


Biosolids & Agronomic Loading Math Part 1 Basics

Steve & Brad


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Biosolids & Agronomic Loading Math Part 1 Basics

Steve Moehlmann
MMES.help

Biosolids

Math

Basics

Brad Tingley
Des Moines WRF

Agronomic Loading Math

Basics

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Certification

- Certified in Wastewater Treatment?
- Certified in Land Application?
- Certified ABC Biosolids Land Applier?

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Special Thanks!

- Brad Tingley, Des Moines WRF
- Tom Atkinson, Iowa DNR
- Larry Hare, Des Moines WRF
- Tim Runde, Des Moines WRF
- Scott Wienands, Nutri-Ject Systems
- Emy Lieu, Iowa DNR

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Biosolids

Raw Sludge → Biosolids Cake → Land Appl

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Our Goals

Calculate biosolids and agronomic loading math basics for Class II Biosolids using anaerobic digestion

- Wastewater treatment operators who apply biosolids as part of their job
- Land application specialists who apply Class II Biosolids that have been anaerobically digested and dewatered

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Biosolids Land Application Field Guide

Iowa Water Environment Association

2nd Edition 2011

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IAWEA Definitions

Agronomic Rate – Amount of nitrogen (or other nutrient) which can be utilized by the crop to be grown.

Biosolids – Primarily organic solids produced by waste water treatment processes that are beneficial for recy-cling on land as a soil conditioner and nutrient source for plant growth.

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Biosolids Math Basics
Steve Moehlmann, MMES.help

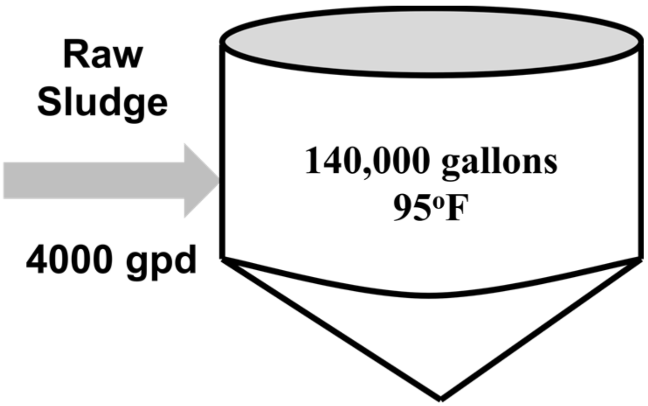
1. Hydraulic Retention Time (HRT)
2. Volatile Solids Reduction % (VSR%)
3. Cake Solids (Solids)

Chapter 67 Land Application of
Class II Biosolids Requirements

Processes to Significantly Reduce Pathogens Anaerobic Digestion: "Values for the **mean cell residence time** *(MCRT)* and temperature shall be between **15 days at 35°** to 55°C and 60 days at 20°C"

Vector Attraction: "The mass of **volatile solids** *(VS)* in the sewage sludge shall be reduced by a **minimum of 38**%

Data for Hydraulic Retention Time



Calculate MCRT
Anaerobic Digestion

To calculate MCRT, we will calculate HRT

MCRT = HRT

Hydraulic Retention Time, days

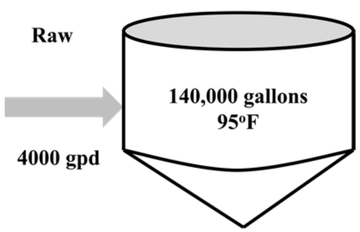
ABC Wastewater Treatment Grade 1 – 4

ABC Formula for Detention Time

$$\frac{\text{Volume}}{\text{Flow}} = \frac{\text{Digester Volume gal}}{\text{Raw Sludge Flow gpd}}$$

Hydraulic Retention Time, days

Anaerobic Digestion



$$\text{HRT} = \frac{\text{Volume}}{\text{Flow}} = \frac{140{,}000\ \text{gal}}{4000\ \text{gpd}}$$

= 35 days

HRT = 35 Days @ 95ºF

HRT = 35 Days @ 95ºF

Anaerobic Digestion

✓Chapter 67: MCRT > 15 days at 35ºC

MCRT = HRT = 35 days

35 days @ 95ºF > 15 days @ 35ºC

ºF = (ºC)(1.8) + 32 = (35)(1.8) + 32

= 63 + 32

= 95ºF

Volatile Solids Reduction %

Wastewater Treatment Grade 3 & 4

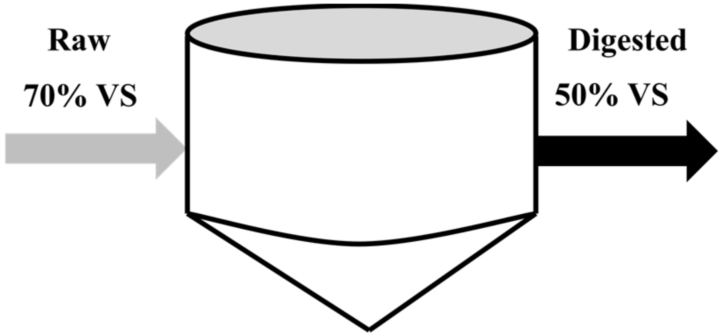
$$\text{VSR}\ \% = \frac{VS_{in} - VS_{out}}{VS_{in} - (VS_{in} \times VS_{out})} \times 100\%$$

VS_{in} and VS_{out} must be in decimal form

- VS_{in} is Raw Sludge Volatile Solids
- VS_{out} is Digested Volatile Solids

ABC Formula

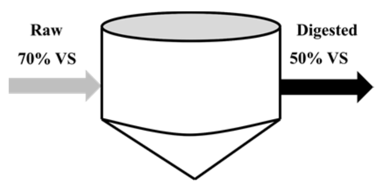
VSR % Data



Volatile Solids Reduction, %

Lab Results

- VS_{in} = 70%
- VS_{out} = 50%



First, convert % to decimal

$$VS_{in} = \frac{VS\%}{100\%} = \frac{70\%}{100\%} = 0.70$$

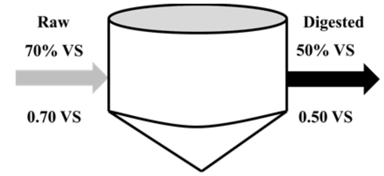
$$VS_{out} = \frac{VS\%}{100\%} = \frac{50\%}{100\%} = 0.50$$

Volatile Solids Reduction, %

Lab Results

VS_{in} = 70% = 0.70

VS_{out} = 50% = 0.50



$$VSR\ \% = \frac{VS_{in} - VS_{out}}{VS_{in} - (VS_{in} \text{ x } VS_{out})} \text{ x } 100\%$$

$$= \frac{0.70 - 0.50}{0.70 - (0.70 \text{ x } 0.50)} \text{ x } 100\%$$

Volatile Solids Reduction, %

$$VSR\ \% = \frac{0.70 - 0.50}{0.70 - (0.70 \text{ x } 0.50)} \text{ x } 100\%$$

0.70 – 0.50 = 0.20

(0.70 x 0.50) = 0.35

$$VSR\ \% = \frac{0.2}{0.70 - 0.35} \text{ x } 100\%$$

Volatile Solids Reduction, %

$$VSR\ \% = \frac{0.2}{0.70 - 0.35} \times 100\%$$

0.70 – 0.35 = 0.35

$$VSR\ \% = \frac{0.2}{0.35} \times 100\%$$

= 0.57 x 100%

= 57%

Volatile Solids Reduction, %

Class II Biosolids

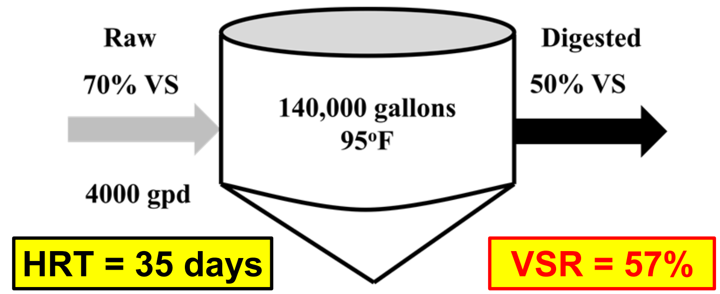
✓Chapter 67: **Volatile solids** in **Class II Biosolids** shall be **reduced > 38%**

VSR % = 57%

57% > 38%

HRT & VSR Data

Anaerobic Digestion & Class II Biosolids



Belt Filter Press Dewatered Cake Solids

Data

- 2500 lbs
- 18% Solids

Belt Filter Press Dewatered Cake Solids (CS), lbs

2500 lbs of BFP Cake @ 18% Solids

(BFP Cake lbs)(% Solids as decimal)

$$\text{\% Solids as decimal} = \frac{\text{\% Solids}}{100} = \frac{18\%}{100}$$

= 0.18 Solids

Cake Solids lbs = (2500 lbs)(0.18 Solids)

= **450 lbs Solids**

Agronomic Loading Math Brad Tingley, Des Moines WRF

- Pre-Application
- Plant Available Nitrogen
- Phosphorus, Potassium, & Zinc
- Site Selection & Coverage Area
- Target Agronomic Rate
- Application Rate and Carry-Over
- Calibrating Applicator
- Actual Application Rate

Land Application

Who's Under 30?

- 503 adopted 1993
- Chapter 67 in 1994

Lab Results

- ppm or mg/kg
- % Solids
- Available nutrients

Analyte	Result
1G61201-01	BFP Cake - Monthly
Nitrogen, Ammonia	7720 mg/kg dry
Nitrogen, Organic	26400 mg/kg dry
pH, Soils	8.5 pH
% Solids	18.0 %
Nitrogen, Kjeldahl, total	34200 mg/kg dry
Solids, total	18.0 %
Nitrogen, Nitrate	<5.6 mg/kg dry
Arsenic, total	2.55 mg/kg dry
Cadmium, total	<0.9 mg/kg dry
Chromium, total	34.9 mg/kg dry
Copper, total	226 mg/kg dry
Mercury, total	<0.6 mg/kg dry
Potassium Oxide	2230 mg/kg dry
Potassium, total	1840 mg/kg dry

Pre-Application

Sample Biosolids

- Nutrients
- Pollutants
- Solids

Analyte	Result
1G61201-01	BFP Cake - Monthly
Nitrogen, Ammonia	7720 mg/kg dry
Nitrogen, Organic	26400 mg/kg dry
pH, Soils	8.5 pH
% Solids	18.0 %
Nitrogen, Kjeldahl, total	34200 mg/kg dry
Solids, total	18.0 %
Nitrogen, Nitrate	<5.6 mg/kg dry

Nitrogen

- Ammonia N
  - Ammonia (NH_3) or Ammonium (NH_4^+)
- Organic Nitrogen – unavailable to plants
- Nitrate (NO_3^-)/Nitrite (NO_2^-)
- Total Kjeldahl Nitrogen (TKN)

Plant Available Nitrogen (PAN)

- Organic N - Slow Release
- Ammonia N - Immediately available
  - Volatilization
- Nitrate/Nitrite - Immediately available
  - Insignificant amounts present in Biosolids

Plant Available Nitrogen

Nitrogen	Lab Results	Availability
Organic N	26,400 mg/kg	Slow release
Ammonia N	7720 mg/kg	Immediately
Nitrate/Nitrite	< 5.6 mg/kg	Immediately

Phosphorus, Potassium, & Zinc

- Phosphorus (P)
  - Lab reports elemental P, convert to P_2O_5
- Potassium (K)
  - Convert to K_2O
- Zinc – Pollutant
  - Important micronutrient
  - Include when reporting agronomic values

Organic N

lbs/Dry Ton = ppm x 0.002

lbs/Dry Ton x 0.20 = 1st year PAN

- 20% (0.20) available 1st growing season

Carry-Over N from Organic N

- 10% (0.10) available 2nd growing season
- 5% (0.05) available 3rd growing season

Ammonia N

Ammonia N ppm x 0.002 = lbs/Dry Ton PAN

- 100% available **EXCEPT** for
  - **Lost to volatilization or off-gassing**
- WRF uses 50% loss factor when not incorporated within 48 hrs

Total N

Ammonia N + Organic N + Nitrate N

- Surface application of cake solids
- Immediate incorporation

Nutrient	mg/kg or ppm
Ammonia N	7720
Organic N	26,400
Nitrate N	< 5.6

Lab Results / PPM		NUTRIENT	ANALYSIS		LBS/DRY TON AVAIL		
TKN	56975	NITROGEN	LBS/T	% AVAIL	YR 1	YR 2	YR 3
NH4	8038	ORGANIC	97.9	20%	19.6	9.8	4.9
NO3	6	AMMONIA	16.1	1.0	16.1	0.0	0.0
Organic	48950	NITRATE	0.0	100%	0.0	0.0	0.0
		If Incorporated in 48 Hrs.		TOTAL	35.7	9.8	4.9
% Solids	17	If Not Incorporated in 48 Hrs.		TOTAL	27.6		
P2O5	70575	P AS P205	141.2	50%	70.6		
K2O	4145	K AS K20	8.3	100%	8.3		
Zinc	615	ZINC	1.2	VARIES	1.2		

RATE: DRY TONS/ACRE	TOTAL PLANT AVAILABLE NITROGEN (PAN) LBS/ACRE			
	YR 1 Inc.	YR1 Uninc.	YR 2	YR 3
1	36	28	9.8	4.9
2	71	55	19.6	9.8
3	107	83	29.4	14.7
4	143	111	39.2	19.6
5	178	138	49.0	24.5
6	214	166	58.7	29.4
7	250	193	68.5	34.3
8	285	221	78.3	39.2

Target Rate	Wet Tons/Acre	
No Carryover	Incorp.	Unincorp.
140	23	30
180	30	38

To covert Dry Tons/Acre to Wet Tons/Acre -- Devide Dry Ton Amount by %Solids (as a decimal)
Example ***6 (DT) / .17 (17%) = 35.29 Wet Tons/Acre***

To Calculate Wet Tons/Acre -- Target Nitrogen Rate (Devided by) Lbs. Nitrogen per DT (Devided by) Percent Sloids (as Decimal)
Example - Bean to Corn 140 Lbs. Nitrogen ***140 (Lbs. N Desired) / 23.7 (Lbs. N per DT - if not inc.) / .19 (19% Solids) = 31 (Wet Tons per Acre)***

To Find *Tons* Needed Per Pass	Length	X	Width	÷	43560	x	Rate	Tons/Pass	÷	2	Tons/Unit
Example	1200	X	25	÷	43560	x	33	22.72727273	÷	2	11.36363636

This is the number of Spreaders Working in the field- Could be 1, 2, or 3

To Find *Width* of a Pass	Tons/Unit	x	2	Tons/Pass	÷	Rate	x	43560	÷	Length	Width
Example	13	x	2	26	÷	33	x	43560	÷	1200	28.6

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Lab Results / PPM		NUTRIENT	ANALYSIS		LBS/DRY TON AVAIL		
TKN	56975	NITROGEN	LBS/T	% AVAIL	YR 1	YR 2	YR 3
NH4	8038	ORGANIC	97.9	20%	19.6	9.8	4.9
NO3	6	AMMONIA	16.1	1.0	16.1	0.0	0.0
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RATE: DRY TONS/ACRE	TOTAL PLANT AVAILABLE NITROGEN (PAN) LBS/ACRE			
	YR 1 Inc.	YR1 Uninc.	YR 2	YR 3
1	36	28	9.8	4.9
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4	143	111	39.2	19.6
5	178	138	49.0	24.5
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Target Rate	Wet Tons/Acre	
No Carryover	Incorp.	Unincorp.
140	23	30
180	30	38

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Ammonia N Calculations

lbs/Dry Ton = ppm x 0.002

Ammonia N = 7720 ppm

Ammonia N lbs/Dry Ton = ppm x 0.002

= 7720 x 0.002

= 15.44 lbs/Dry Ton

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Organic N Calculations

lbs/Dry Ton = ppm x 0.002 x % PAN as decimal

Organic N = 26,400 ppm

PAN = ppm x 0.002 x % PAN as decimal

1st Season PAN = 20%

20% as decimal = $\frac{\%}{100} = \frac{20\%}{100}$ = 0.20

PAN lbs/Dry Ton = 26,400 x 0.002 x 0.20

= 10.56 lbs/Dry Ton

Nitrate N Calculations

lbs/Dry Ton = ppm x 0.002

Nitrate N = 5.6 ppm

Nitrate N lbs/Dry Ton = ppm x 0.002

= 5.6 x 0.002

= 0.0112 lbs/Dry Ton

Total PAN for 1st Season

Ammonia N + Organic N + Nitrate N

- Ammonia N = 15.44 lbs/Dry Ton
- Organic N = 10.56 lbs/Dry Ton
- Nitrate N = 0.0112 lbs/Dry Ton

PAN lbs/Dry Ton = 15.44 + 10.56 + 0.0112

= 26.0112 lbs/Dry Ton

Phosphorus (P) Calculation

lbs/Dry Ton = ppm x 0.002 x 2.29 x % as decimal

Phosphorus to P_2O_5 (Phosphate) Equivalent

50% available to crop

Potassium (K) Calculation

lbs/Dry Ton = ppm x 0.002 x 1.2

Potassium to **K_2O** Potash Equivalent

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Site Selection

- Area
- Crop rotation
- Nutrient requirements

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Zinc Calculation

lbs/Dry Ton = ppm x 0.002

lbs/Dry Ton = ppm x 0.002

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Jasper County, Iowa (IA099)

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
5B	Ackmore-Colo complex, 2 to 5 percent slopes	2.1	0.9%
8B	Judson silty clay loam, 2 to 5 percent slopes	26.7	11.6%
63C	Chelsea loamy fine sand, 5 to 9 percent slopes	3.0	1.3%
63D	Chelsea loamy fine sand, 9 to 14 percent slopes	2.3	1.0%
65E	Lindley loam, 14 to 18 percent slopes	0.5	0.2%
120B	Tama silty clay loam, 2 to 5 percent slopes	26.6	11.5%
120C2	Tama silty clay loam, 5 to 9 percent slopes, eroded	43.5	18.9%
120D2	Tama silty clay loam, 9 to 14 percent slopes, eroded	28.2	12.2%
133+	Colo silt loam, 0 to 2 percent slopes, occasionally flooded, overwash	63.4	27.5%
175B	Dickinson fine sandy loam, 2 to 5 percent slopes	2.4	1.0%
220	Nodaway silt loam, shallow loess, 0 to 2 percent slopes, occasionally flooded	4.4	1.9%
620C2	Port Byron silt loam, 5 to 9 percent slopes, moderately eroded	6.8	2.9%

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Actual Coverage Area

Agronomic rate = lbs/acre of nutrient

1 acre = 43,560 square feet

Total Area, acres $= \frac{\text{Area, square feet}}{\text{43,560 sq}}$

$= \frac{\text{L (feet) x W (feet)}}{\text{43,560 sq}}$

Actual Coverage Area = Total Area - Setbacks

Target Agronomic Rate for Crop

Calculate Nitrogen needed for your crop

Corn following Corn can use 200 lbs of N/acre

PAN lbs/Dry Ton = 26.0112 lbs/Dry Ton

Dry Tons/acre $= \frac{\text{lbs N needed/acre}}{\text{lbs N/Dry Ton}}$

$= \frac{\text{200 lbs N needed/acre}}{\text{26 lbs N/Dry Ton}}$

Target Agronomic Rate for Crop

Dry Tons/acre $= \frac{\text{lbs N needed/acre}}{\text{lbs N/Dry Ton}}$

$= \frac{\text{200 lbs N needed/acre}}{\text{26 lbs N/Dry Ton}}$

= 7.69 Dry Tons/acre

Organic Nitrogen Carry-Over

If we applied on this same site last year, we need to credit the Carry-Over N for the Organic N applied previously. Let’s say we applied at the same rate and same values

Carry-Over PAN = ppm x 0.002 x % PAN as decimal

= 26,400 x 0.002 x 0.10

= 5.28 lbs/Dry Ton

Biosolids & Agronomic Loading Rate Math Part 1 Basics

Organic Nitrogen Carry-Over

Carry-Over PAN = 5.28 lbs/Dry Ton

Applied Last Year = 7.69 Dry Tons/acre

Carry-Over N = Applied Last Year x Carry-Over N

= 7.69 Dry Ton/acre x 5.28 lbs/Dry Ton

= 40.6 lbs/acre

Reduce N needed by 40.6 lbs/acre

Organic Nitrogen Carry-Over

Reduce N needed by 40.6 lbs/acre

Corn can use 200 lbs/acre of N

N needed = 200 lbs/acre – 40.6 lbs/acre

= 159.4 lbs/acre

Now we can recalculate the target rate in Dry Tons

Target Agronomic Rate for Crop

Target Rate is 159.4 lbs N needed

Dry Tons/acre $= \frac{\text{lbs N needed}}{\text{lbs N/Dry Ton}}$

$= \frac{\text{159.4 lbs N needed}}{\text{26 lbs N/Dry Ton}}$

= 6.13 Dry Tons

Convert Dry Tons to Wet Tons

Wet Tons, acre $= \frac{\text{Dry Tons}}{\text{\% Solids as decimal}}$

Target application rate = 6.13 Dry Tons/acre

Lab Results = 18% Solids

18% as decimal $= \frac{\%}{100} = \frac{18\%}{100} = 0.18$

Wet Tons, acre $= \frac{\text{6.13 Dry Tons/acre}}{0.18}$

Convert Dry Tons to Wet Tons

$$\text{Wet Tons, acre} = \frac{6.13 \text{ Dry Tons/acre}}{0.18}$$

= 34 wet tons/acre

34 wet tons/acre will provide 159 lbs PAN needed for our target agronomic rate for corn

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Wet Tons of Biosolids Needed for Site Selected

To calculate how wet tons of Biosolids are needed for a site, we need to calculate

- lbs of PAN
- Biosolids Dry Tons (DT)
- Biosolids Wet Tons (WT)

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Wet Tons of Biosolids Needed for Site

DATA

- Site = 20 acres
- PAN Needed = 159 lbs/acre
- PAN Available = 26 lbs PAN/DT Biosolids
- Biosolids = 18% Solids

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Total PAN Needed for Site

- PAN Needed = 159 lbs/acre
- Site = 20 acres

Total PAN Needed = PAN Needed x Site

= 159 lbs/acre x 20 acres

= 3180 lbs

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Bisolids Needed for Site

- PAN Needed = 3180 lbs
- PAN Available = 26 lbs/DT Biosolids

$$\text{Biosolids Needed} = \frac{\text{PAN Needed}}{\text{PAN Available}}$$

$$= \frac{3180\ \text{lbs}}{26\ \text{lbs/DT of Biosolids}}$$

= 122 DT Biosolids

Wet Tons of Biosolids Needed for Site

- Biosolids Needed = 122 DT
- Biosolids = 18% Solids = 0.18 Solids

$$\text{Biosolids Wet Tons} = \frac{\text{Biosolids DT}}{\text{\% Solids as decimal}}$$

$$= \frac{122\ \text{DT}}{0.18}$$

= 678 Wet Tons

To covert Dry Tons/Acre to Wet Tons/Acre -- Devide Dry Ton Amount by %Solids (as a decimal)

Example *6 (DT) / .17 (17%) = 35.29 Wet Tons/Acre*

To Calculate Wet Tons/Acre -- Target Nitrogen Rate (Devided by) Lbs. Nitrogen per DT (Devided by) Percent Sloids (as Decimal)

Example - Bean to Corn 140 Lbs. Nitrogen *140 (Lbs. N Desired) / 23.7 (Lbs. N per DT - if not inc.) / .19 (19% Solids) = 31 (Wet Tons per Acre)*

To Find *Tons* Needed Per Pass	Length	X	Width	÷	43560	x	Rate		Tons/Pass	÷	2	Tons/Unit
Example	1200	X	25	÷	43560	x	33		22.72727273	÷	2	11.36363636

This is the number of Spreaders Working in the field- Could be 1, 2, or 3

To Find *Width* of a Pass	Tons/Unit	x	2	Tons/Pass	÷	Rate	x	43560	÷	Length	Width
Example	13	x	2	26	÷	33	x	43560	÷	1200	28.6

Calibrating Applicator

Data

- Spreader holds 12 wet tons
- Coverage width = 15 feet
- Applying 34 wet tons/acre

$$\text{Coverage Area per Load} = \frac{\text{Wet Tons/Load}}{\text{Application Rate}}$$

Coverage Area per Load

- Spreader = 12 wet tons
- Applying 34 wet tons/acre

$$\text{Coverage Area per Load} = \frac{\text{Spreader}}{\text{Application Rate}}$$

$$= \frac{\text{12 wet tons}}{\text{34 wet tons/acre}}$$

= 0.35 acres/load

Coverage Length per Load

- Coverage Width = 15 feet
- Coverage Area = 0.35 acres/load

To calculate the Coverage Length

- First, we need to convert Coverage Area per Load in acres to square feet
- Then calculate the length using the area formula

Convert Coverage Area from Acres to Square Feet

- Coverage Area = 0.35 acres/load

1 acre = 43,560 square feet (sf)

Area, sf = acres x 43,560 sf/acre

= 0.35 acre x 43,560 sf/acre

= 15,246 square feet

Coverage Length in Feet

- Coverage Area =15,246 square feet
- Area sf = Length feet x Width feet

$$\text{Length ft} = \frac{\text{Area square feet}}{\text{Width feet}}$$

$$= \frac{\text{15,246 square feet}}{\text{15 feet}}$$

= 1016 ft

Coverage Length per load is 1016 feet

Actual Application Rate

- Once the application is complete, we need to calculate the actual rate applied

- N value is affected by incorporation immediately or within 48 hours

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Actual Application Rate

Data

- Biosolids Applied = 600 wet tons
- Solids = 18% = 0.18
- PAN = 26 lb N/DT
- Site = 20 acres

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Biosolids Applied

- Biosolids Applied = 600 wet tons
- Solids = 18% = 0.18

Biosolids DT = Biosolids WT x % Solids
= 600 WT x 0.18
= 108 DT of Biosolids applied

108 DT of Biosolids applied to 20 acres

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PAN Applied

- Biosolids Applied = 108 Dry Tons
- PAN Available = 26 lbs PAN/Biosolids DT

PAN Applied lbs = Biosolids DT x PAN Available
= 108 DT x 26 lbs PAN/DT
= 2808 lbs of PAN applied

2808 lbs of PAN applied to 20 acres

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PAN Applied per Acre

- PAN Applied = 2808 lbs of PAN
- Site = 20 acres

PAN Applied/Acre $= \frac{\text{PAN Applied}}{\text{Site}}$

$= \frac{2808 \text{ lbs of PAN}}{20 \text{ acres}}$

= 140 lbs of PAN/acre

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How Did We Do?

- PAN Needed = 159 lbs/acre
- PAN Applied = 140 lbs/acre

Too much, too little, or just right?

Are we in compliance with Chapter 67?

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Resources

- IAWEA Biosolids Land Application Guide, 2nd Ed
- Minnesota Pollution Control Agency Land Application of Biosolids Manual, 2001
- Recommended Standards for Wastewater Facilities, 2014 Edition
- IAC Chapter 67 Standards for the Land Application of Sewage Sludge, March 16, 2022
- USEPA – A Plain English Guide to the EPA Part 503 Biosolids Rule

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Resources

- ABC Formula/Conversion Table
  - Biosolids Land Application Certification Exam
  - Wastewater Certification Exams
- CSUS Operation of Wastewater Treatment Plants Volume II, 7th Edition
- Anaerobic Sludge Digestion Process by the Michigan Department of Environmental Quality Operation Training & Certification Unit
- USEPA Control of Pathogens and Vector Attraction in Sewage Sludge

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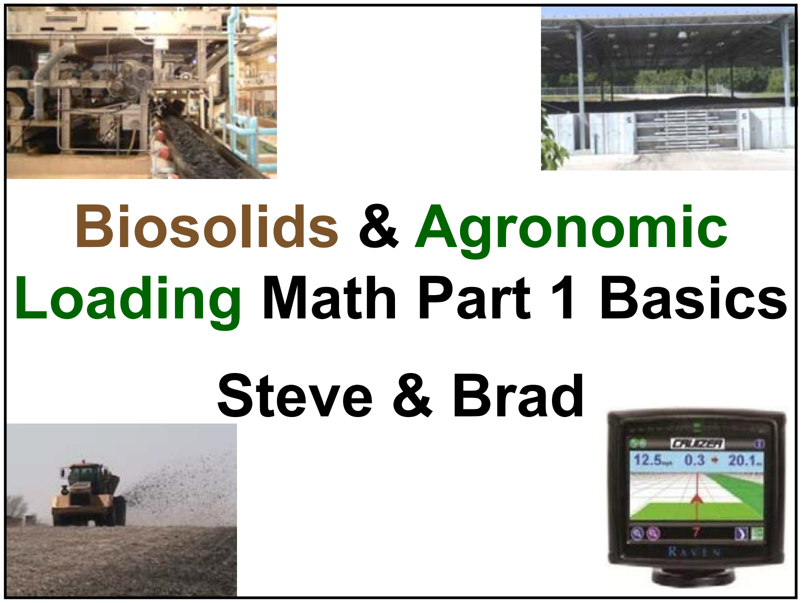
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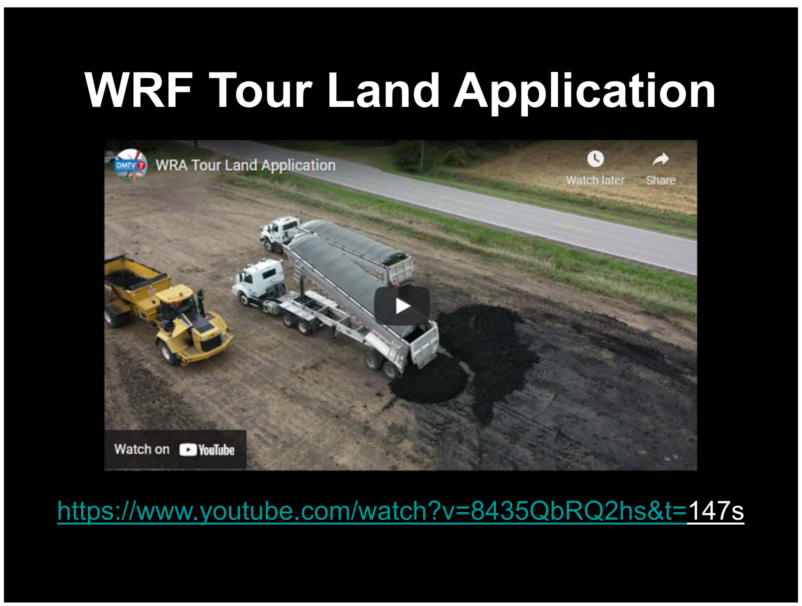
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