determine solids flowing into the system.

Materials & Methods: Field Work (continued)

2. Measure flow rate and total flow into the system using a flow meter (cont'd)

2.1

Doppler ultrasonic insert velocity sensor

2.2

MACE Agriflo Xci

2.3

Flow meter installed on 1st stage inlet

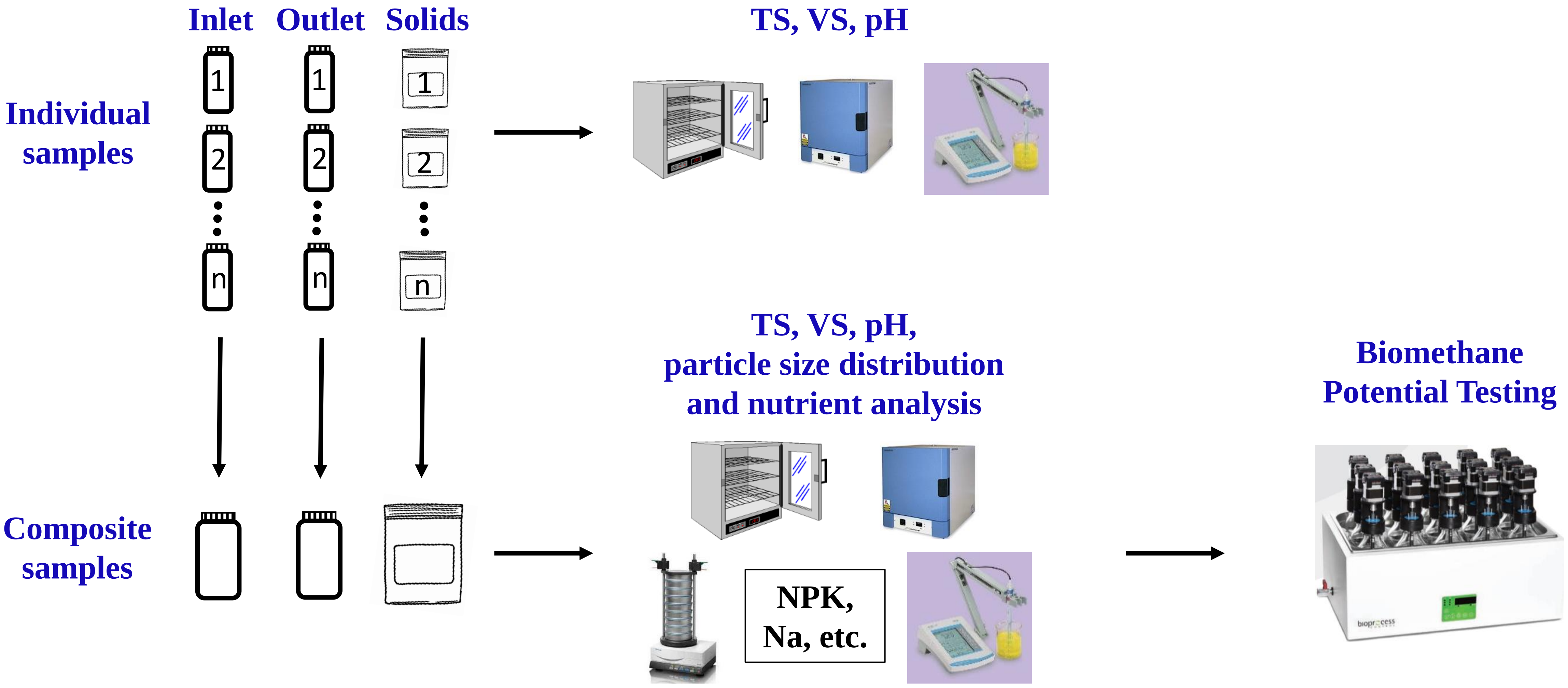
3. Regularly sampled separator inlet and outlet
   3.1. Coarse separators operation controlled by float sensors
   3.2. Fine separator operation controlled by timer
   3.2. Sample inlet and outlet of both stages every 20-30 minutes

Flow meter equipment: Measuring and Control Equipment (MACE) | **Images:** http://macemeters.com

Materials & Methods: Field Work (continued)

4. Weighed separator solids and collected composite sample
   4.1. Loader transferred solids into trailer
   4.2. Researchers collected samples of separator solids
   4.3. Farm scale used to weigh solids

Materials & Methods: Lab Analysis



Images: Plastic Bag: Shutterstock | Oven: ClipartXtras | Muffled furnace: Cole Parmer™ | BMP Unit: Bioprocess Control™

Methodology: Total Solids removal efficiency determination

TS removal efficiency equations

$$TS_{In} = \sum_{i-\text{start}}^{i-end} (\emptyset_{m\ In} *\ TSc_{In})_i$$

$$TS_{Out} = TS_{In} - TS_{Solids}$$

$$TS_{removal} = \frac{TS_{In} - TS_{Out}}{TS_{In}} x100\%$$

Key Definitions

TS_{In}	Total solids in the inlet (ton, db)
TS_{Out}	Total solids in the outlet (ton, db)
TSc_{In}	Concentration total solids in inlet (%)
TS_{Solids}	Total solids separated (ton, db)
$TS_{removal}$	Total solids removal efficiency (%)
$\emptyset_{m\ In}$	Mass flow rate of the inflow (ton, db)

Methodology: Total Solids removal efficiency determination

TS removal efficiency equations

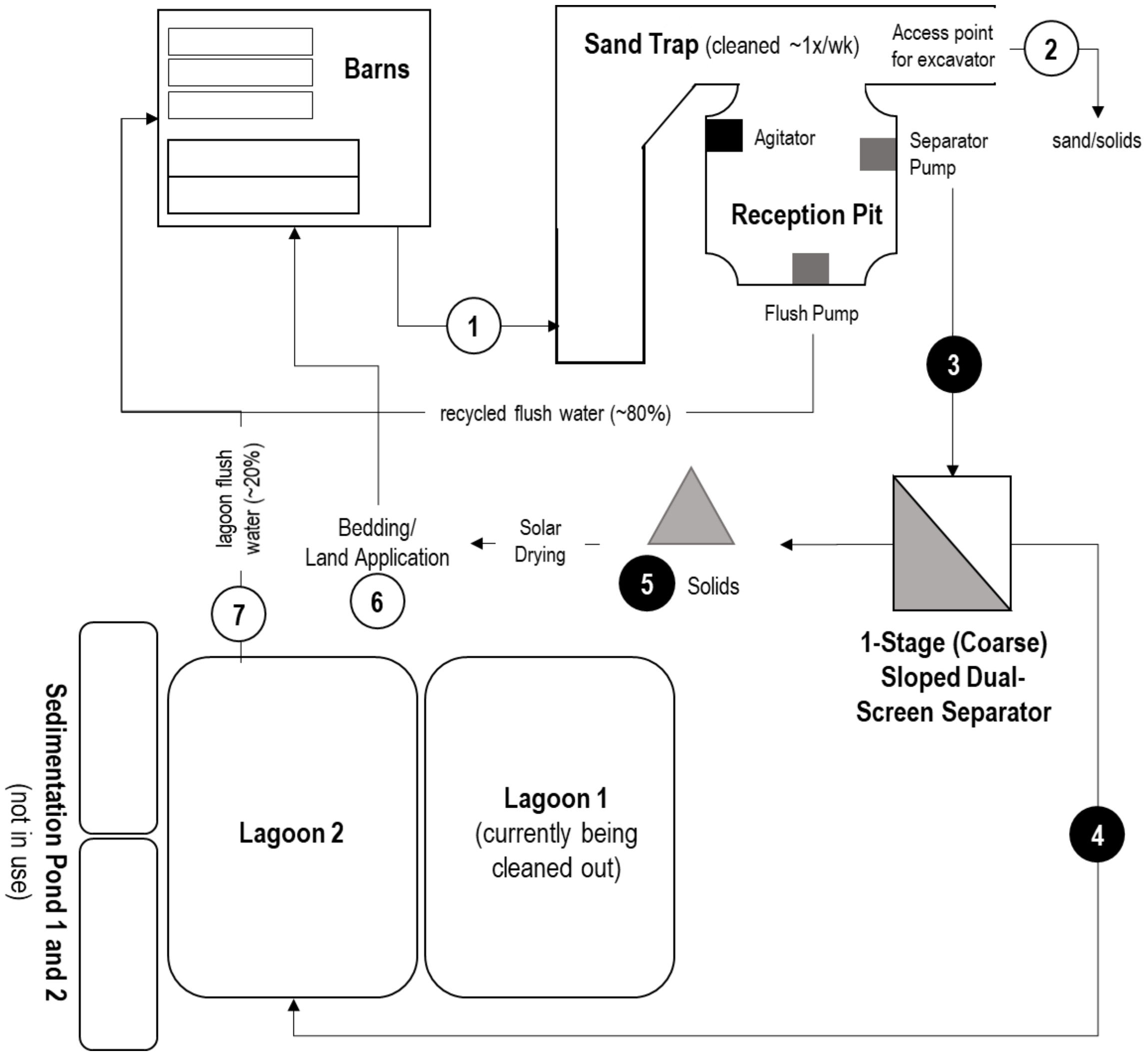
$$TS_{In} = \sum_{i-start}^{i-end} (\emptyset_{m\ In} * TSc_{In})_i$$

$$TS_{Out} = TS_{In} - TS_{Solids}$$

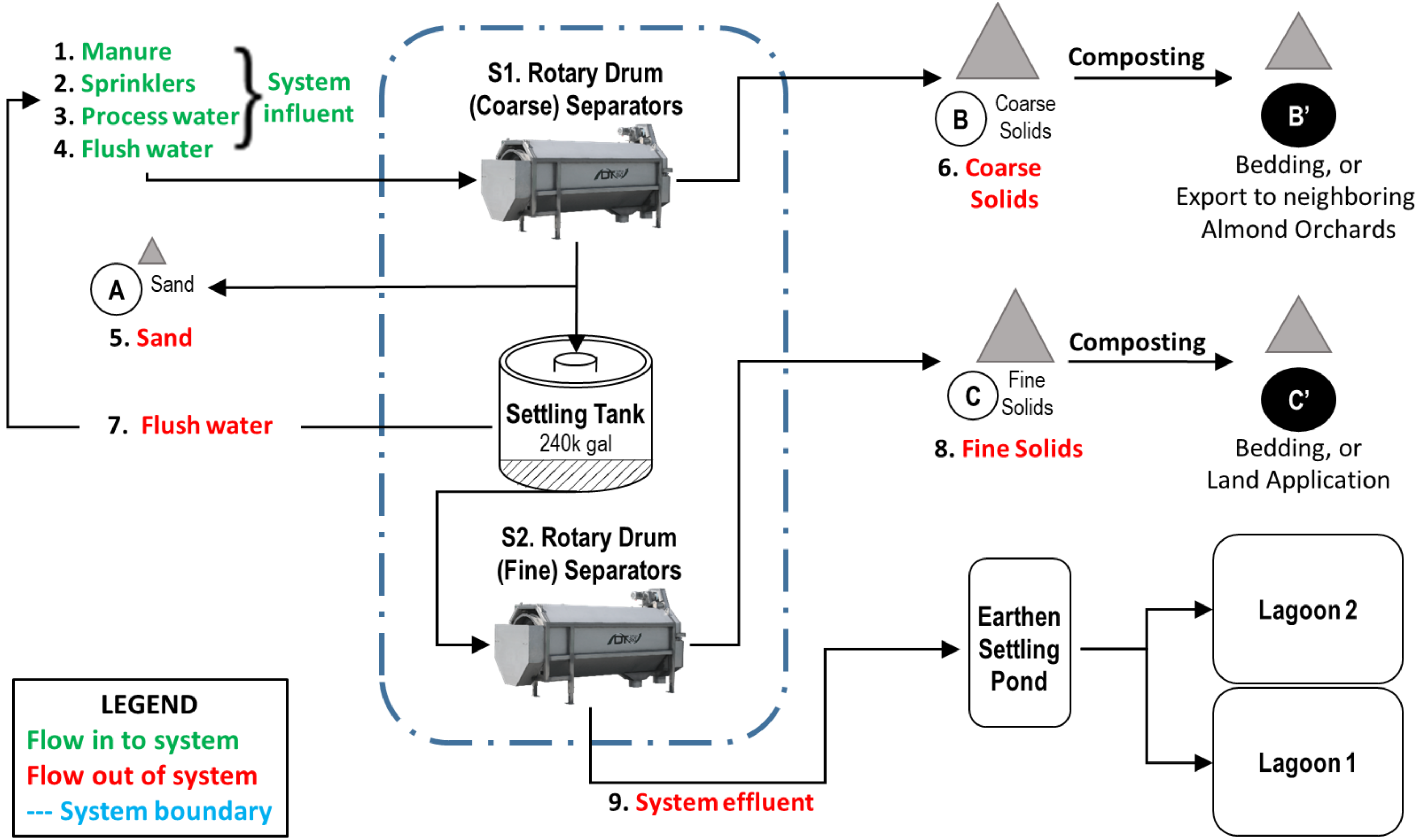
$$TS_{removal} = \frac{TS_{In} - TS_{Out}}{TS_{In}} x100\%$$

Key Definitions

TS_{In}	Total solids in the inlet (ton, db)
TS_{Out}	Total solids in the outlet (ton, db)
TSc_{In}	Concentration total solids in inlet (%)
TS_{Solids}	Total solids separated (ton, db)
$TS_{removal}$	Total solids removal efficiency (%)
$\emptyset_{m\ In}$	Mass flow rate of the inflow (ton, db)



Unique System Design, Summer 2017 Data



Methodology: Solids removal efficiency determination

Full system TS and VS removal efficiency

$$TS_{System\ rem} = TS_{1\ rem} + TS_{2\ rem} + TS_{ST\ rem} + TS_{Cent\ rem}$$

Settling tank TS and VS removal efficiency

$$TS_{ST\ rem} = \frac{TS_{ST\ in} - TS_{2in}}{TS_{ST\ in}} \times 100\%$$

$$TS_{ST\ in} = TS_{1\ in} - TS_{1\ solids}$$

1st, 2nd stage, and centrifuge TS removal efficiency

$$TS_{rem} = \frac{TS_{in} - TS_{out}}{TS_{in}} \times 100\%$$

$$TS_{in} = \sum_{i-\mathrm{start}}^{i-end} (\emptyset_{m\ in} \times TSc_{in})_i$$

$$TS_{out} = TS_{in} - TS_{solids}$$

Key Definitions

TS	Total solids (tons, db)
$TS_{1,\ 2,\ ST}$	Separator 1, 2, settling tank total solids
TS_{in}	Total solids into unit operation (tons, db)
TS_{out}	Total solids out unit operation (tons, db)
TS_{solids}	Separator total solids (tons, db)
$\emptyset_{m\ in}$	Mass flow rate of the inflow (tons, db)
TSc_{in}	Concentration total solids in inlet (%)
TS_{rem}	Total solids removal efficiency (%)
TS_{System}	Full system solids

February 2022		
Stage	% TS Removal	% Contribution
1st stage	5.9%	6.5%
Settling Tank	73.7%	80.7%
2nd Stage	9.6% (49.5%)	54.6%
Biolynk System	89.2%	97.7%
Centrifuge	2.1% (23.0%)	2.3%
Biolynk + Centrifuge	91.3%	100.0%

- Removal/reduction values calculated based on 1st stage inlet except those in ()
- Values in () represent removal/reduction calculated based on the inlet of the unit operation itself

Temperature Measurements

We monitored compost temperature, ambient and pile internal temperatures during active composting

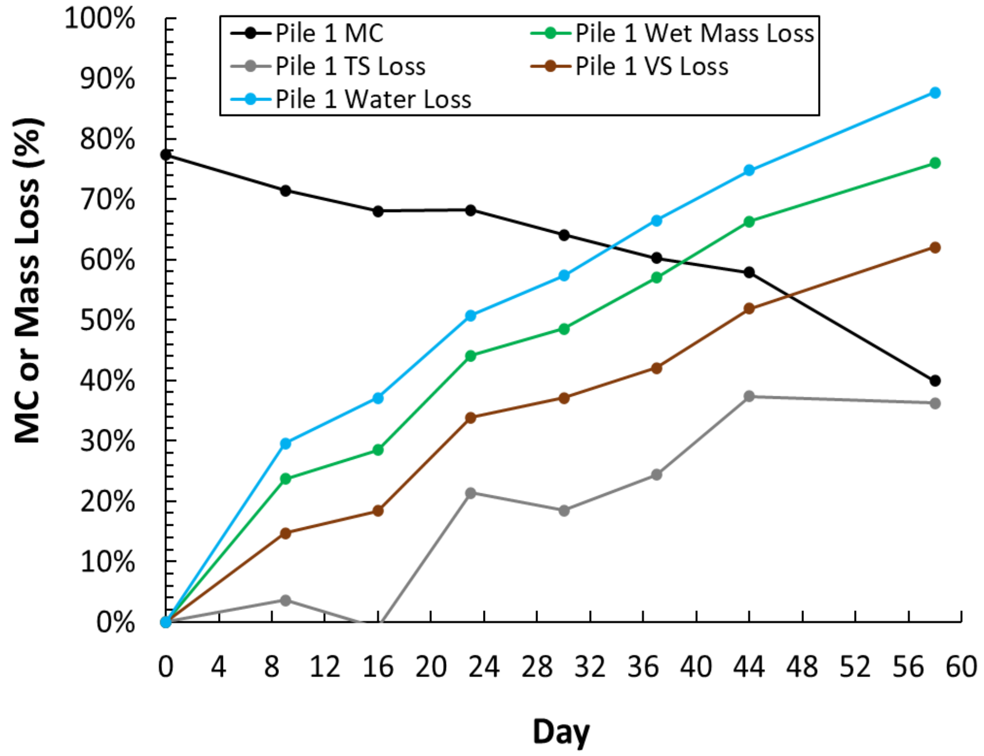
HOBO® Temperature Sensor (Onset®, MA)

Ambient Temp sensor

Internal temperature sensor

Mass Balance Measurements

We measured compost windrow dimensions and bulk density to determine mass and moisture changes during active composting.

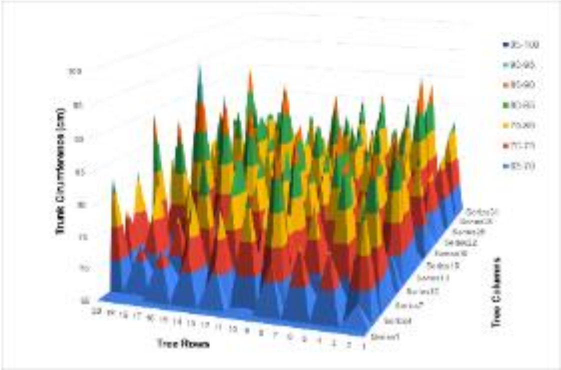


Compost Pile 1: Manure Only (2019)

Ongoing lab work and data analysis

- **Soil & amendment quality/safety**
  - Physicochemical properties
  - Pathogens: *E.coli* and *Salmonella*

- **Tree health & almond quality/safety**
  - Tree trunk circumference
  - Almond yield – no differences observed
  - Pathogens: *E.coli* and *Salmonella*



- **Soil emission (CO_2, CH_4 and N_2O)**
  - Static chambers were used to measure soil emission fluxes