Manure Solid Liquid Separation
Nutrient Form and Fate

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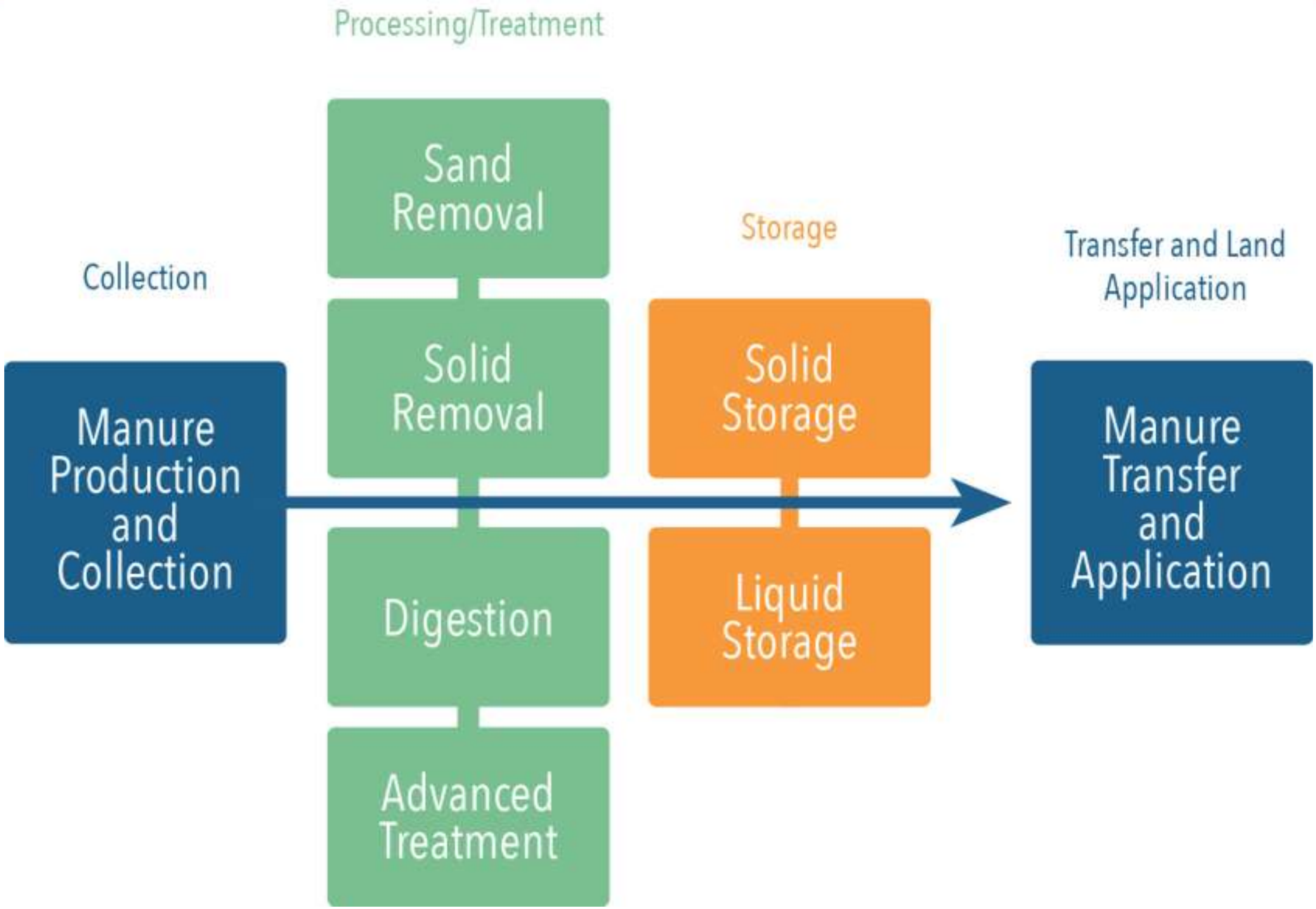
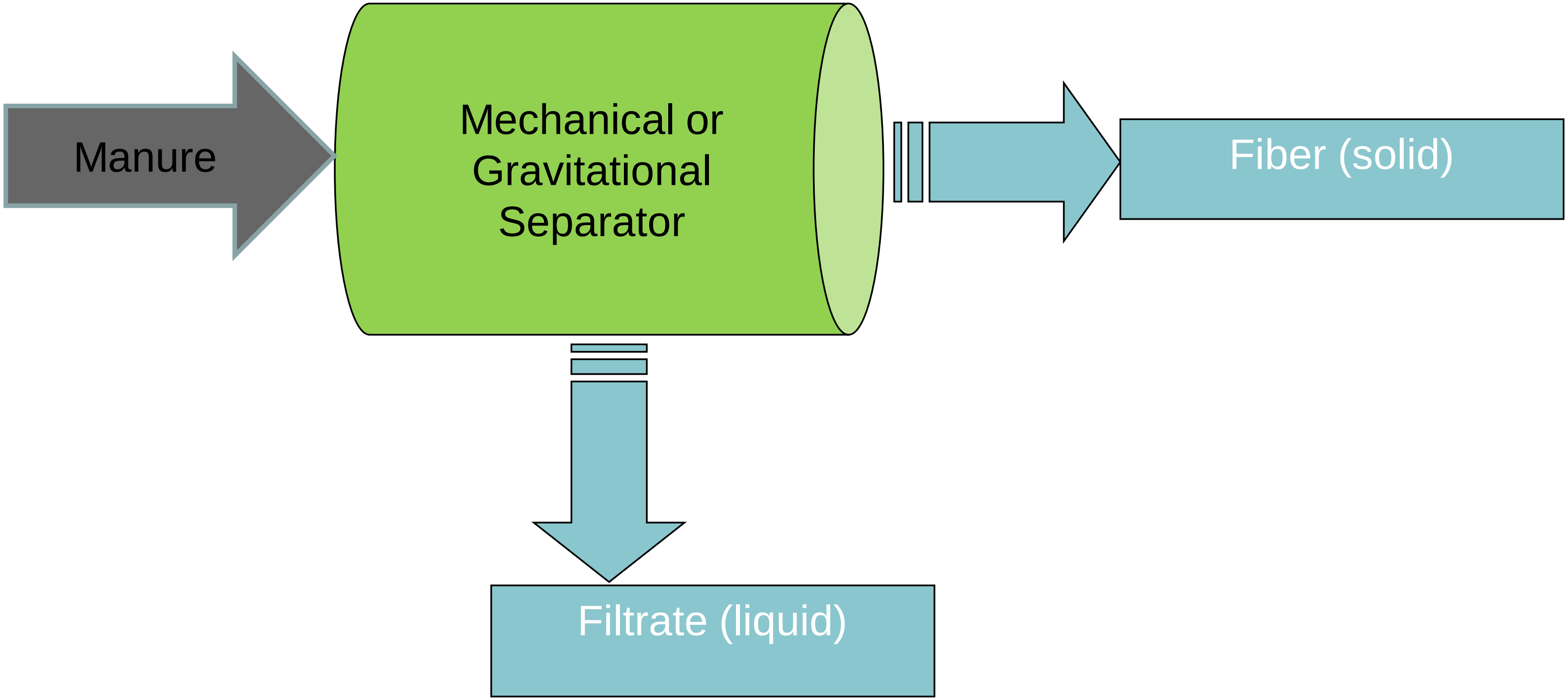
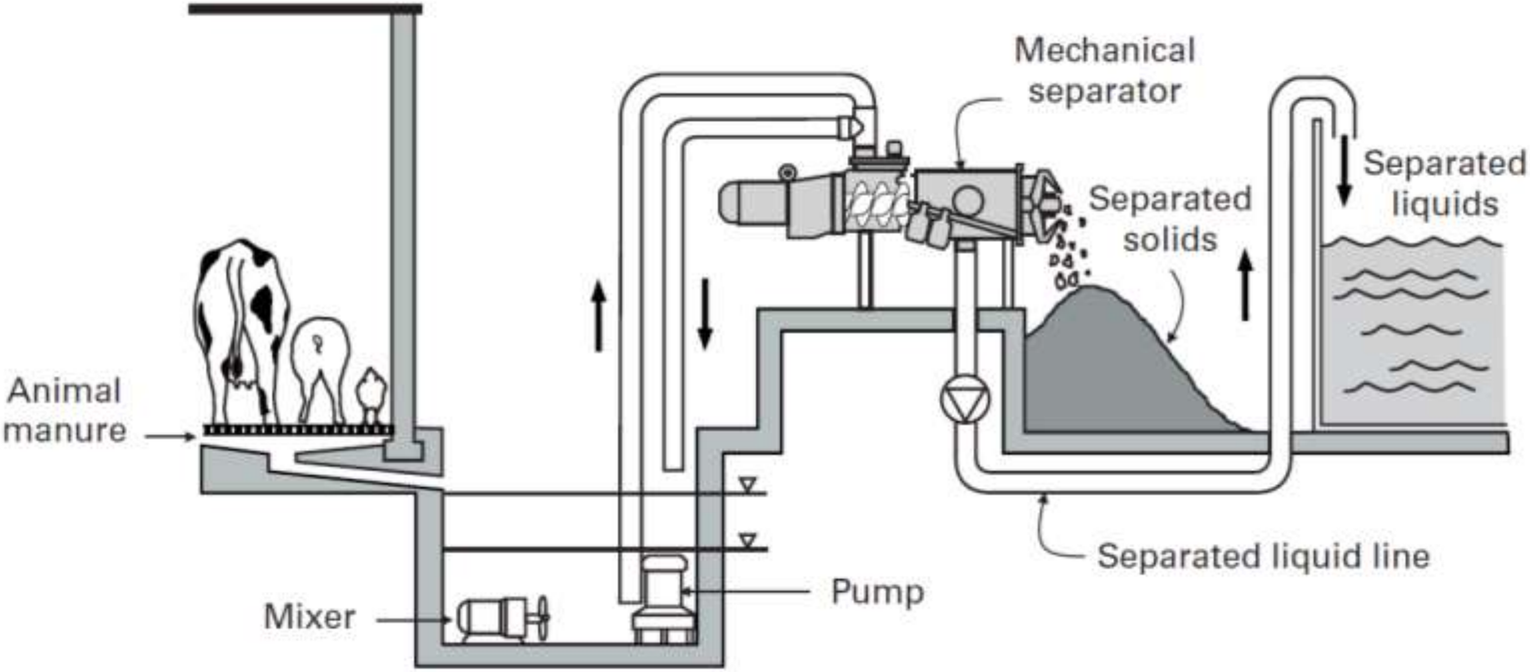
Manure Systems




Manure
Mechanical or Gravitational Separator
Fiber (solid)
Filtrate (liquid)



Midwest Plan Service, 2001

Separation Technologies

- Gravity settling (passive)
- Mechanical separation (active)
  - ♦ Screens
    - – Stationary inclined (static) screens
    - – Vibrating screens
    - – Rotating screens
  - ♦ Presses
    - – Roller presses
    - – Belt presses
    - – Screw presses
  - ♦ Centrifuges

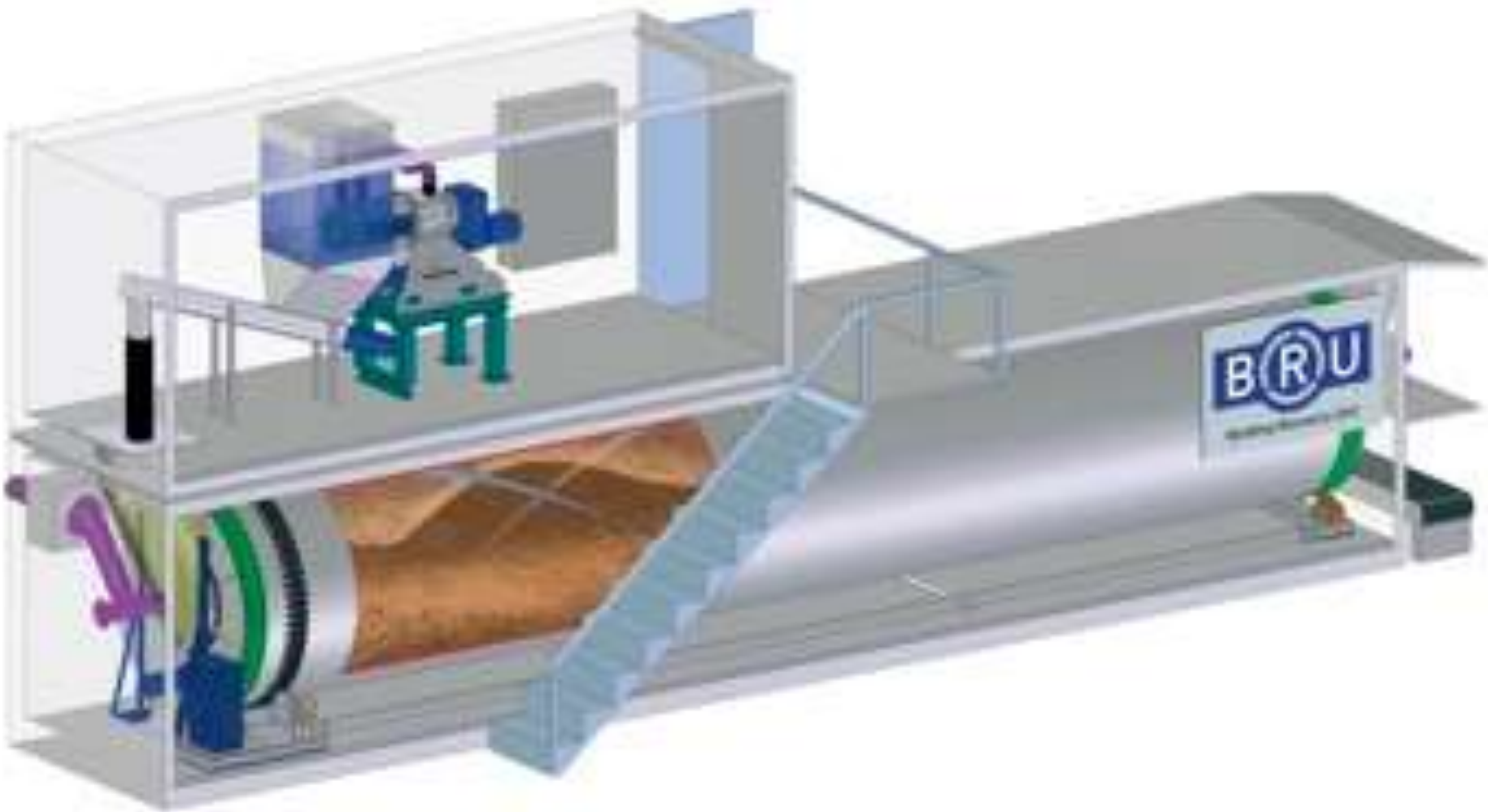

Screen separator

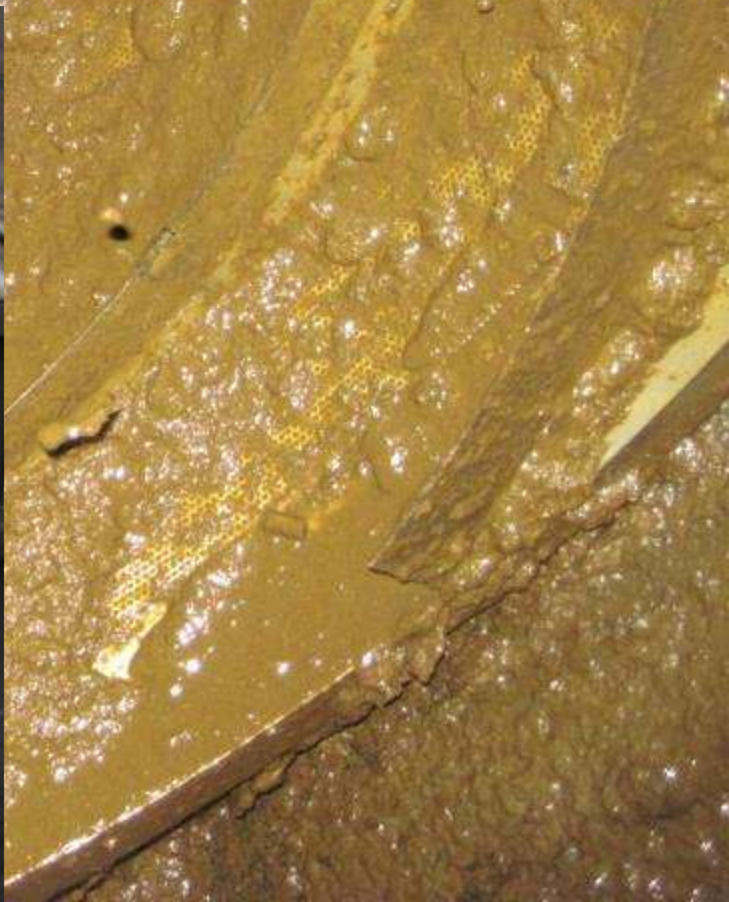
Source: Katers, John. 2008. Value-added Opportunities for Separated Manure Solids presentation.

Screw Press Separator

Centrifuge

Bedding Recovery Unit




Dissolved air flotation

R. Sheffield

- Air is dissolved in the waste water stream and injected at bottom of unit
- Fine solids are carried or "floated" to surface
- Chemical addition of polymers and flocculent is needed for optimum efficiency

Advanced Treatment

Mass Separator Efficiency

Component	Mass separation efficiency (%)[1]
Total solids	45
Total nitrogen	18
Organic nitrogen	20
Inorganic nitrogen	15
Total phosphorous	21

[1]From Chastain (2013) based on (Gooch, Inglis, and Czymmek 2005; Chastain, Vanotti, and Wingfield 2001)

Meta-analysis

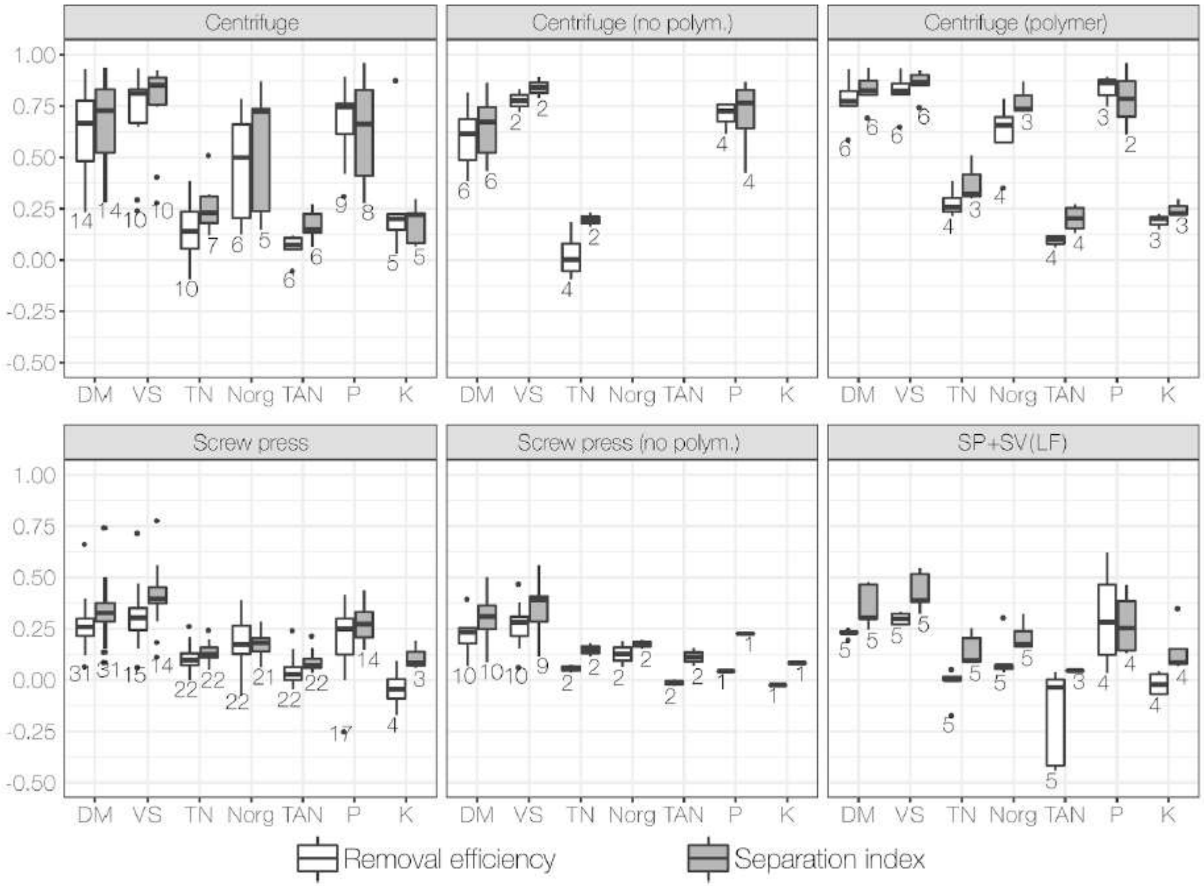


Fig. 2. Efficiency indicators (Removal Efficiency and Separation index) for different separation equipment (C, SP and SP + SV of LF) and digestate components (DM, VS, TN, TAN, Norg P, K). C: centrifuge. SP: screw press. SP + SV(LF): screw press followed by sieving of the liquid fraction. The number below the boxplots indicate the number of observations.

Guilayn, F., J. Jimenez, M. Rouez, M. Crest, D. Patureau. 2019. Digestate mechanical separation: Efficiency profiles based on anaerobic digestion feedstock and equipment choice. *Bioresource Technology*, 274:180-189,

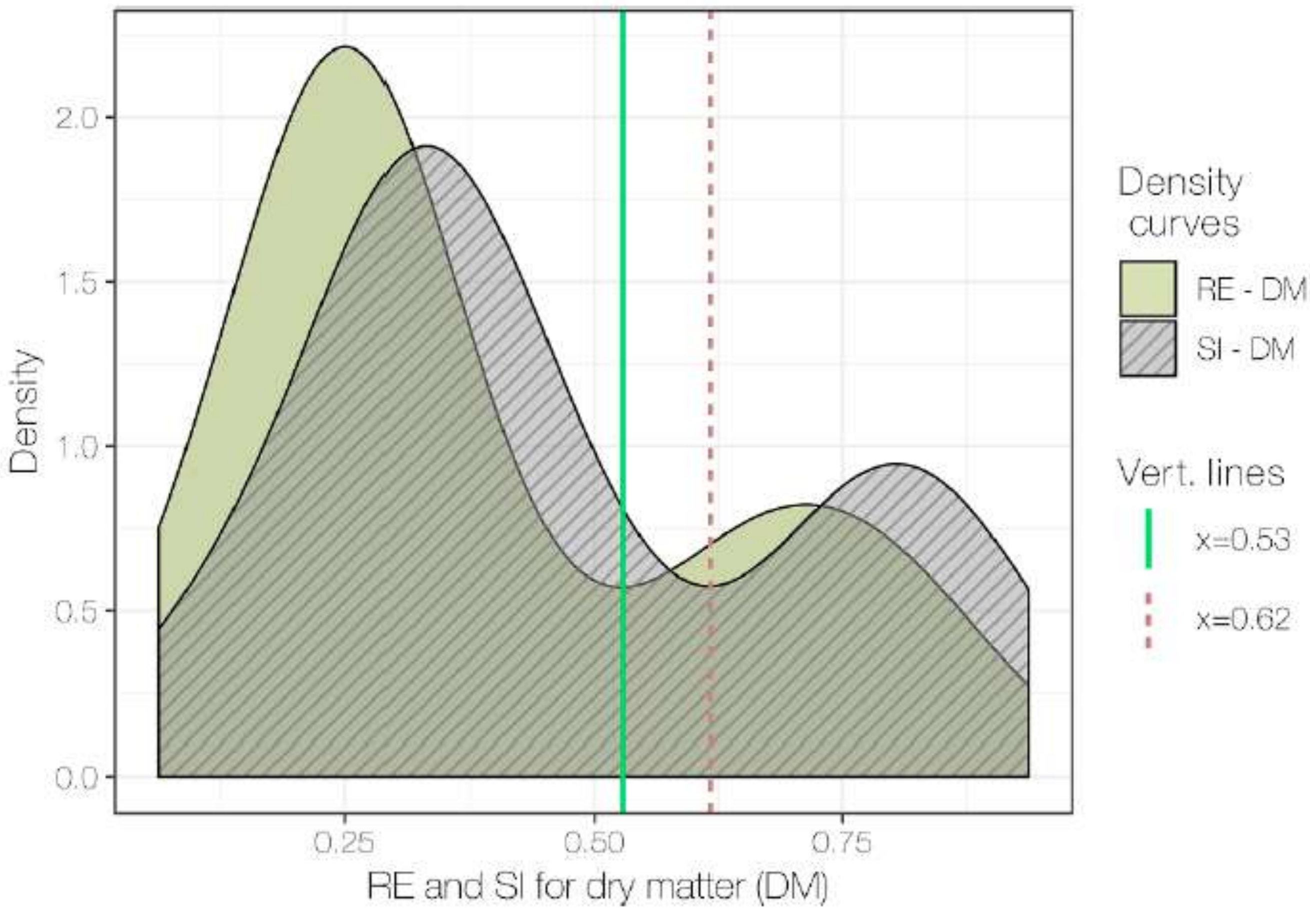


Fig. 4. Density curves for dry matter (DM) removal efficiency (RE) and separation index (SI).

Guilayn, F., J. Jimenez, M. Rouez, M. Crest, D. Patureau. 2019. Digestate mechanical separation: Efficiency profiles based on anaerobic digestion feedstock and equipment choice. *Bioresource Technology*, 274:180-189,

Low vs High Efficiency

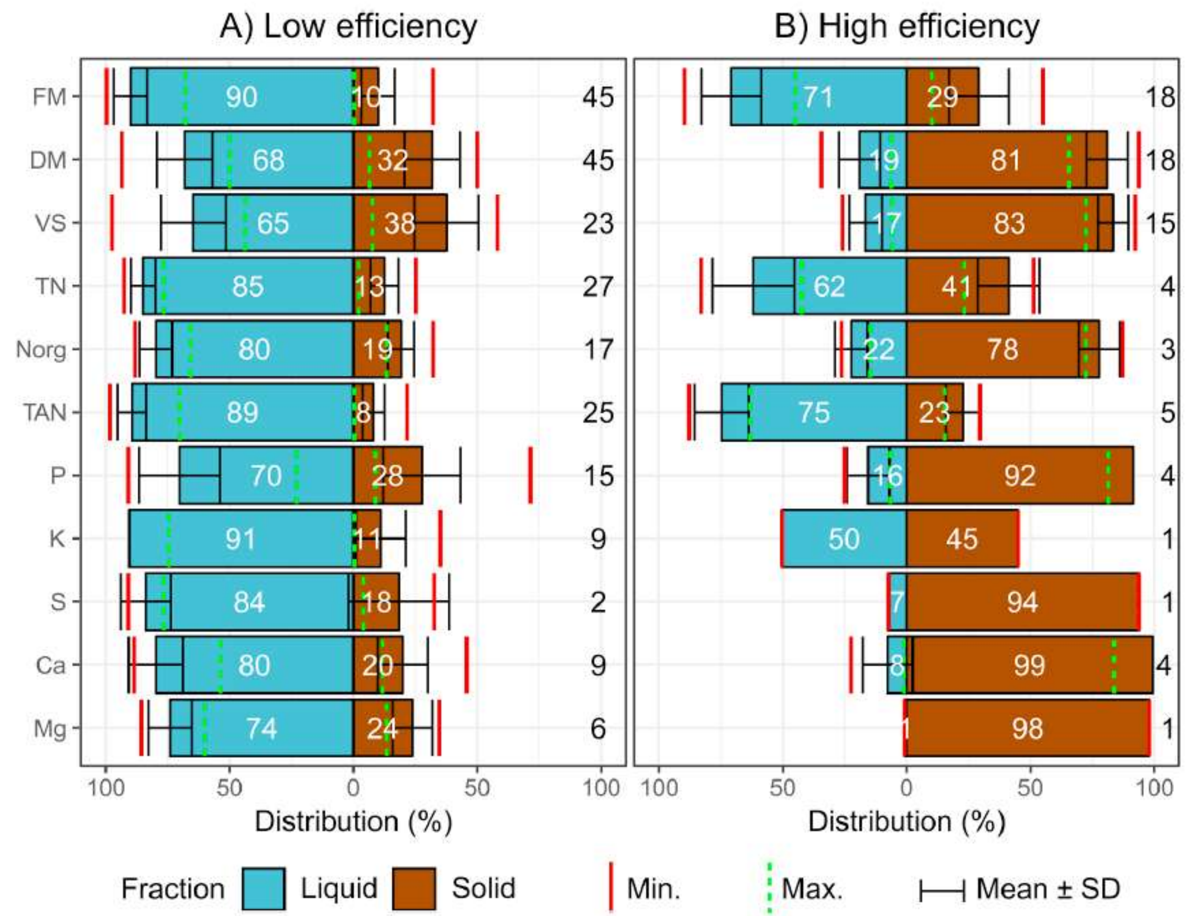
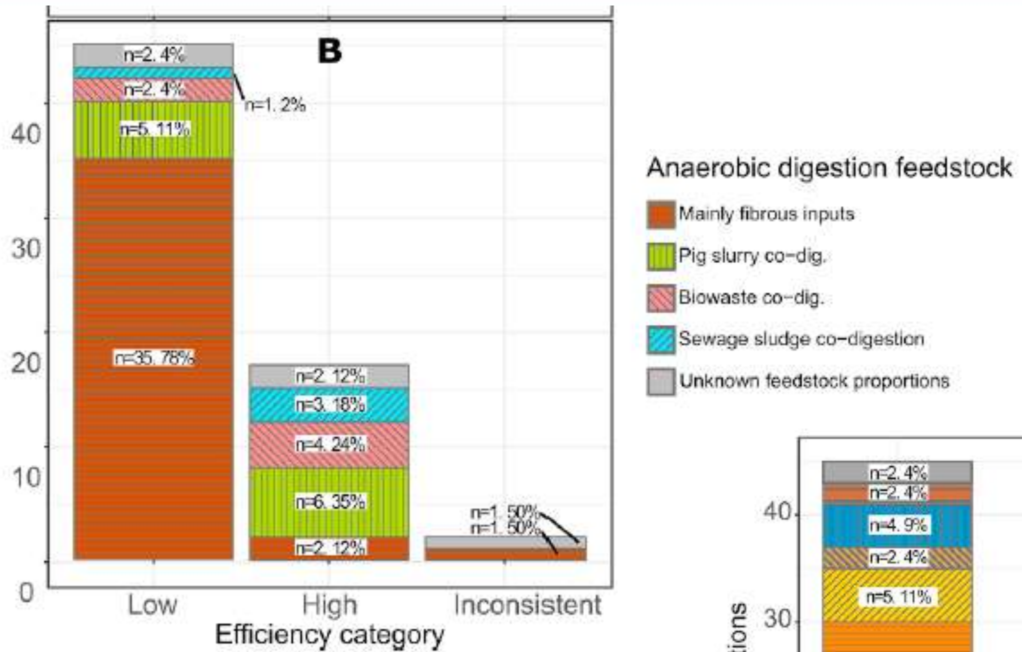
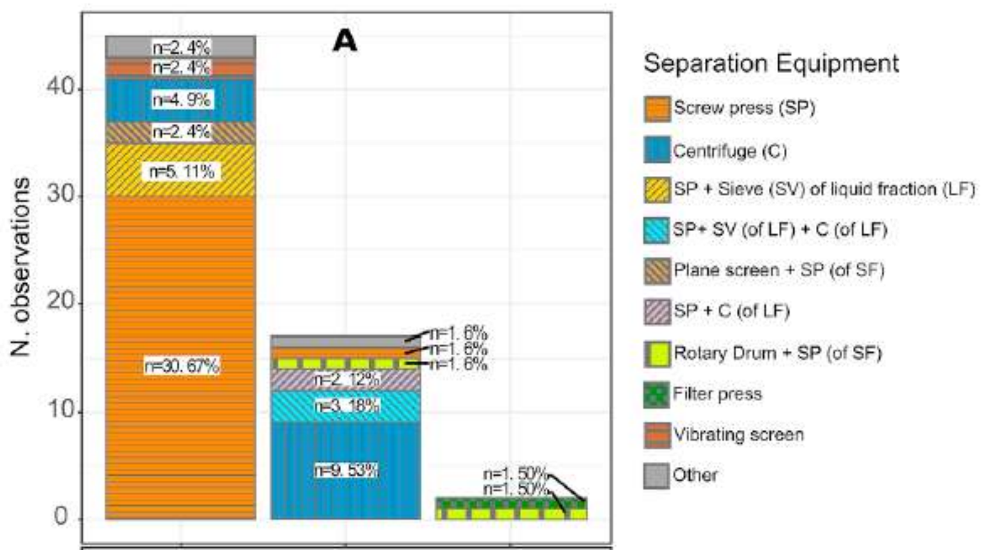


Fig. 5. Mass distributions profiles of digestate mechanical separation according to low (a) and high (b) efficiency categories. The solid fraction distribution correspond to the separation index. The numbers in the right indicate the number of observations. FM: fresh matter. DM: dry matter. VS: volatile solids. TN: total nitrogen. Norg: organic nitrogen. TAN: total ammoniacal nitrogen. P: total phosphorus. K: total potassium. S: total sulfur. Ca: total calcium. Mg: total magnesium.

Guilayn, F., J. Jimenez, M. Rouez, M. Crest, D. Patureau. 2019. Digestate mechanical separation: Efficiency profiles based on anaerobic digestion feedstock and equipment choice. *Bioresource Technology*, 274:180-189,

Separation Efficiency





Guilayn, F., J. Jimenez, M. Rouez, M. Crest, D. Patureau. 2019. Digestate mechanical separation: Efficiency profiles based on anaerobic digestion feedstock and equipment choice. *Bioresource Technology*, 274:180-189,

Fig. 6. Separation equipment classified according to efficiency categories and separation equipment (a) and anaerobic digestion feedstock (b). C: centrifuge. FP: filter press. LF: liquid fraction. PS: lane screen. RD: rotary drum. RS: rotary screen. SF: solid fraction. SP: screw Press. SV: sieve. VS: vibrating screen.

Separation Efficiency

Table 2
Summary of scenarios. Anaerobic digestion feedstock, separation equipment and resulting efficiency category.

Anaerobic digestion feedstock	Equipment	Efficiency	N. obs
Mainly silage, cattle manure and other fibrous inputs	SP*, PS + SP of SF, RS or VS. None with polymer.	Low	32
	C* (without polymer)	Low	3
	SP (with polymer) or SP + C of LF (polymer prior to C)	High	2
	FP*	Inconsistent classification	1
Biowaste, animal slurry, sewage sludge. Mono or co-digestion. Small proportions of fibrous inputs	C (with or without polymer). SP + C of LF, SP + SV of LF + C of LF or RD, all with polymer	High	15
	SP*, PS + SP of SF, RS or VS. None with polymer.	Low	9
	RD + SP of SF, polymer prior to RD	Inconsistent classification	1
	C (without polymer)	Low	1

C: centrifuge. FP: filter press. LF: liquid fraction. PS: plane screen. RD: rotary drum. RS: rotary screen. SF: solid fraction. SP: screw press. SV: sieve. VS: vibrating screen. *: includes cases with lack of information on polymer application.

Guilayn, F., J. Jimenez, M. Rouez, M. Crest, D. Patureau. 2019. Digestate mechanical separation: Efficiency profiles based on anaerobic digestion feedstock and equipment choice. *Bioresource Technology*, 274:180-189,

WI Separation Efficiencies

Separator	RE_{DM}	In DM
SP	0.41	7.9
SP	0.30	5.3
SP	0.52	8.1
SP	0.36	5.0
SP	0.32	4.9
SP	0.33	4.9
SP	0.33	5.9
C	0.39	4.6
SP	0.41	9.7

Separation Efficiencies (based on solids)

	TS (%)	VS (%)	TN (%)	NH3+NH4 (%)	TP (%)	TK (%)
Total efficiencies (all separators combined)	42.8%	51.2%	12.7%	0.4%	29.5%	7.7%
Centrifuge	49.9%	56.7%	15.1%	1.0%	67.1%	9.0%
Screw Press	40.3%	49.1%	11.3%	0.4%	27.3%	6.6%

TN:TP

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	Slurry	Liquid	Solid
SP	10.1	11.5	2.5
SP	6.6	5.8	6.7
SP	8.9	11.6	2.1
SP	6.0	6.7	4.0
SP	6.9	6.4	2.9
SP	6.3	6.5	4.7
SP	6.5	7.6	2.5
SP	6.5	8.1	2.2
C	7.8	17.3	1.6

WI Slurry TN:TP Average 6.5 for TS<11%

Emission Losses

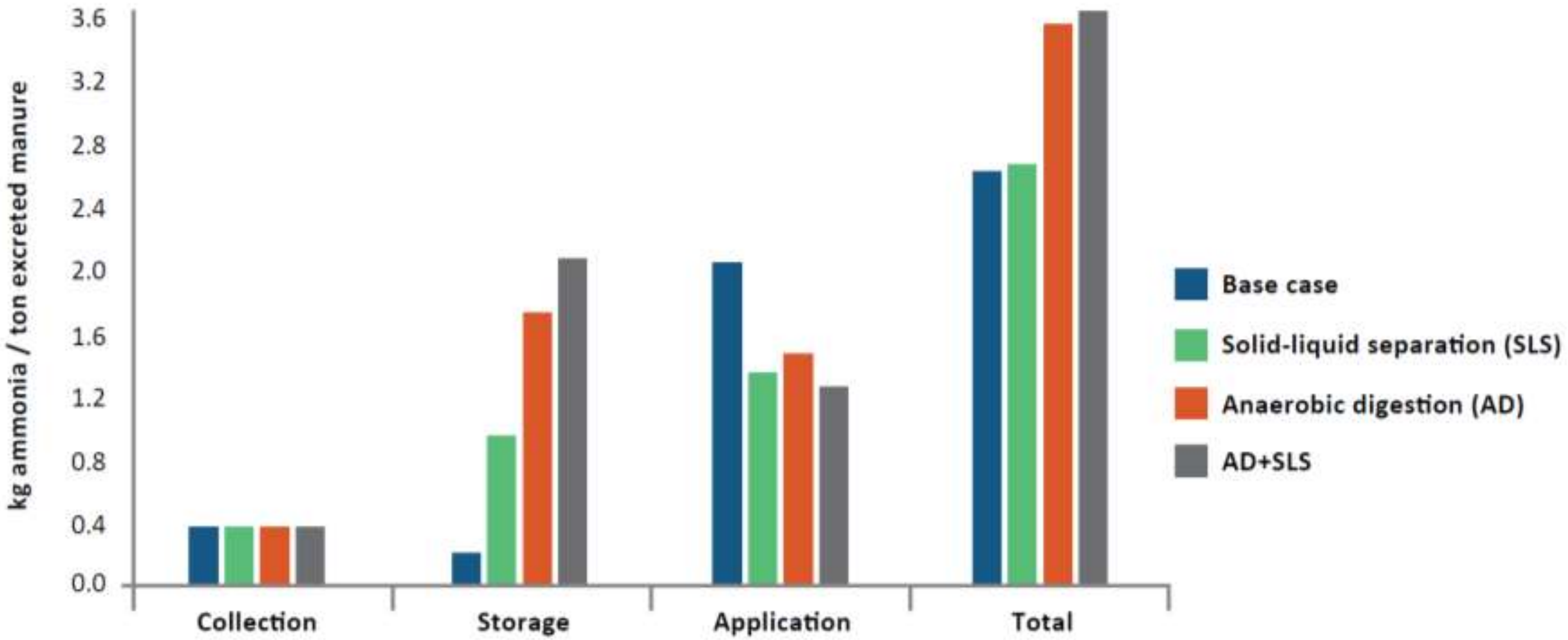


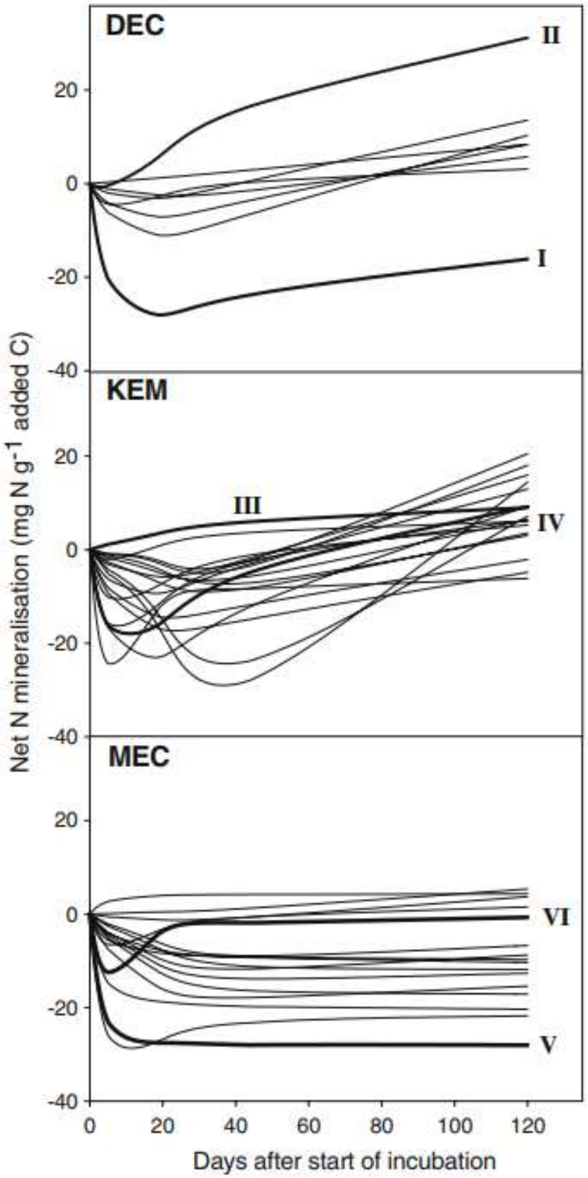
Figure 3. Modeled ammonia losses from manure management in a dairy system with no manure processing (base case), a system with solid-liquid separation (SLS), a system with anaerobic digestion (AD), and a system combining solid-liquid separation and anaerobic digestion (AD+SLS) (Aguirre-Villegas et al. 2014).

Aguirre-Villegas, Horacio A. et al. 2018. UWEX A4131-10, GWQ 082.

Percent of TN that is NH4+NH3

	Slurry	Liquid	Solid
SP	48%	56%	4%
SP	37%	37%	1%
SP	61%	63%	2%
SP	58%	56%	1%
SP	58%	82%	1%
SP	40%	42%	0%
SP	55%	60%	2%
SP	50%	64%	3%
C	60%	67%	4%

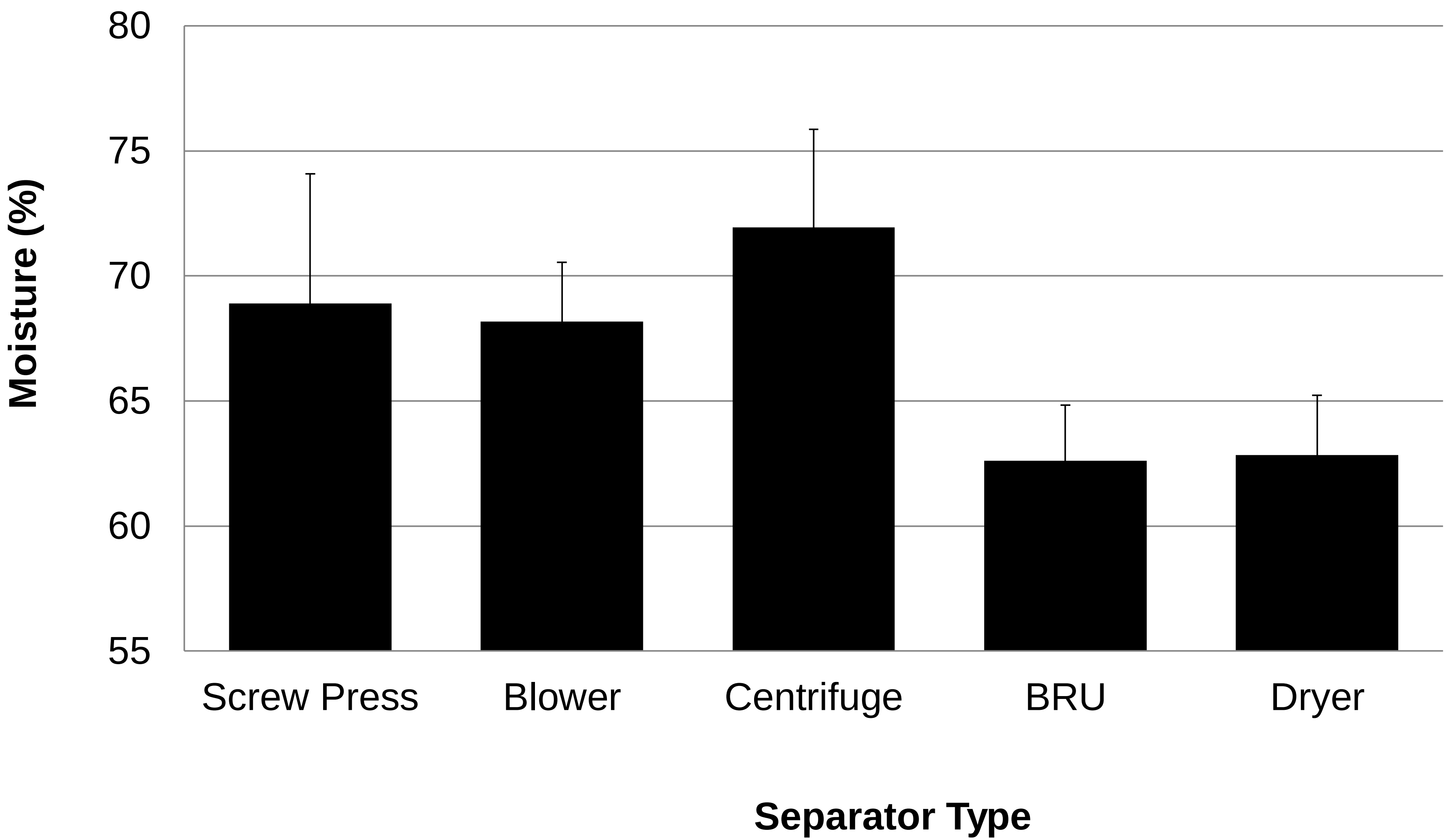
Nitrogen Mineralization of Solid Fraction



- DEC – centrifuges
- KEM – polymer or other chemical pretreatment for flocculation and separation
- MEC - mechanical separation(vibrating screens, screw presses, etc.)

K. Peters and L.S. Jensen. 2011, Biochemical characteristics of solid fractions from animal slurry separation and their effects on C and N mineralization in soil. Biol Fertil Soils, 47:447-455.

Moisture of Solids by Separator Type



Pathogen Fractionation

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Table 7. Microbe detection frequencies and concentrations in unseparated manure, separated liquids, separated solids, and separated solids after secondary treatment. For detection frequencies, *n* refers to the number of samples. Unless otherwise noted, concentrations are the minimum, maximum, and geometric mean of detected concentrations (i.e., nondetects have been excluded).

Microbe†	Detection frequency				Concentration			
	Unseparated‡	Liquids	Solids	Solids, secondary	Unseparated	Liquids	Solids	Solids, secondary
	% (no.)				copies wet g^{-1}			
Bacteroidales-like CowM3	96 (153)	93 (150)	86 (148)	57 (42)	1.9×10^4–2.9×10^8, 2.1×10^6	1.3×10^4–3.3×10^7, 1.1×10^6	4.8×10^1–8.5×10^5, 6.1×10^3	1.4×10^2–2.2×10^4, 1.8×10^3
Bovine *Bacteroides*	98 (153)	95 (150)	89 (148)	79 (42)	2.6×10^3–4.3×10^7, 9.3×10^5	2.4×10^3–3.0×10^7, 5.0×10^5	4.8×10^1–4.1×10^6, 3.2×10^3	9.9×10^1–2.0×10^4, 1.0×10^3
Bovine polyomavirus	100 (153)	97 (150)	76 (148)	17 (42)	2.4×10^3–7.1×10^7, 2.3×10^5	3.6×10^3–9.7×10^7, 2.6×10^5	8.6×10^1–1.8×10^6, 5.8×10^3	3.0×10^1–5.2×10^4, 3.2×10^3
Bovine enterovirus	30 (152)	16 (150)	17 (116)	3 (30)	1.4×10^4–9.0×10^7, 1.6×10^5	1.7×10^4–4.2×10^5, 7.2×10^4	7.4×10^2–2.1×10^4, 2.0×10^3	6.0×10^3 ($n = 1$)
Clostridium perfringens	23 (153)	7 (130)	15 (115)	3 (29)	1.1×10^3–3.8×10^5, 1.7×10^4	2.5×10^3–7.8×10^4, 1.5×10^4	1.6×10^2–8.3×10^3, 1.3×10^3	1.1×10^3 ($n = 1$)
Campylobacter jejuni	26 (152)	10 (134)	12 (125)	6 (32)	9.1×10^2–1.2×10^5, 5.8×10^3	2.5×10^3–1.0×10^6, 3.5×10^4	5.5×10^1–5.2×10^3, 4.0×10^2	2.0×10^2–4.3×10^3, 9.4×10^2
Bovine coronavirus	12 (150)	1 (149)	1 (136)	0 (38)	1.1×10^4–1.4×10^7, 5.1×10^5	1.9×10^4 ($n = 1$)	1.9×10^4 ($n = 1$)	Not detected
Group A rotavirus	22 (153)	15 (150)	5 (136)	0 (38)	8.7×10^3–7.6×10^7, 1.5×10^5	2.5×10^4–3.0×10^7, 3.2×10^5	8.3×10^2–6.8×10^5, 3.0×10^3	Not detected
Salmonella spp.	4 (111)	0 (144)	1 (125)	0 (35)	3.1×10^3–2.2×10^4, 1.2×10^4	Not detected	7.1×10^1 ($n = 1$)	Not detected

† Bovine adenovirus, enterohemorrhagic *Escherichia coli*, *Cryptosporidium parvum*, and *Giardia lamblia* were never detected in separated liquid or solid samples, so they are not included in this table.

‡ For facilities with digesters, unseparated manure samples are the same as digester effluent. For facilities without digesters, unseparated manure samples are untreated manure.

Burch, T., S. Spencer, S. Borchardt, R.A. Larson, and M. Borchardt. 2018. Fate of Manure-Borne Pathogens during Anaerobic Digestion and Solids Separation. *Journal of Environmental Quality*, 47(1):336-344.

Efficiency comparison

Technology	Initial TS (%)	TP Removal (%)
Settling Basin	~4	28
Screw Press	variable	15-24
Centrifuge	variable	40-60
Dewatering using Geotextiles	0.71	46
Inclined Plane		53
Screens	0.4-3.2	<17
Screens with Polymers	0.4-3.2	34-65
Chemical Precipitation	0.87-1.5	80-90

Screens

Screen size[b] (mm)	TSS		VSS		TKN		TP	
	Amount retained (g/L)	Fraction of TSS (%)	Amount retained (g/L)	Fraction of VSS (%)	Amount retained (mg/L)	Fraction of TKN (%)	Amount retained (mg/L)	Fraction of TP (%)
3.360	0.74	6.4	0.38	6.7	43.13	7.6	10.57	6.8
2.000	2.76	23.9	0.94	16.6	43.85	7.7	8.16	5.7
1.588	3.24	28.1	1.78	31.4	33.04	5.8	8.86	6.0
1.000	3.78	32.8	1.60	28.3	66.11	11.6	16.66	11.4
0.794	3.18	27.6	2.18	38.5	66.12	11.6	16.67	12.1
0.590	3.98	34.5	2.48	43.8	77.93	13.7	16.96	12.3
0.500	3.92	34.0	1.54	27.2	59.81	10.5	15.16	11.0
0.297	4.22	36.6	1.90	33.6	60.68	10.6	15.43	11.1
0.250	4.82	41.8	2.14	37.8	78.26	13.7	23.26	16.7

Garcia, M.C., A.A. Szogi, M.B. Vanotti, and J.P. Chastain. 2007, Solid-liquid separation of dairy manure with PAM and chitosan polymers. *Proceedings of the 16-19 Sept 2007 International Symposium on Air Quality and Waste Management for Agriculture, Broomfield, Colorado.* ASABE Pub. No. 701P0907cd.

Screens with polymers

Polymer rate (mg/L)	Removal efficiency [a] (%)							
	TSS		VSS		TKN		TP	
	PAM							
0	64.9	(0.090)	64.3	(4.44)	18.9	(0.021)	19.6	(2.68)
60	71.6	(0.232)	73.8	(2.06)	37.1	(0.436)	34.4	(1.03)
120	75.9	(0.671)	74.2	(0.823)	35.8	(2.60)	33.8	(5.05)
180	82.8	(0.246)	79.8	(2.03)	48.1	(3.56)	44.4	(5.31)
240	86.8	(1.47)	83.5	(2.63)	55.9	(5.65)	52.0	(8.64)
300	90.0	(1.15)	87.6	(1.75)	63.9	(3.36)	58.9	(4.73)
360	92.7	(0.285)	92.4	(0.835)	65.0	(4.69)	57.8	(5.93)
420	94.9	(0.575)	92.9	(1.67)	74.0	(8.76)	66.4	(9.43)
480	95.0	(0.614)	93.0	(0.208)	73.1	(3.56)	64.9	(2.73)

Garcia, M.C., A.A. Szogi, M.B. Vanotti, and J.P. Chastain. 2007, Solid-liquid separation of dairy manure with PAM and chitosan polymers. *Proceedings of the 16-19 Sept 2007 International Symposium on Air Quality and Waste Management for Agriculture, Broomfield, Colorado.* ASABE Pub. No. 701P0907cd.

Chemical & polymer P separation

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- Significant additions of chemical and polymer
- 80-90% TP removal
- Dairy manure at 0.87% & 1.5% TS
- Chemical additions alone cost $0.01

Conclusions

- Separation systems are highly variable
- Most separators currently installed are low efficiency
- Investigating improved performance may have significant advantages in terms of nutrient separation
- Higher removal efficiency for phosphorus than nitrogen
- Solids fraction – could have concerns for nitrogen availability, variability in systems

Thank You!

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