Management of Farmstead Area Runoff: Potential of Agricultural Filter Strips

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Outline

- Background
- Source Characterization
- Field Study
- Laboratory Study
- Laboratory to Field Scale Comparison
- Conclusions

Farmstead Runoff

- Potential diffuse pollution source
- Environmental concerns, potential for ground and surface water contamination
- Cost
- Need for assessment of current practices
- Lack of viable data for reliable performance evaluation
  - Research examined feedlot runoff as a whole, no source investigation
  - Lack of data for infiltration
- Implications for regulations and current applications

Research

1. Source Characterization
2. Field Scale Agricultural Filter Strips
3. Soil Column Laboratory Investigation

Source Characterization: Treatment and Management

- Effective treatment is dependent upon effective management practices
- Management can effectively reduce contaminants in runoff and the loading to treatment systems through:
  - source reduction
  - reduction in transport mechanisms
  - removal/degradation prior to reaching waterways
- Practices include, but are not limited to:
  - covering pollutant sources prior to precipitation
  - sweeping impervious surfaces
  - maintaining faces on feed bunkers

◉ Management is time consuming

Runoff Characterization Objectives

- Determine dairy feedlot water quality characteristics.
- Analyze individual source water quantity and quality impacts.
- Outline on-farm management practices to reduce the pollutant quantity and increase water quality.

- Comprehensive management plan
- Grab samples will be collected during precipitation events
- Laboratory analysis

Runoff Characterization – Laboratory and Data Analysis

- 9 storm events from July 2008 to June 2009
- Water quality analysis
  - 19 parameters
  - Includes nutrients, metals, oxygen demand, etc.
- Determine if there is a statistically significant difference in source water quality (SAS 2008)
  - ANCOVA – Rainfall, Season
  - Difference of least squares means
- Make farm recommendations

Average Source Concentrations

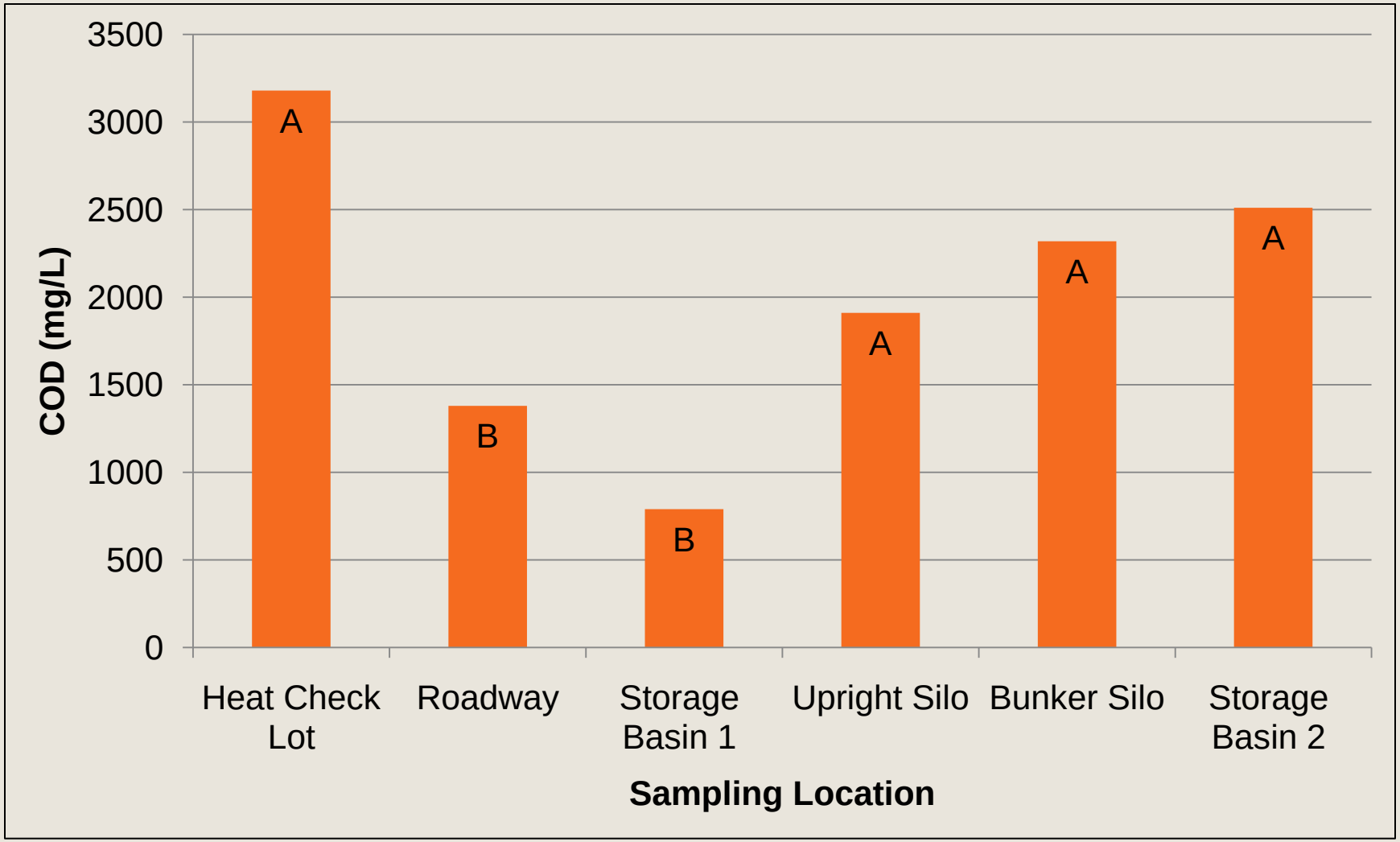
Location	pH	Alkalinity (mg/L)	PO_4^- (mg/L)	COD (mg/L)	BOD_5 (mg/L)	Ammonia (mg/L)	NO_2^- (mg/L)	NO_3^- (mg/L)	TKN (mg N/L)	SO_4^- (mg/L)
Bunker Silo	5.87	277	17	2320	900	18	0.14	14	115	12
Heat Check Lot	8.35	940	17	3180	930	58	0.12	13	355	112
Roadway	6.37	168	11	1380	410	10	0.08	5	54	21
Upright Silo	6.61	193	16	1910	730	28	0.46	7	101	20
Storage Basin 1	7.06	445	8	790	240	23	0.08	8	54	11
Storage Basin 2	5.21	136	20	2510	1180	36	0.22	4	74	7

Larson, R.L. (2009). "Storm Water Runoff Characterization for Animal Feeding Operation." ASABE 2009 International Conference, Reno Nevada, June 24-29, 2009.

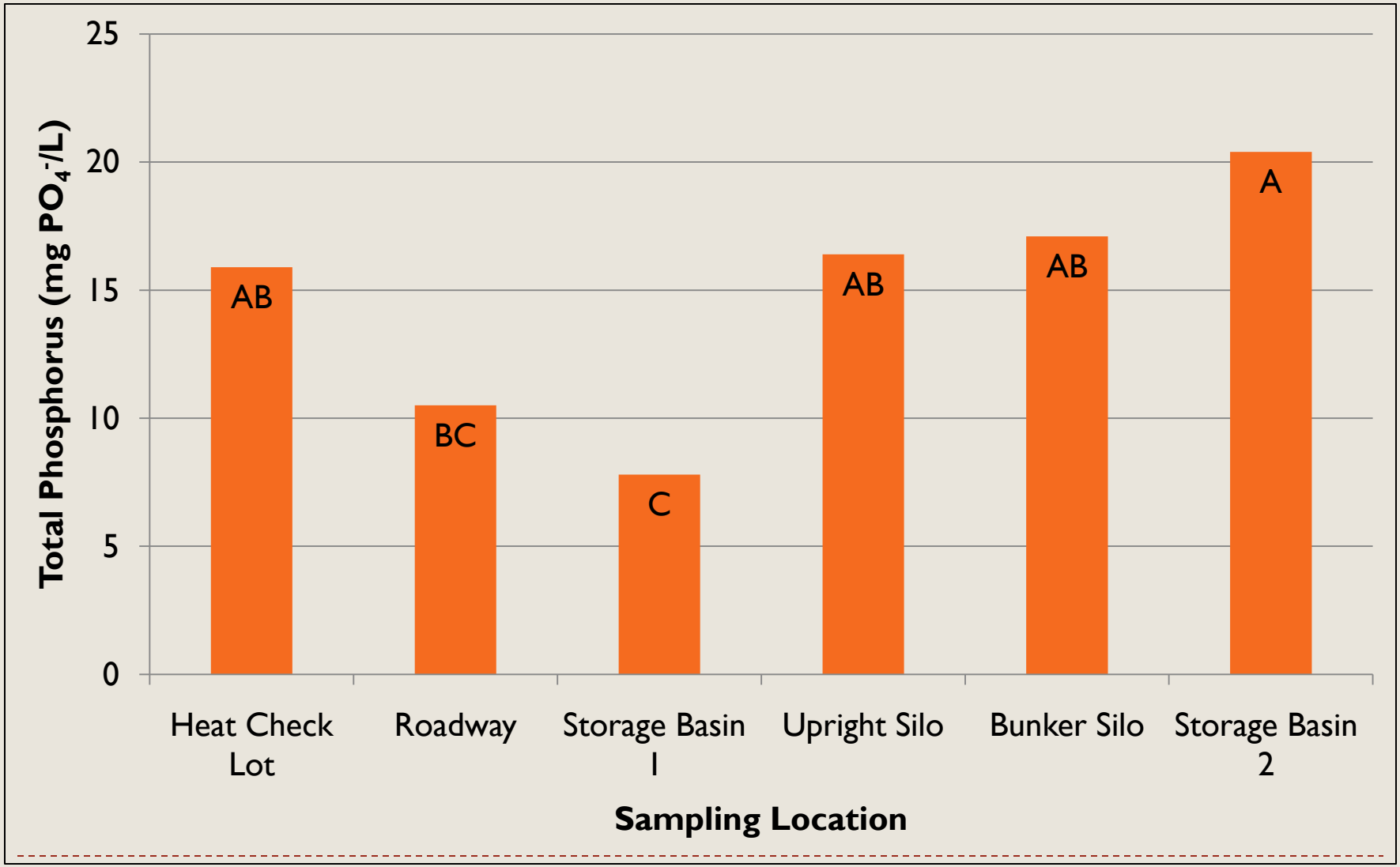
Average Source Concentrations

Location	TS (mg/L)	VS (mg/L)	TSS (mg/L)	VSS (mg/L)	Mn (µg/L)	Fe (µg/L)	TOC (mg/L)	Conductance (umhos/cm)	Cl (mg/L)	As (µg/L)
Bunker Silo	2490	1310	410	190	418	3950	990	1342	39	4.9
Heat Check Lot	4910	2060	1030	800	491	2530	1250	6730	526	4.3
Roadway	1880	1340	370	250	216	1180	440	836	39	1.7
Upright Silo	1540	1210	780	540	221	3650	570	1124	24	11.8
Storage Basin 1	2490	900	450	270	216	3200	210	1226	151	2.3
Storage Basin 2	2970	910	310	250	411	5560	790	1384	26	3.0

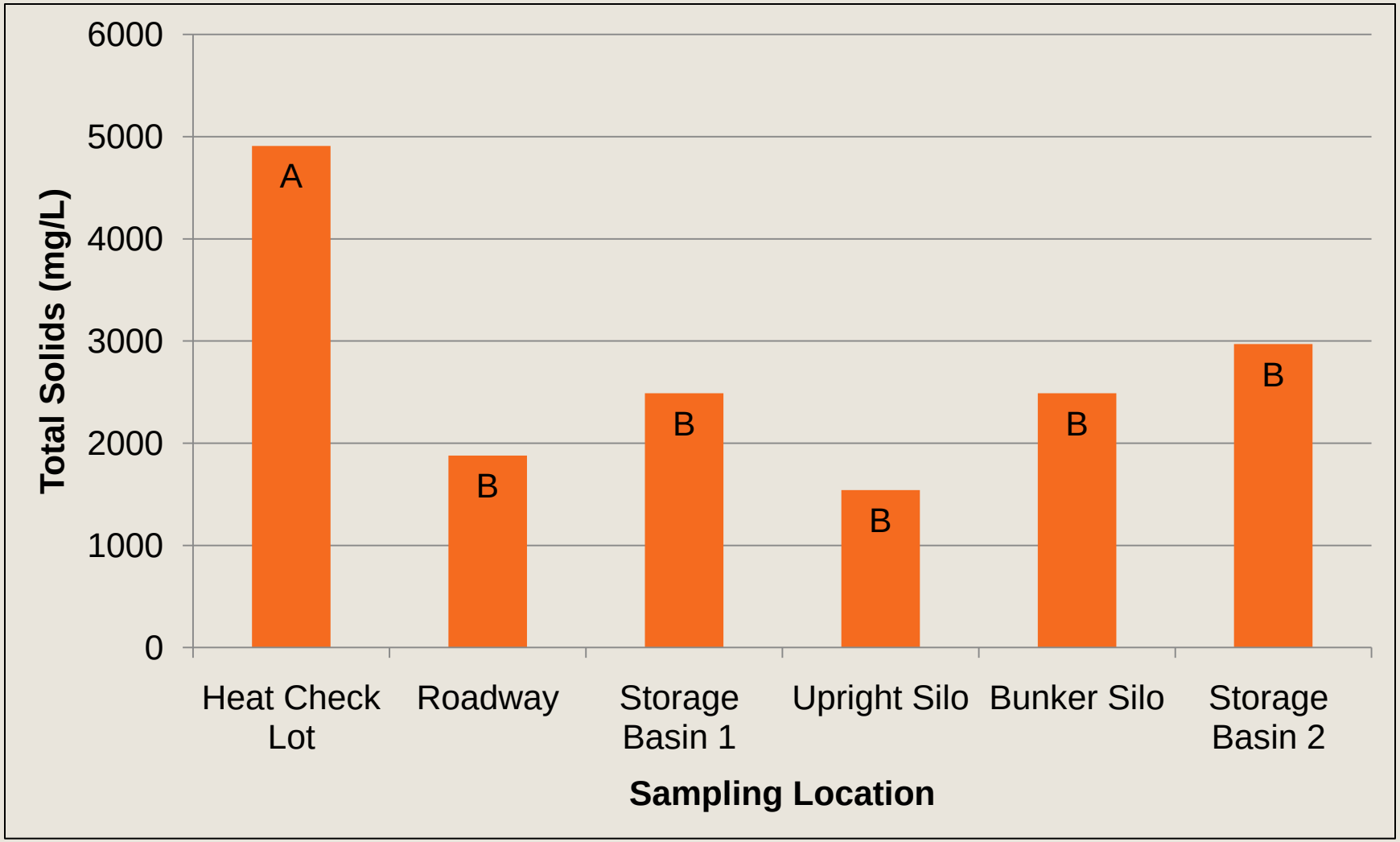
COD (Location Season)



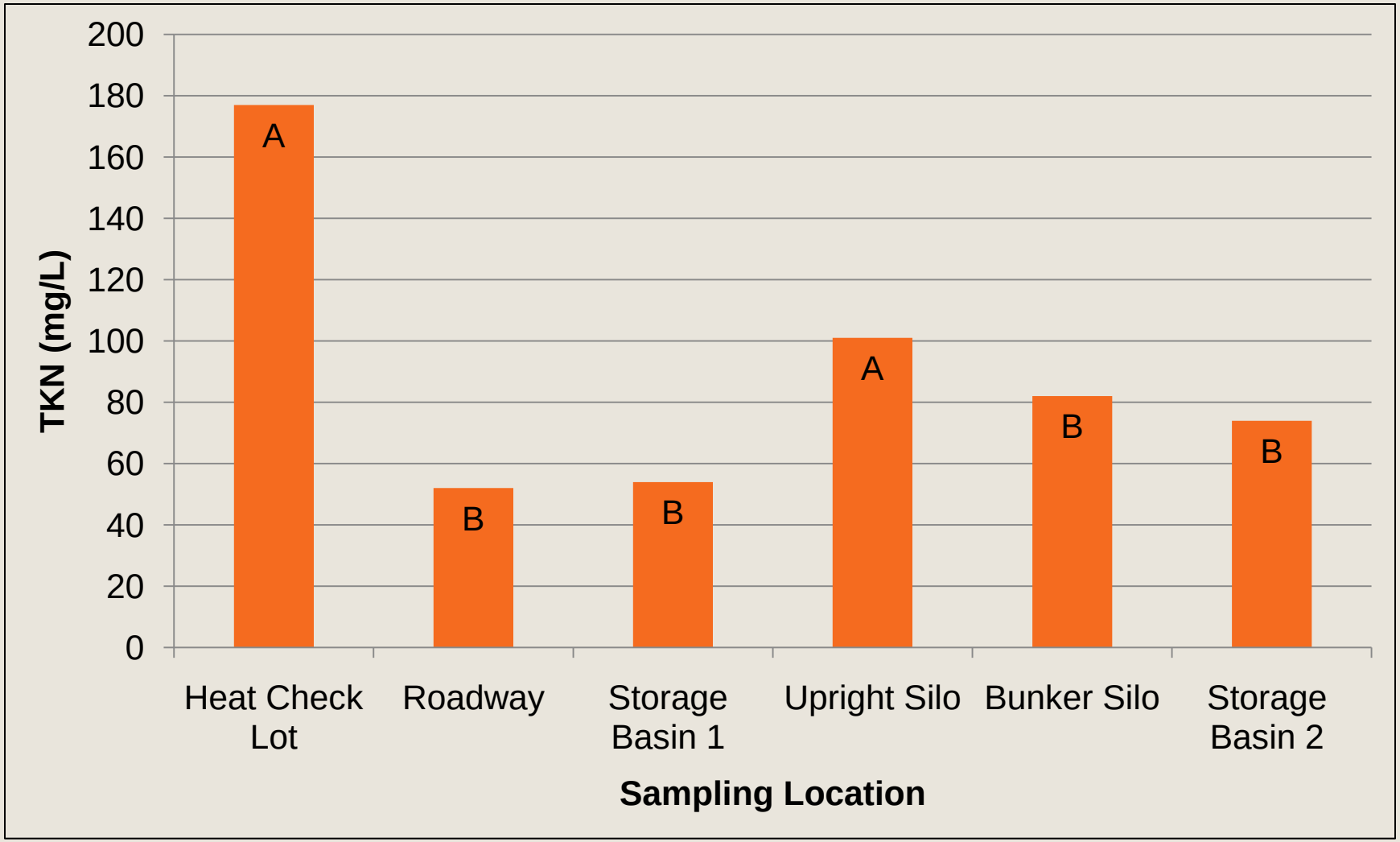
Phosphorus (Location Season)



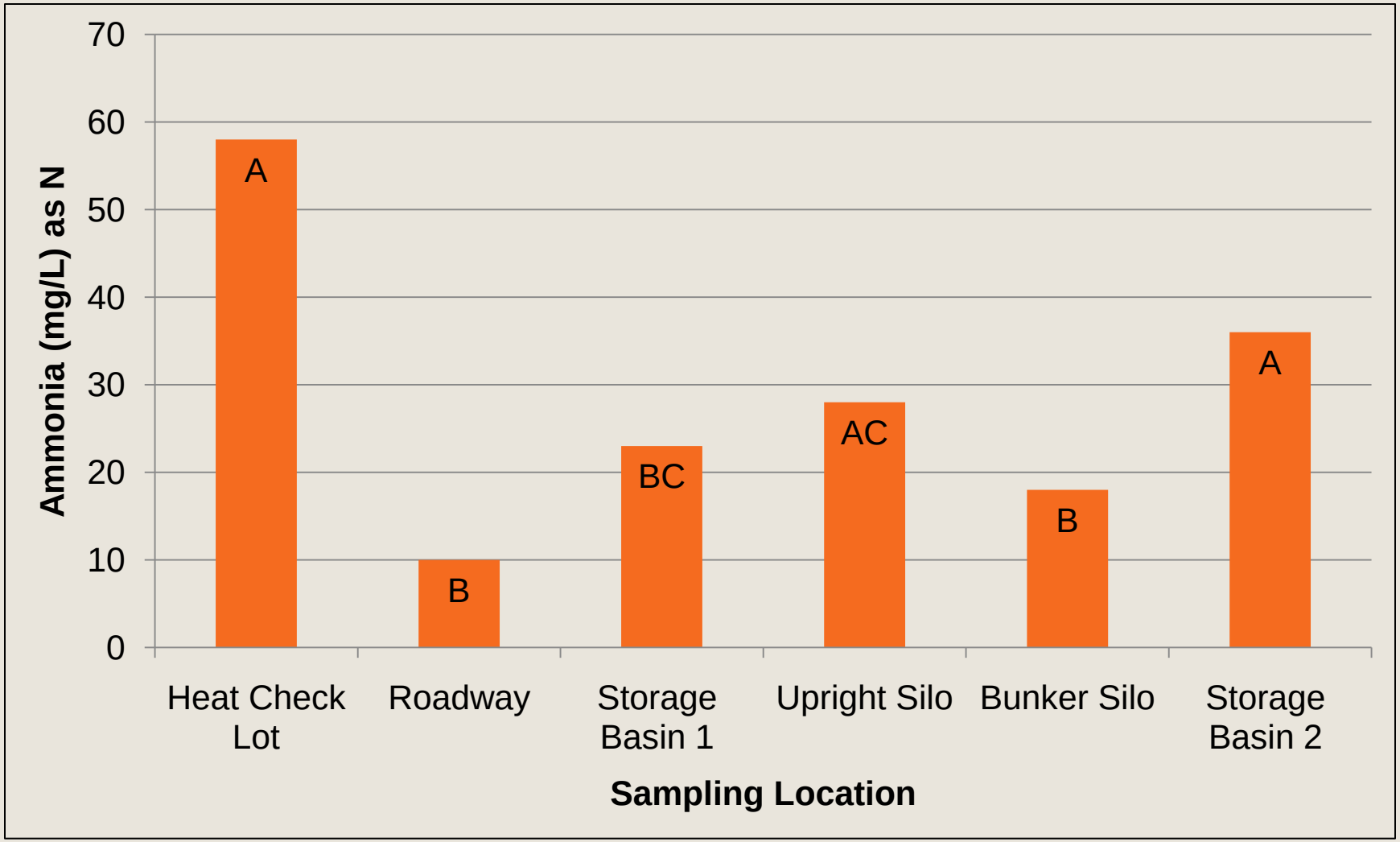
Total Solids (Location Rainfall Season)



TKN (Location Season)



Ammonia (Location Season)



Source Characterization Conclusions

- Determine dairy feedlot water quality characteristics.

- Analyze individual source water quantity and quality impacts.
- Outline on-farm management practices to reduce the pollutant quantity and increase water quality.

Source Characterization Conclusions

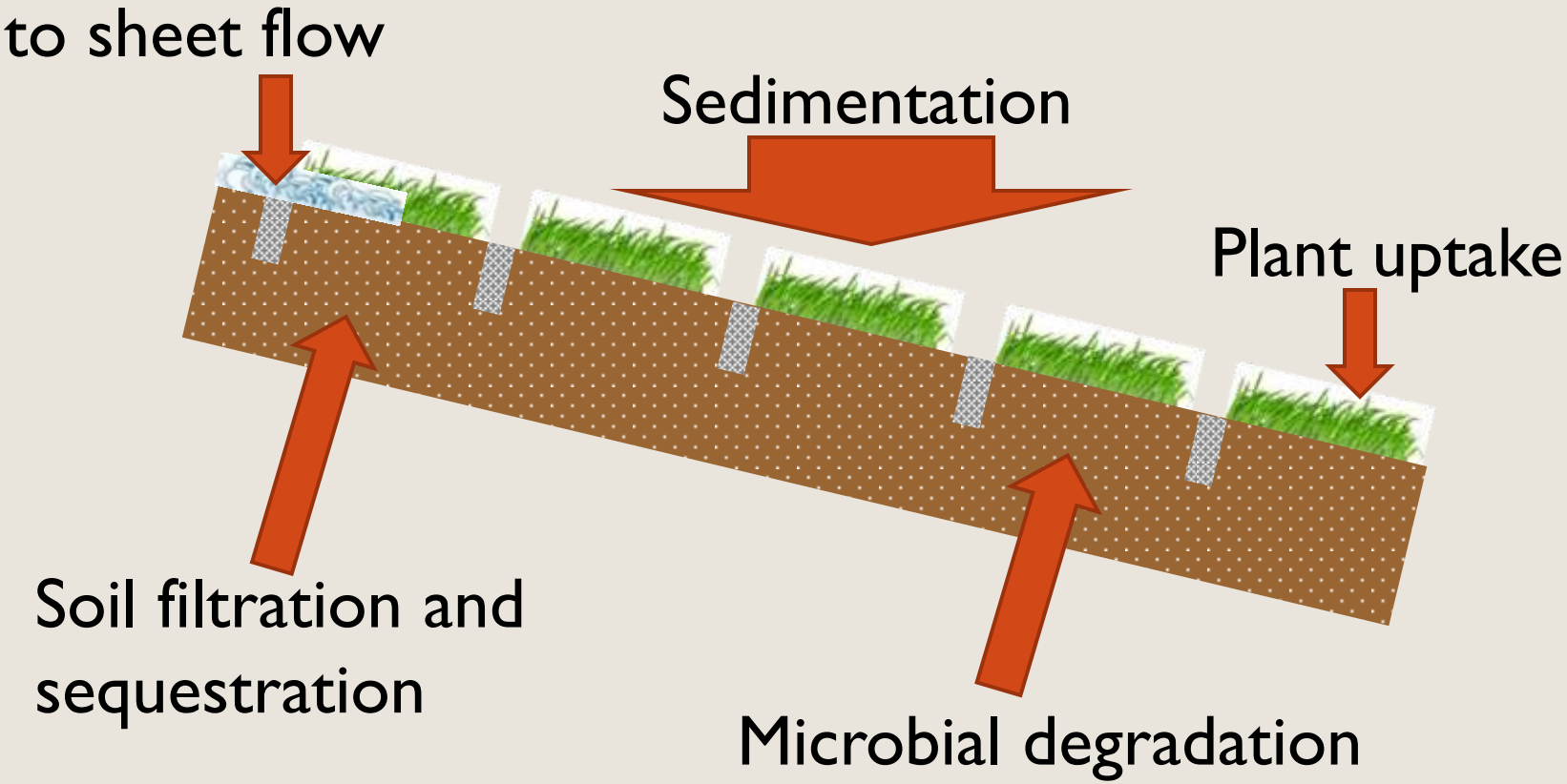
- Published data on feedlot water quality characteristics
- Analysis of statistically significant difference in source water quality, composite vs. source for water quantity
  - Manure and feed produce high runoff pollutant concentrations
  - Footprint of feedlot area, feed sources area greater concern
- Farm management practices:
  - Upright silo harvesting/loading critical
  - Open bunker feed large source problem, quantity and quality
    - Maintain feed faces, sweep, and cover feed
  - Exposed wastes pose a greater potential for contamination
  - Quantity generally larger concern than quality
    - Examine foot print and dilution

Field Treatment System - Background

- Mechanisms for pollutant removal
  - Sediment trapping
  - Plant uptake
  - Infiltration treatment processes
    - Biological activity
    - Adsorption
    - Filtration
    - Oxidation

- Microbial degradation rates dependent upon environmental conditions
- Filter strip design: soil, slope, width, length, vegetation

Filter Strip Removal Mechanisms



Field Scale Objectives

- Assess the surface and subsurface water quality at two field sites.
- Assess current practice standards in regards to operation and maintenance procedures.
- Determine if agricultural filter strips are an effective agricultural treatment/management option as designed, with a particular emphasis on metal leaching into groundwater.
- Determine treatment consistency throughout season and rainfall events.

Sampling

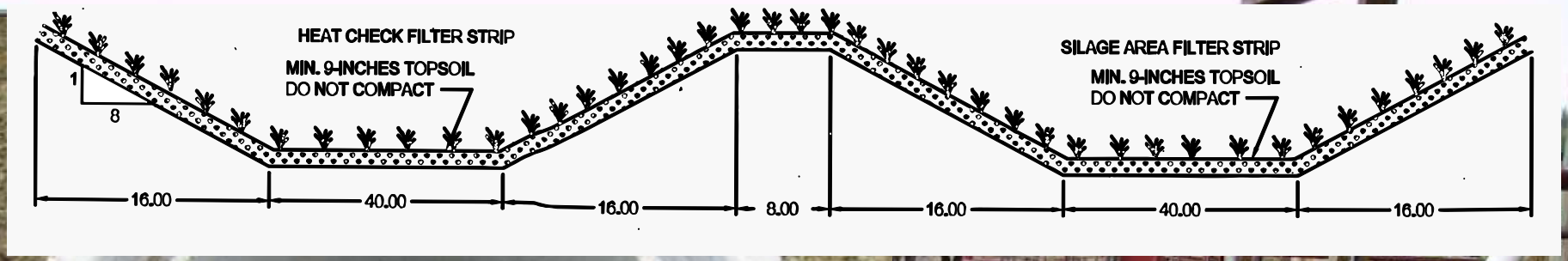
- Sampling Sept 2009 to June 2010
- 2 farmstead sites
  - MSU Dairy
    - 160 head
    - 10 sampling events
    - 2 filter strips, 1.14 acre and 1.28 acre drainage area
  - Small MI dairy
    - 40 head
    - 6 sampling events
    - 1 filter strip, 0.5 acre drainage area
- 17 water quality parameters analyzed
- Influent, surface and subsurface sampling

Filter Strip Design

- NRCS Standard
- Vegetation
  - 37% Tuscany II Tall Fescue, 28% Smooth Bromegrass, 20% Graze N Gro Annual Ryegrass, and 12% Chiefton Reed Canarygrass

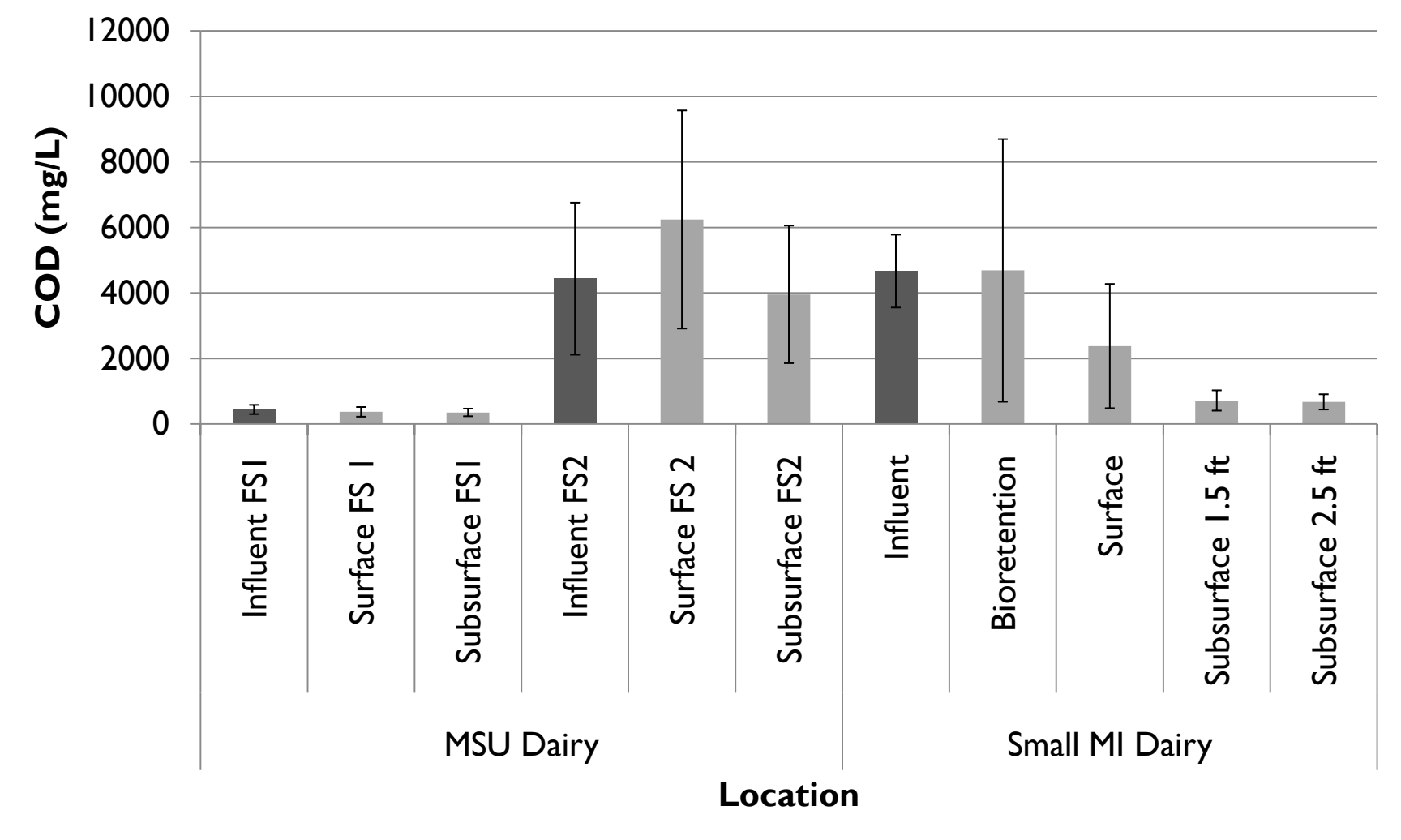
- MSU Dairy
  - 1.14 and 1.28 acre drainage areas
  - Settling (~90,000 gal) and distribution basins (~5,000 gal)
  - 400 ft long, 40 ft wide, 4% slope
  - Sandy loam soils
  - Pump system
  - Rock check at top and every 100 ft down slope

- Small MI Dairy
  - 0.5 acre drainage area
  - Settling basin
  - Bioretention basin
  - Gravity driven system
  - 110 ft long, 40 ft wide, 0.5% slope
  - Sandy soils
  - Gravity driven system
  - Rock check at top and 50 ft down slope

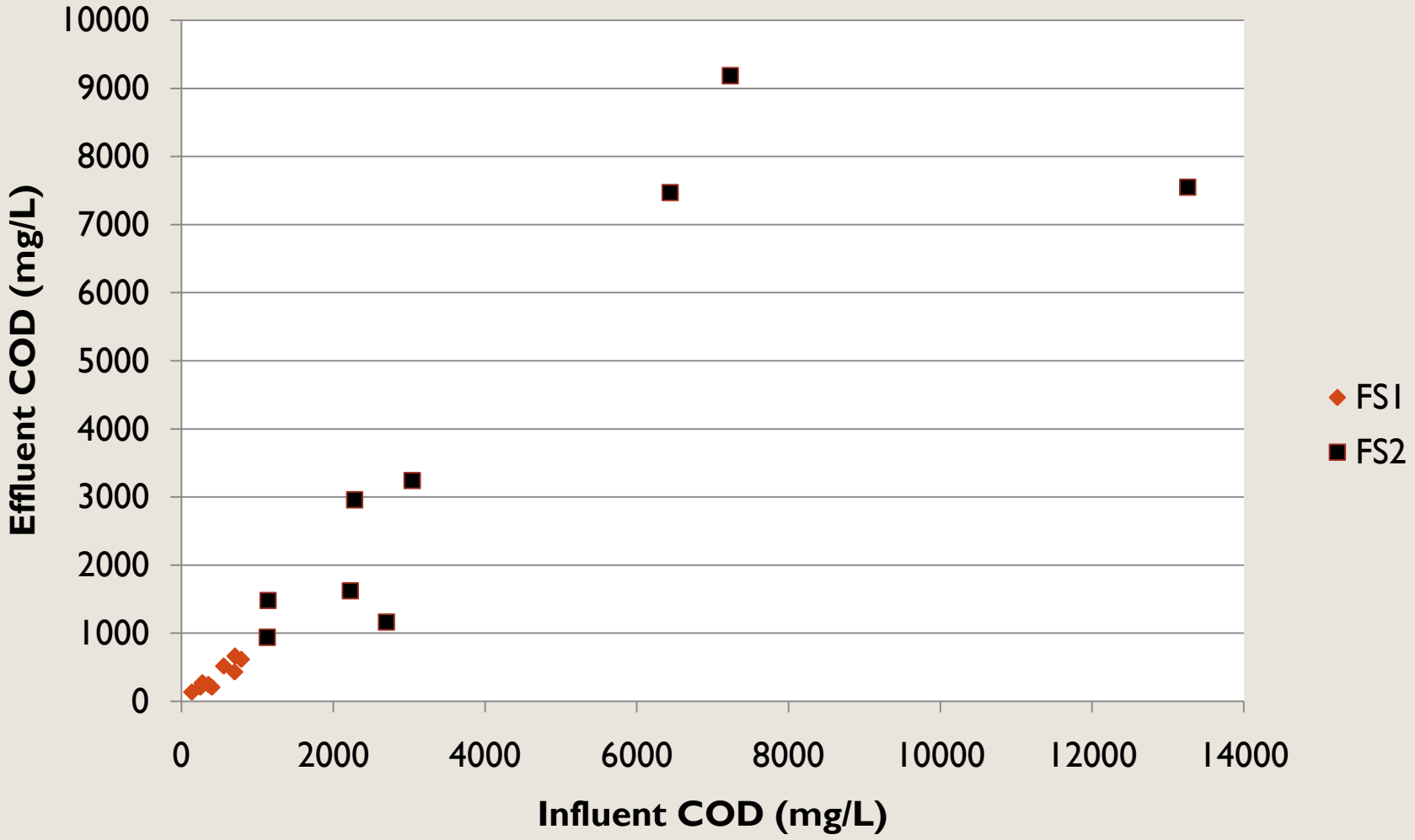

HEAT CHECK FILTER STRIP
MIN. 9-INCHES TOPSOIL
DO NOT COMPACT
1
8
16.00
40.00
16.00
8.00
16.00
40.00
16.00
SILAGE AREA FILTER STRIP
MIN. 9-INCHES TOPSOIL
DO NOT COMPACT


9”–15”

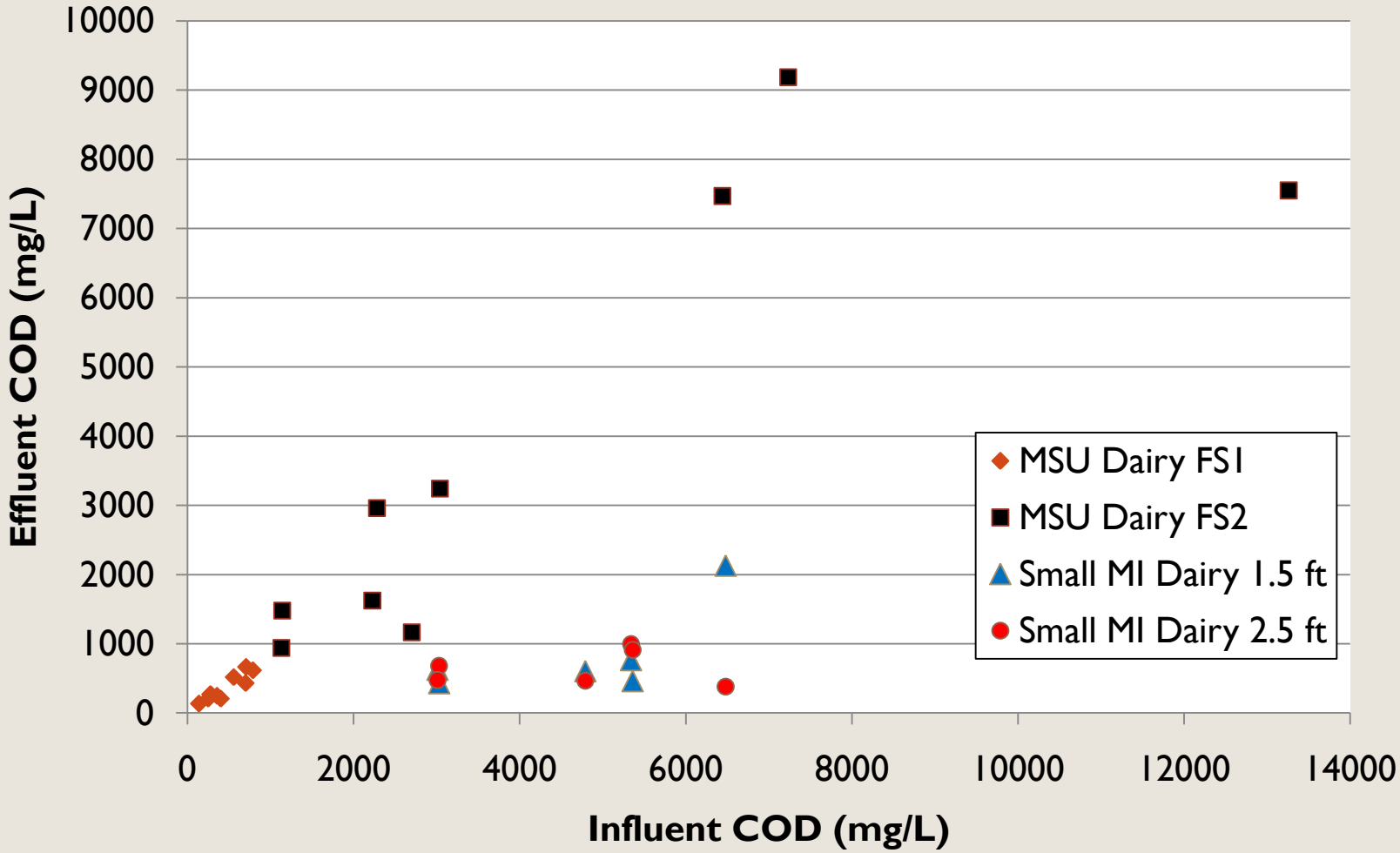
COD


12000
10000
8000
6000
4000
2000
0
COD (mg/L)
Influent FS1
Surface FS 1
Subsurface FS1
Influent FS2
Surface FS 2
Subsurface FS2
Influent
Bioretention
Surface
Subsurface 1.5 ft
Subsurface 2.5 ft
MSU Dairy
Small MI Dairy
Location

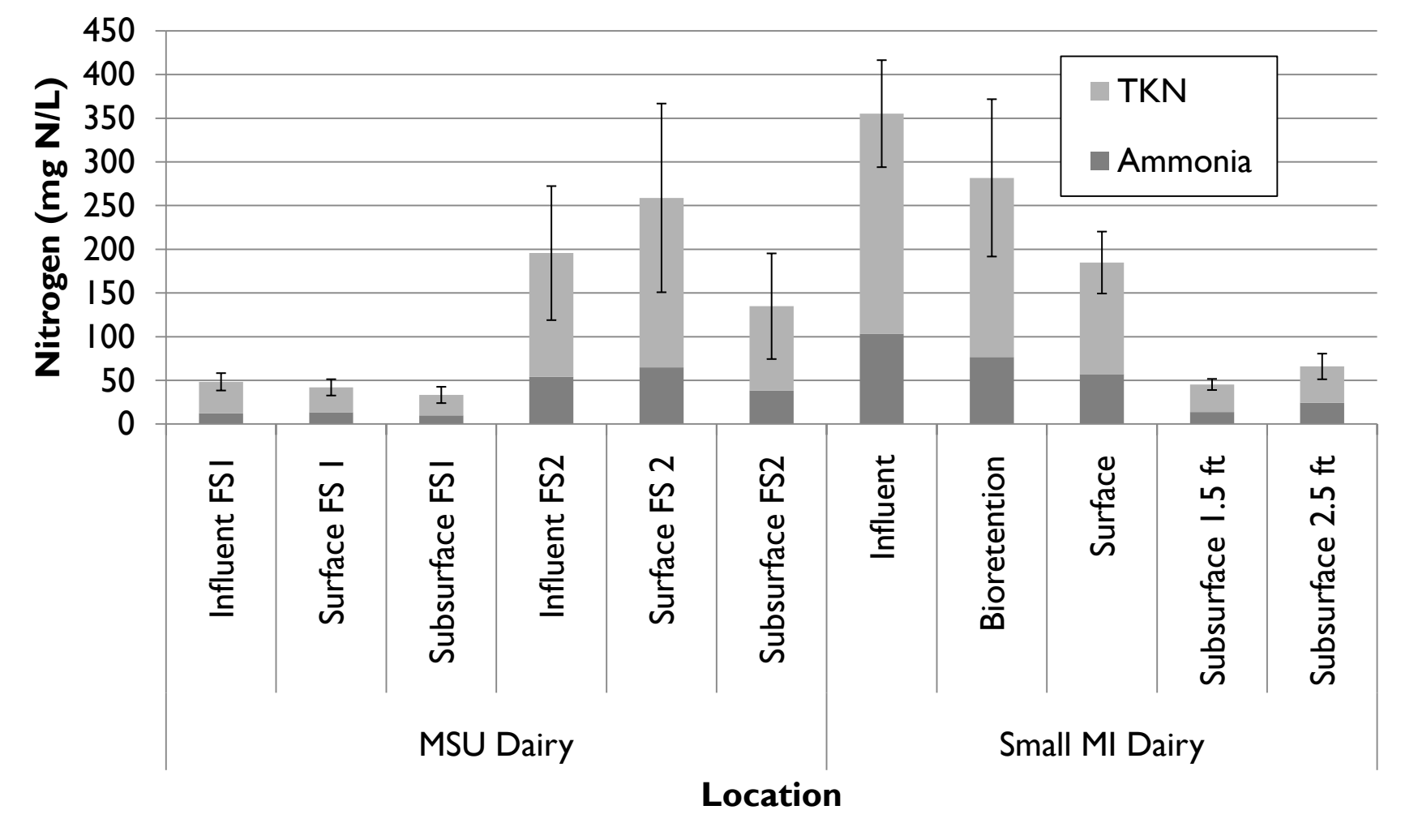
COD MSU Dairy Influent vs. Effluent



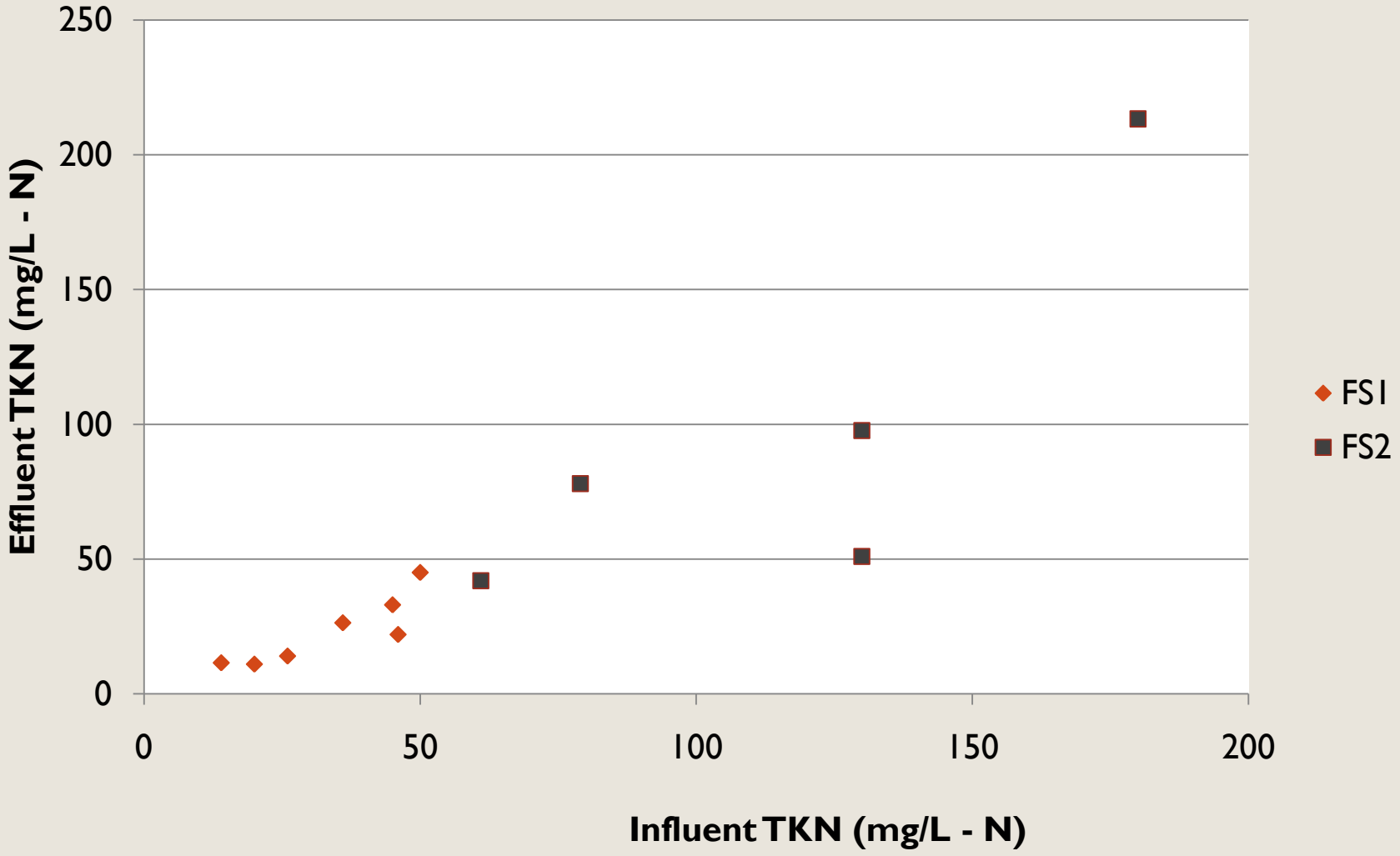
COD Influent vs. Effluent



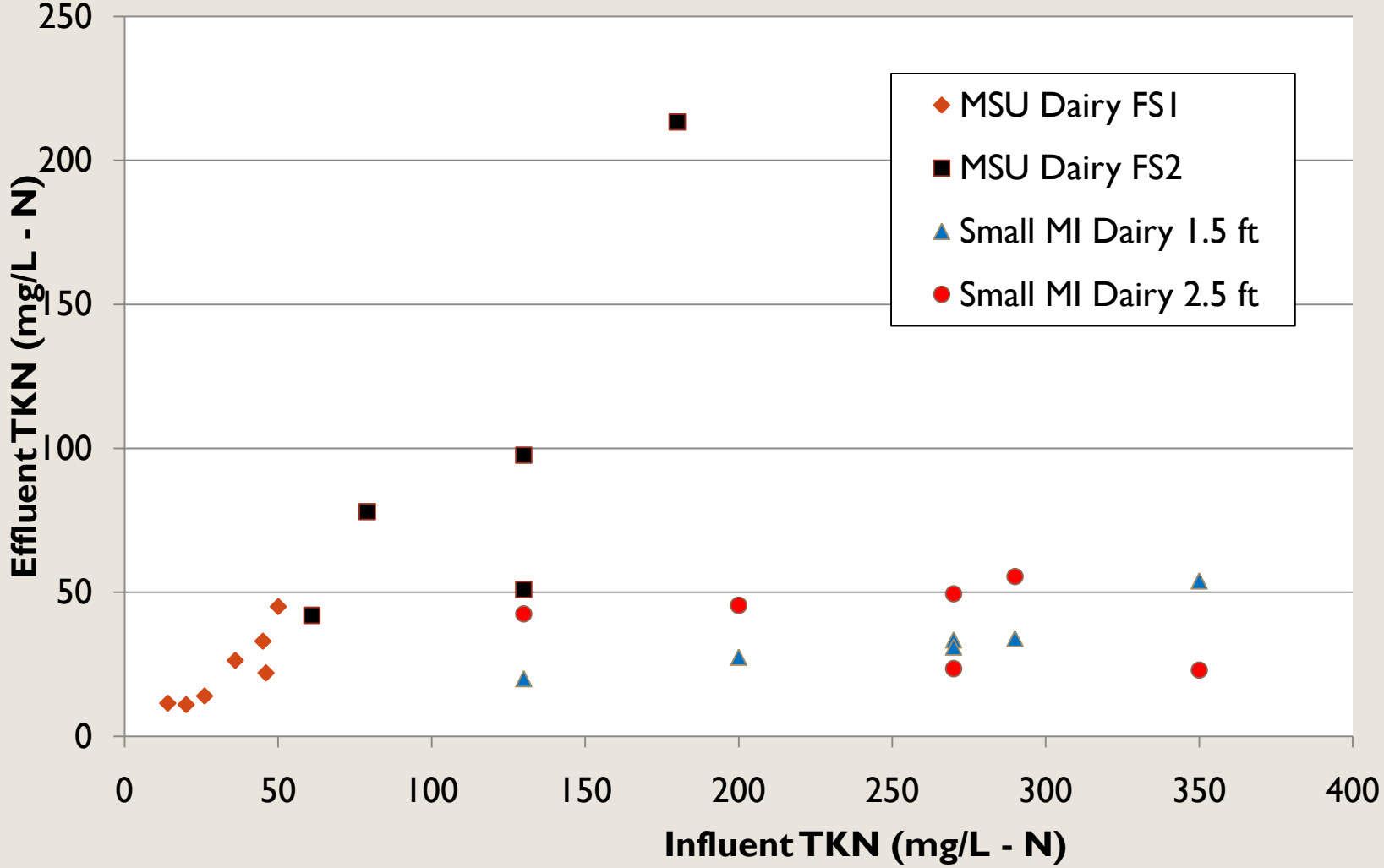
Nitrogen


Nitrogen (mg N/L)
450
400
350
300
250
200
150
100
50
0
TKN
Ammonia
Influent FS1
Surface FS 1
Subsurface FS1
Influent FS2
Surface FS 2
Subsurface FS2
Influent
Bioretention
Surface
Subsurface 1.5 ft
Subsurface 2.5 ft
MSU Dairy
Small MI Dairy
Location

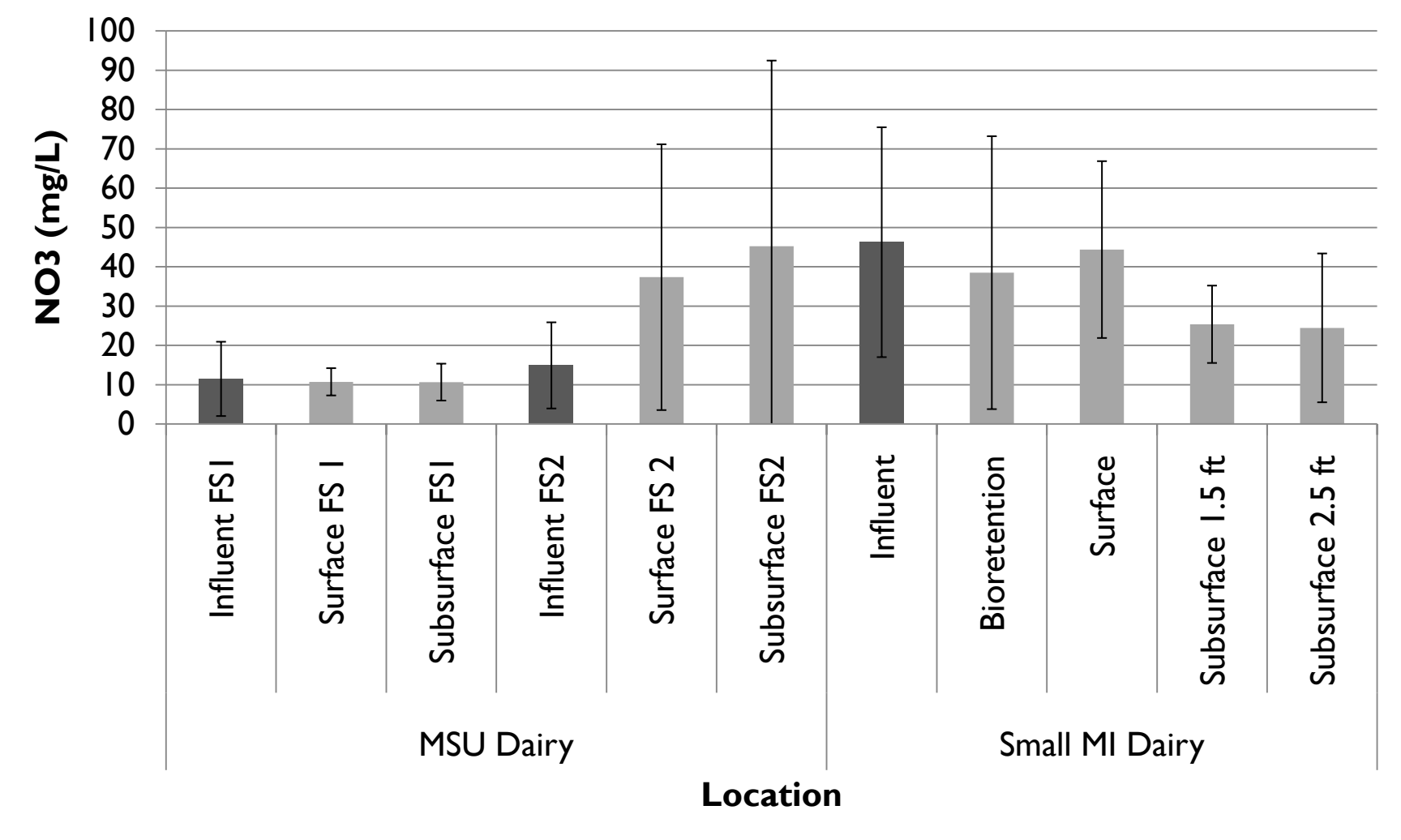
TKN MSU Dairy Influent vs. Effluent



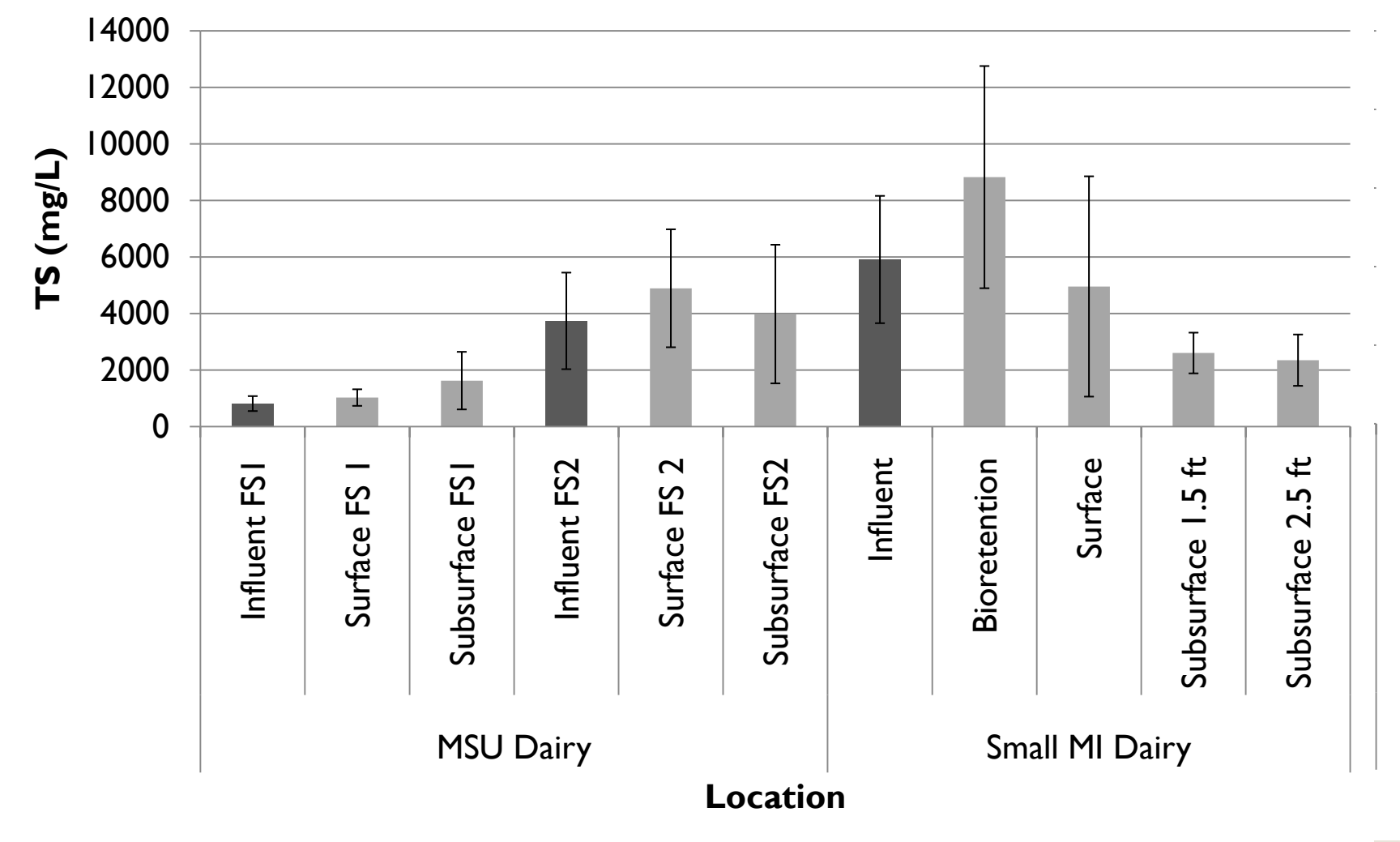
TKN Influent vs. Effluent



Nitrate


NO3 (mg/L)
100
90
80
70
60
50
40
30
20
10
0
Influent FS1
Surface FS 1
Subsurface FS1
Influent FS2
Surface FS 2
Subsurface FS2
Influent
Bioretention
Surface
Subsurface 1.5 ft
Subsurface 2.5 ft
MSU Dairy
Small MI Dairy
Location

Phosphorus


14000
12000
10000
8000
6000
4000
2000
0
TS (mg/L)
Influent FS1
Surface FS 1
Subsurface FS1
Influent FS2
Surface FS 2
Subsurface FS2
Influent
Bioretention
Surface
Subsurface 1.5 ft
Subsurface 2.5 ft
MSU Dairy
Small MI Dairy
Location

Field Treatment System

- Assess the surface and subsurface water quality at two field sites.
- Assess current practice standards in regards to operation and maintenance procedures.
- Determine if agricultural filter strips are an effective agricultural treatment/management option as designed, with a particular emphasis on metal leaching into groundwater.
- Determine treatment consistency throughout season and rainfall events.

Field Treatment System

- Examined data for two field sites at various environmental conditions
  - Greater removal at the sand soil site at the small MI Dairy site
  - Bioretention basin at small MI dairy site responsible for some removal
  - MSU dairy linear correlation between influent to effluent at MSU site, not at small MI dairy site – what is limiting at the MSU site?
- Maintenance and operation:
  - MSU dairy site = mowing, weeding, and solids removal 2x per year
  - Minimize influent concentrations
- Effective treatment option?
  - Removal percentages for 1 – 1.5 ft are not adequate
  - Final concentrations for BOD and COD are similar to septic tank waste
  - Nitrate concentrations (above 10 mg/L) and metal concentrations show leaching of metals and high concentrations of arsenic
- No correlation for season at MSU dairy or for rainfall at either site with removal percentages or final concentrations
  - Seasonal difference may not hold true for improved operation

Laboratory Soil Column Evaluation of Treatment System - Background

- Primary soil assimilation mechanisms
  - Biological oxidation
  - Adsorption
  - Filtration
- Soil pore water = decreased oxygen = anaerobic conditions
- Aerobic conditions = carbon sources are the electron donors with oxygen accepting the electrons
- Decreased oxygen = anaerobic conditions = changes in electron acceptor
  - Diagenesis model (or electron tower)
  - Ranks by free energy yield per mole of organic carbon oxidized
    - O_2, NO_3^-, MnO_2, $Fe(OH)_3$, SO_4^{2-}, and methanogenesis
  - Metal mobilization
- Mn and Fe $\rightarrow$ Reduction mechanisms are biological, physical, or chemical

Laboratory Study Objectives

- Statistically determine the pollutant removal capacity of the volume of the overall soil column system for the various water quality parameters.
- Determine impact of soil depth and total soil volume to pollutant removal.
- Examine the influence of groundwater capillary rise on the depth of soil required for treatment of agricultural runoff.
- Find the degree of treatment variance between two defined soil types, sand and sandy loam, to determine if further detailed analysis is warranted.

Column Design and Operation

- Three treatments
  - Depth: 12, 30, & 48 inches
  - Soil: sand and sandy loam
  - Submergence: air or water
- Vegetation = mixed grass species:
  - tall fescue (38%), smooth bromegrass (28%), annual ryegrass (20%), reed canarygrass (12%)
- Loading:
  - 75 lbs BOD/acre every 3.5 days
- Wastewater Application
  - 1.4 L
  - Synthetic (based on BOD theoretical oxygen demand))
  - 2x per week
- Sample collection
  - Bi-weekly, influent and effluent
- Analyze nutrient cycling, oxygen requirements, metal leaching, and comparison of treatment means

Soil Column Layout

Application	Soil Type	Length (in)	Submergence	Column #'s
Wastewater	Sand	12	Air	12, 25, 26
Wastewater	Sand	30	Air	1, 7, 20
Wastewater	Sand	48	Air	3, 19, 24
Wastewater	Sandy Loam	12	Air	10, 18, 23
Wastewater	Sandy Loam	30	Air	4, 5, 13
Wastewater	Sandy Loam	48	Air	14, 15, 17
Water	Sand	30	Air	30
Water	Sandy Loam	30	Air	22, 29
Wastewater	Sandy Loam	12	Water	2, 11, 21
Wastewater	Sandy Loam	30	Water	6, 16, 28
Wastewater	Sandy Loam	48	Water	8, 9, 27


NO SMOKING


10
SL
11
SL
12
S

Soil Characteristics

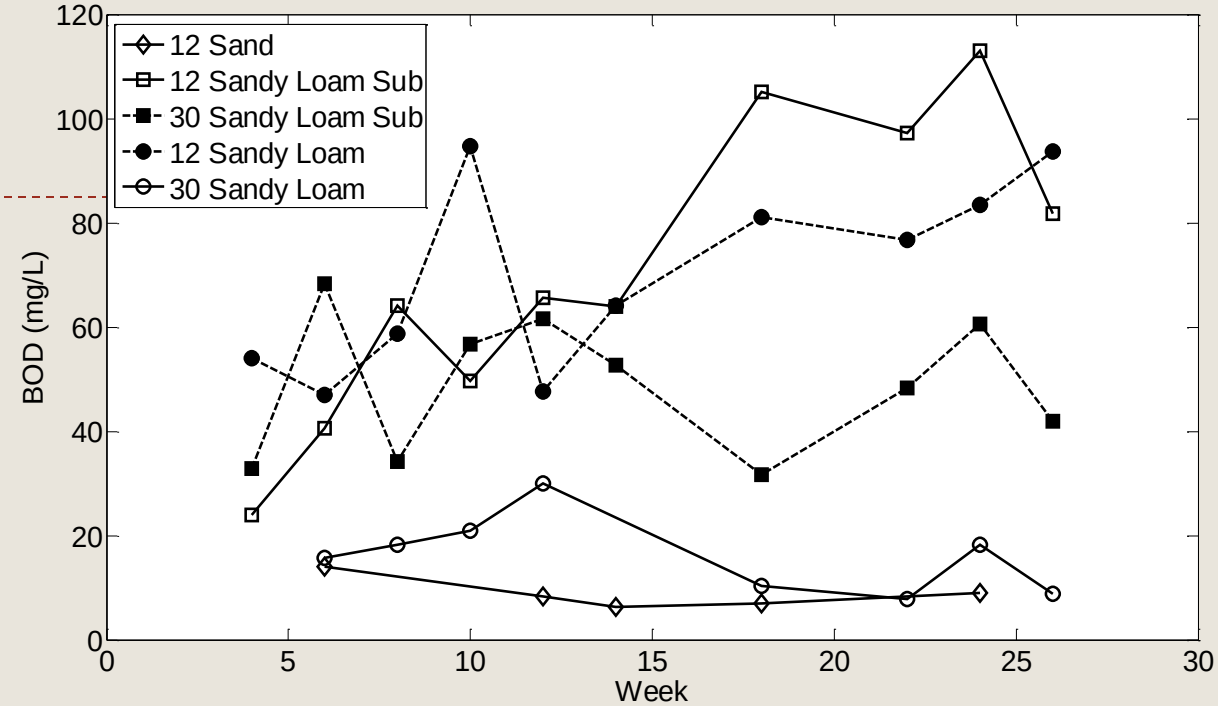
- Porosity:
  - Sandy loam 38%
  - Sand 42%
- Oxygen diffusion rates
- Soil moisture
- Flow Rtes

Depth (in)	Soil Volume (in^3)	Porosity Volume (mL)		Ratio of Wastewater Volume to Pore Space Volume	
		Sand	Sandy Loam	Sand	Sandy Loam
12	339	2335	2113	0.60	0.66
30	848	5838	5282	0.24	0.27
48	1357	9341	8451	0.15	0.17

Parameter	Sand	Sandy Loam
pH	8.8	6.9
P (ppm)	3	98
K (ppm)	8	133
Ca (ppm)	632	966
Mg (ppm)	198	198
Zn (ppm)	3.1	4.9
Mn (ppm)	4.4	13.9
Cu (ppm)	0.8	13.9
Fe (ppm)	8.1	44.7
Organic Matter (%)	0.3	2.3
Chloride (ppm)	61	59
Total N (ppm)	n.d.	0.10
Nitrate-N (ppm)	0.6	11.0
Ammonium-N (ppm)	0.5	1.4
Sand (%)	93.5	69.8
Silt (%)	2.8	25.9
Clay (%)	3.7	4.3

BOD

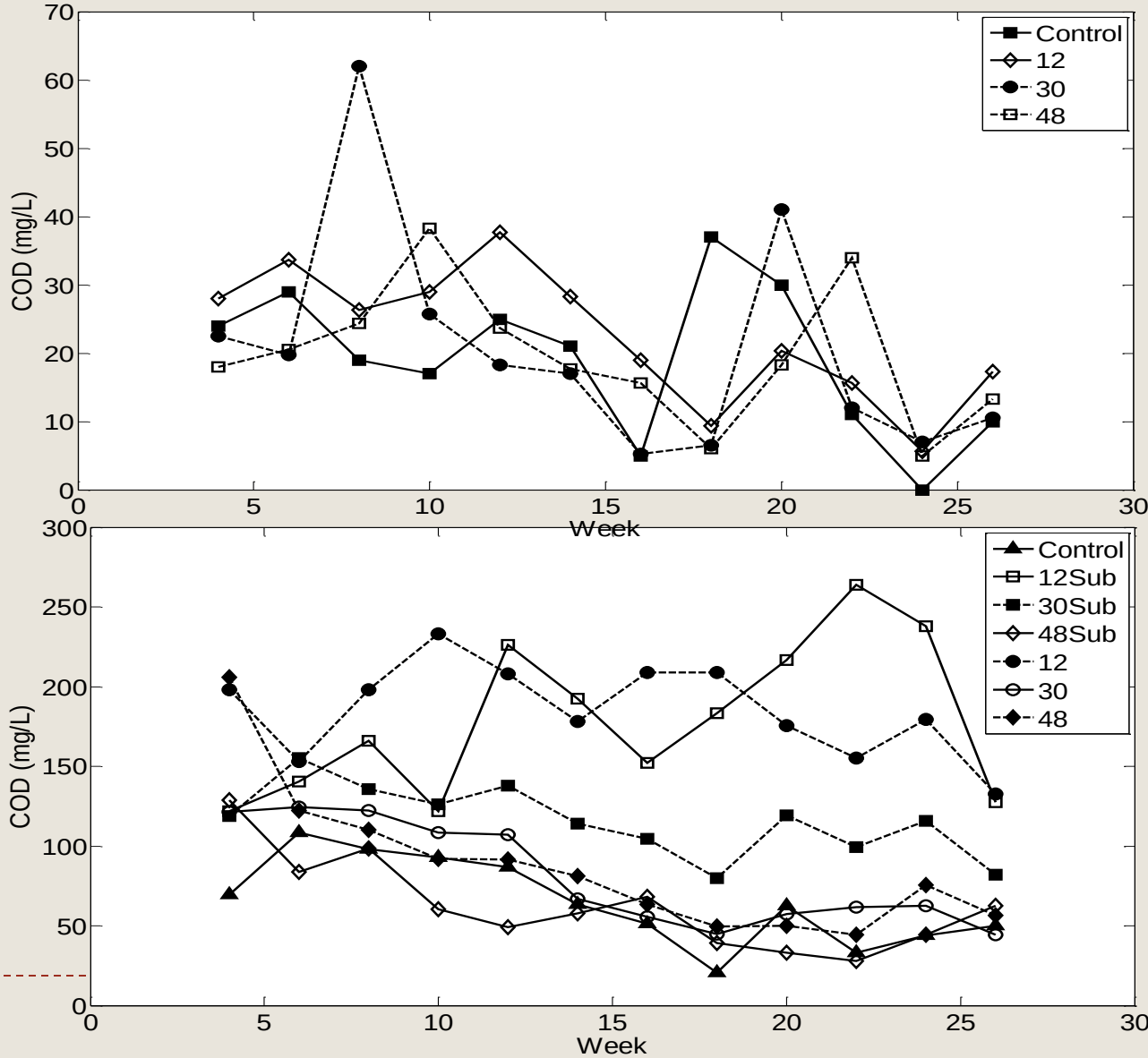
- Results commonly below the detection limit
- 90-99% removal over 12 inches (except sandy loam submerged), below 30 mg/L surface discharge limit
- Statistical difference in soil and depth, and depth*soil interaction
- Sand soils no stat difference in depth from 12-48 inches



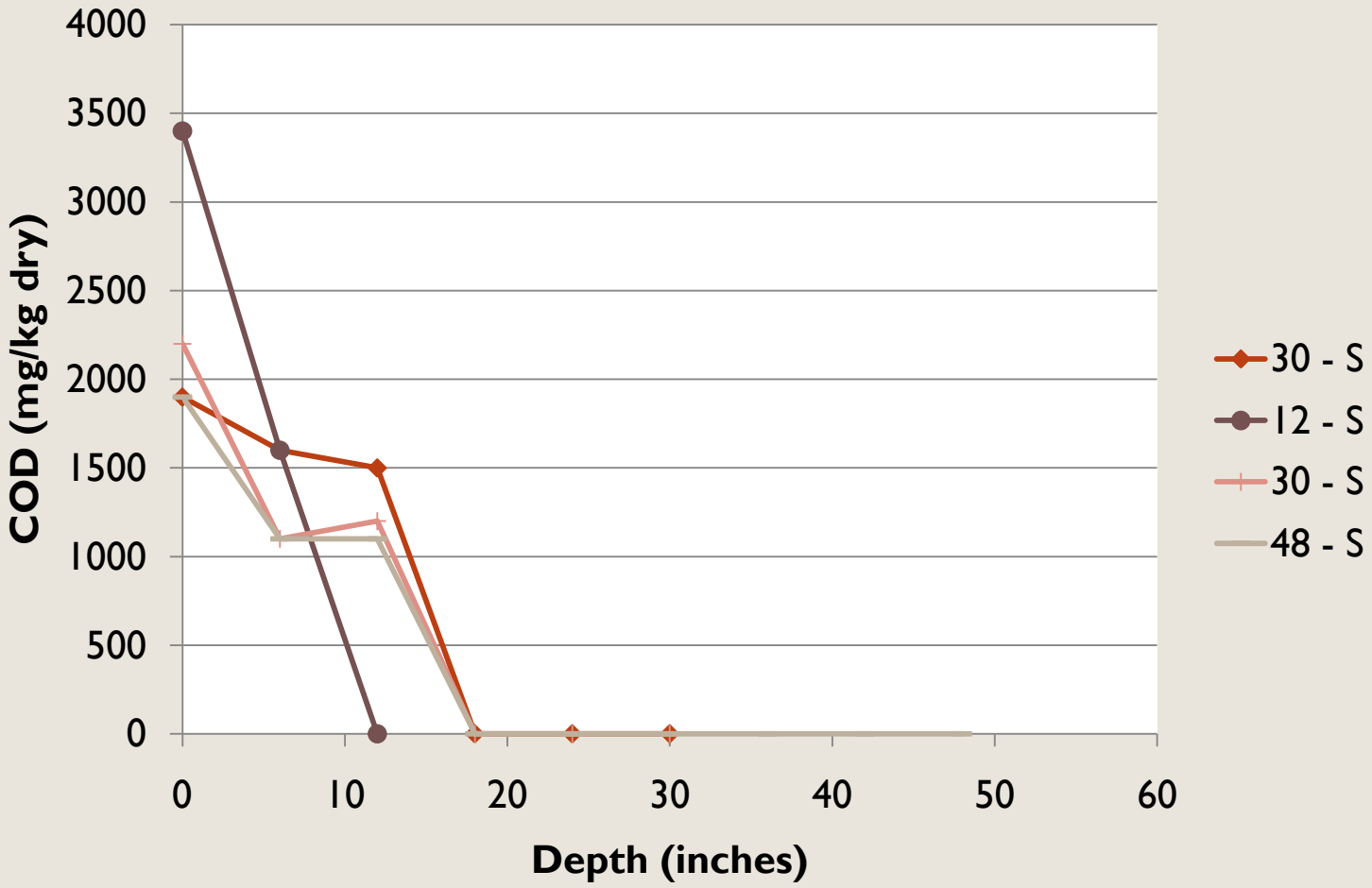
Effect	Soil	Depth	Soil	Depth	Estimate	Std Error	DF	t Value	Pr > |t|
Depth		12		48	35.1619	9.7862	8.25	3.59	0.0067
Soil	Sand		Sandy Loam		-28.2909	8.2397	13.4	-3.43	0.0043
Soil*Depth	Sand	12	Sandy Loam	12	-64.376	17.9825	7.78	-3.58	0.0075
Soil*Depth	Sand	30	Sandy Loam	12	-66.6267	16.0061	20.6	-4.16	0.0005
Soil*Depth	Sand	48	Sandy Loam	12	-65.8154	10.0546	8.8	-6.55	0.0001
Soil*Depth	Sand	48	Sandy Loam	30	-22.7544	8.5357	14.7	-2.67	0.0178
Soil*Depth	Sandy Loam	12	Sandy Loam	30	43.0611	10.3102	11.1	4.18	0.0015
Soil*Depth	Sandy Loam	12	Sandy Loam	48	68.8844	9.6512	7.91	7.14	0.0001
Soil*Depth	Sandy Loam	30	Sandy Loam	48	25.8233	8.0567	14.5	3.21	0.0061

COD Sand (top) Sandy Loam (bottom)

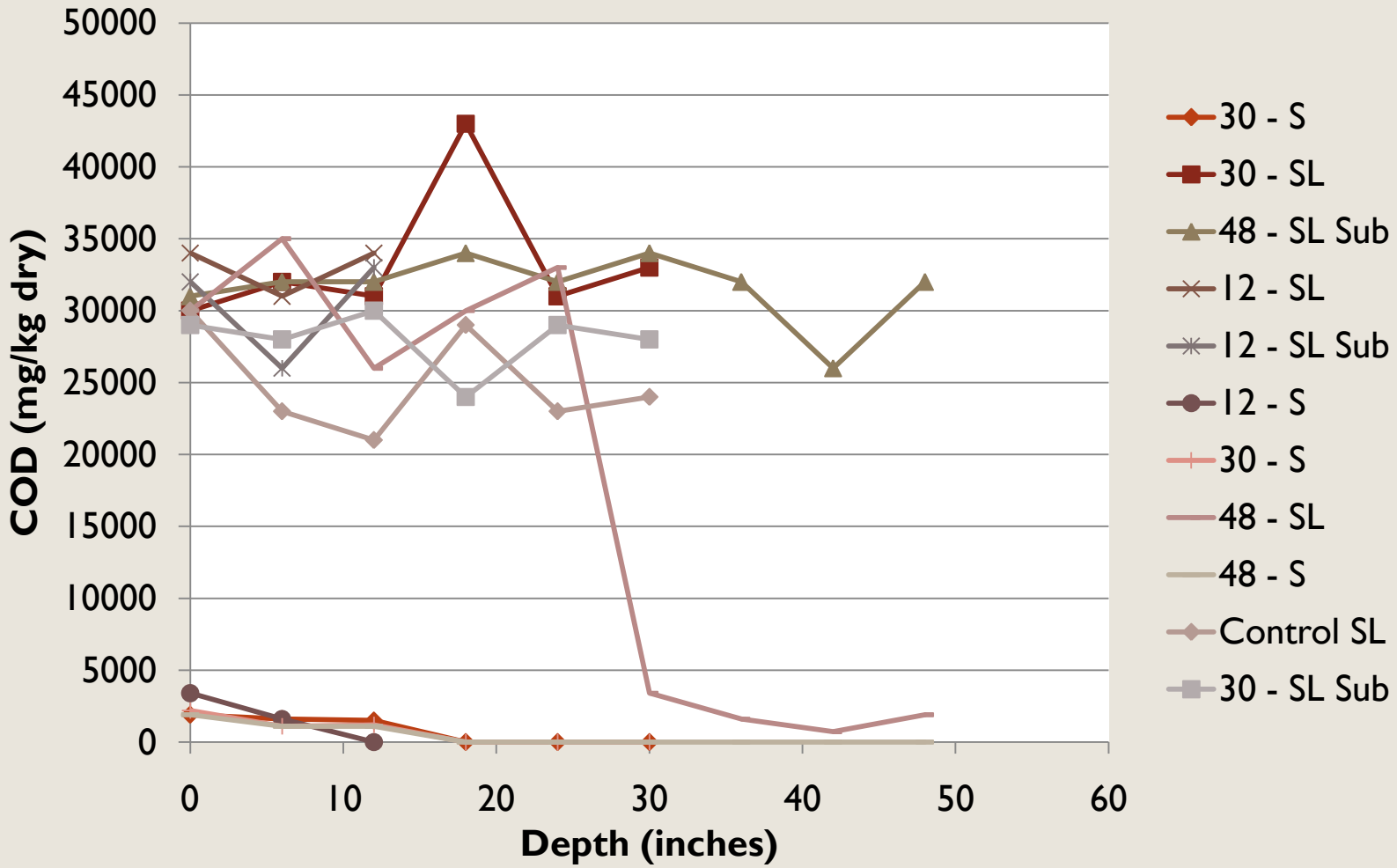
- 12 inch sand significant difference from 48 inch sand only
- Sand effluent range 0-40 mg/L
- Stat model significant for depth, soil, sub and interactions
- BOD_5/COD ratios indicate incomplete removal of organic material in 12 inch columns



Soil COD

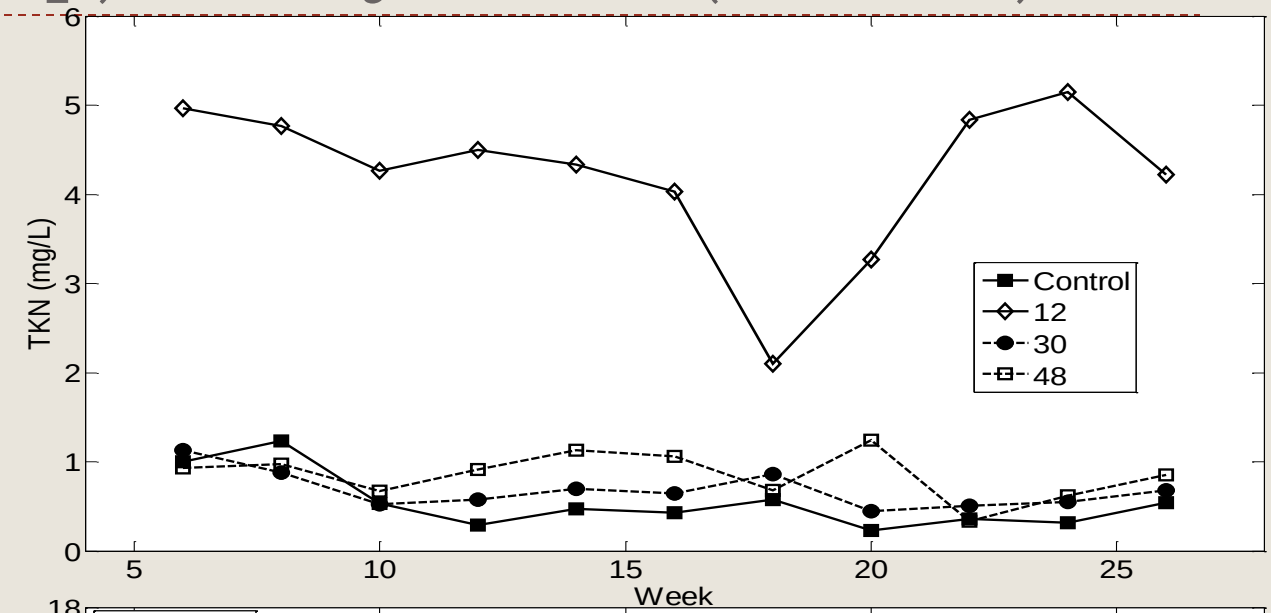

4000
3500
3000
2500
2000
1500
1000
500
0
COD (mg/kg dry)
0
10
20
30
40
50
60
Depth (inches)
30 - S
12 - S
30 - S
48 - S

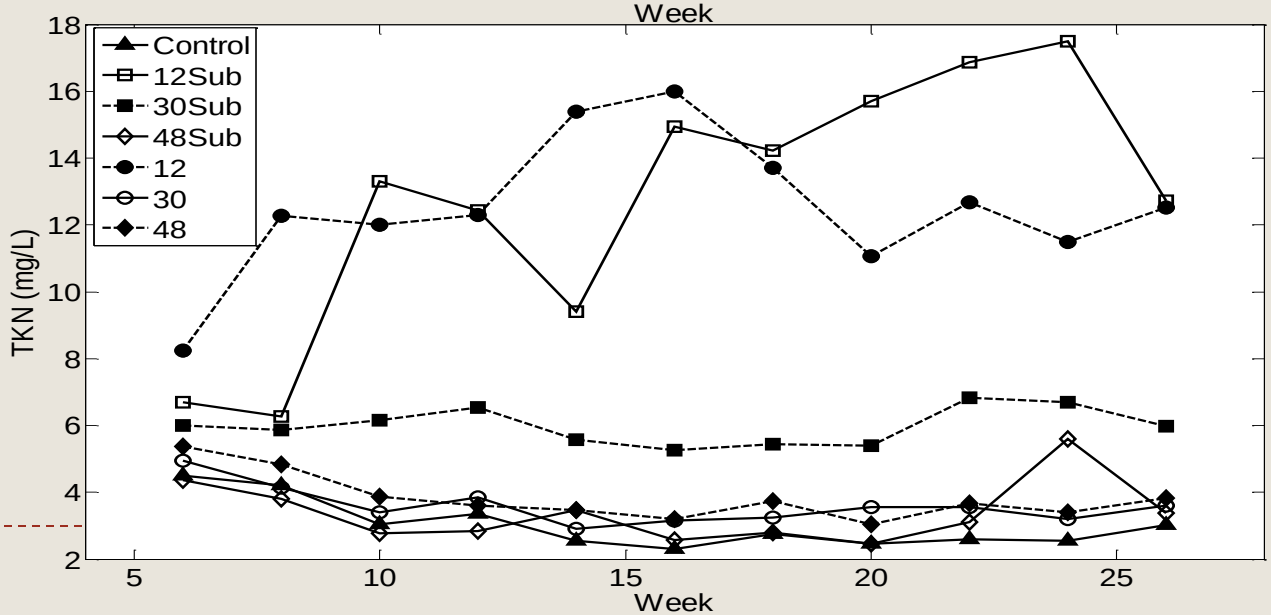
Soil COD


50000
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
COD (mg/kg dry)
0
10
20
30
40
50
60
Depth (inches)
30 - S
30 - SL
48 - SL Sub
12 - SL
12 - SL Sub
12 - S
30 - S
48 - SL
48 - S
Control SL
30 - SL Sub

TKN Sand (top) Sandy Loam (bottom)

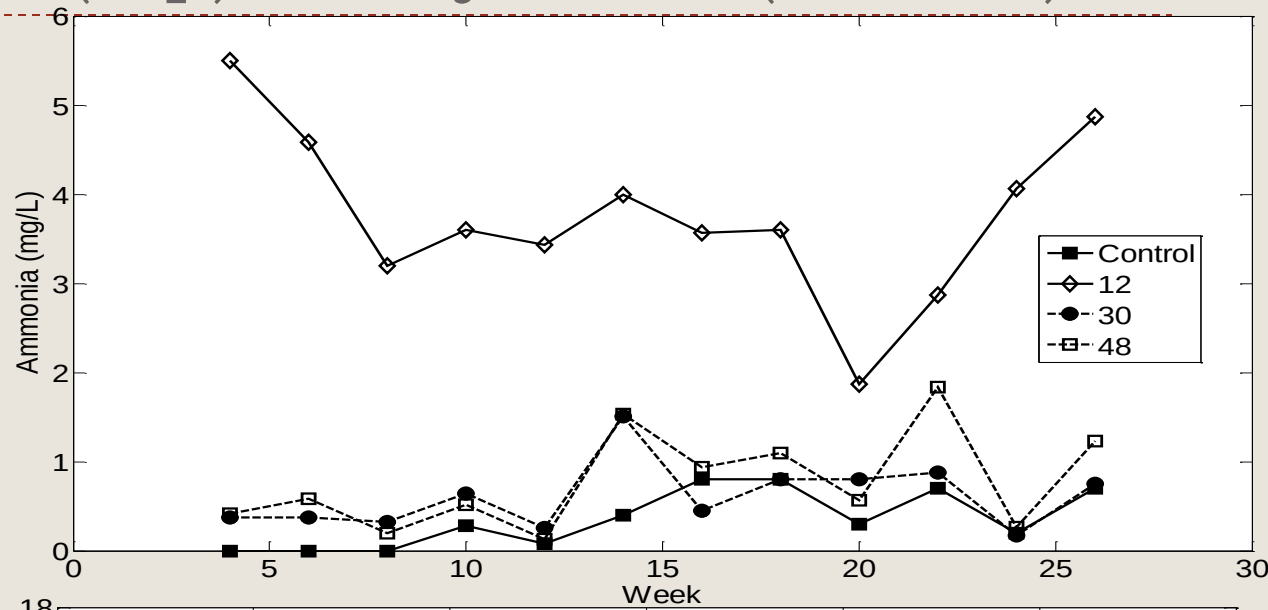
- Stat significance for depth and soil and interactions
- Significant difference in all depths for sandy loam, only for 12 inch in sand
- Increased contact time for microbial degradation in longer columns
- Increased microbial ammonification rates in aerobic conditions
- Significant differences in all depths for submergence

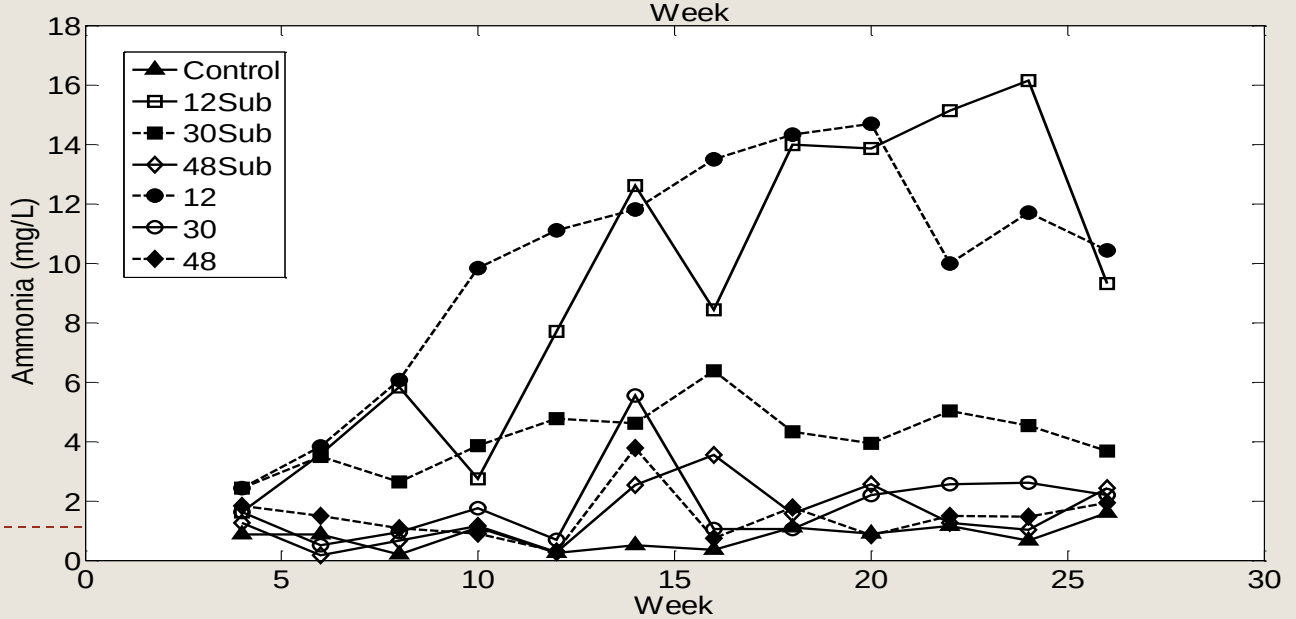




Ammonia Sand (top) Sandy Loam (bottom)

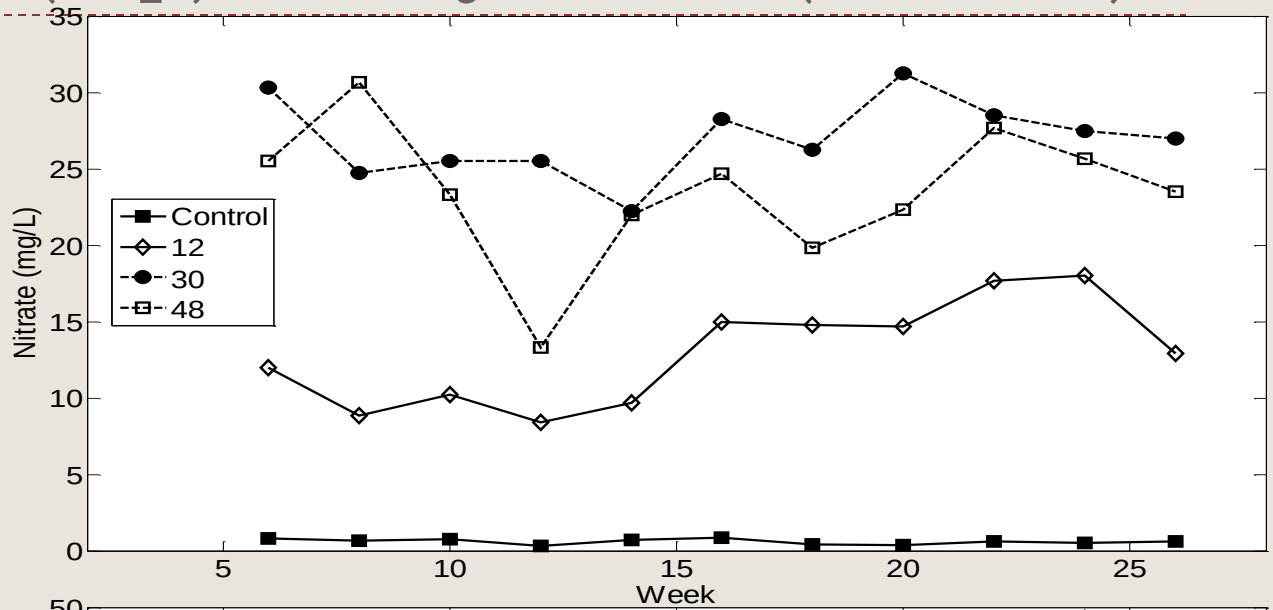
- Optimal conditions for nitrification (pH, carbon source, temp), dependent on aeration
- Typical surface discharge is 8 mg/L-N, except 12 inch sandy loam columns
- Significant difference for depth and soil and interactions
- 12 inch sand performs similarly to 30 and 48 inch sandy loam columns

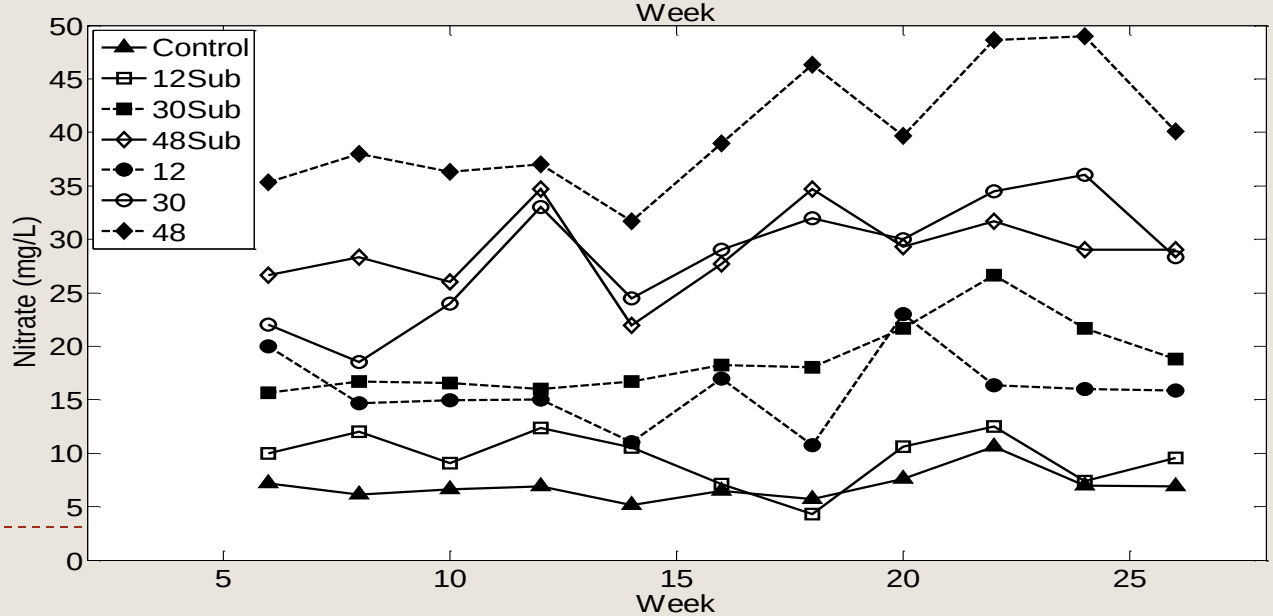




Nitrate Sand (top) Sandy Loam (bottom)

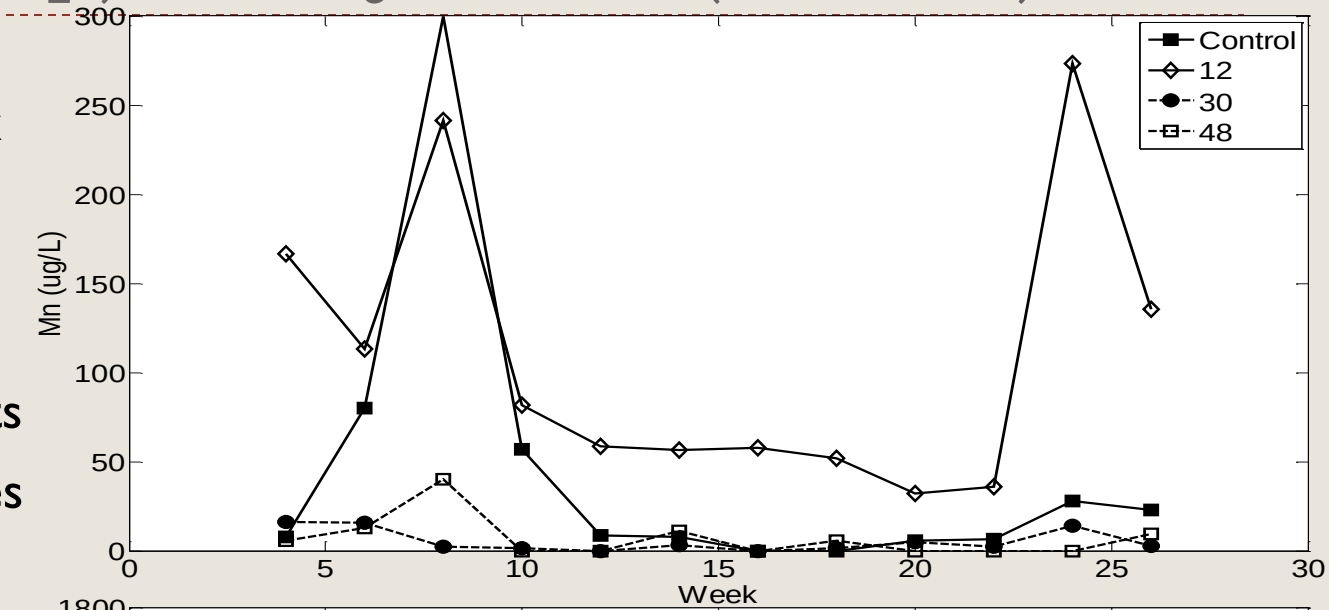
- All effluent concentrations are over the 10 mg/L drinking water standard
- Denitrification inhibited by oxygen, requires soil moisture of 60-90% (organic carbon available)
- Stat difference in soil and between 12 inch and 30 & 48 inch sand columns and all depths of sandy loam columns, and main effect for submergence

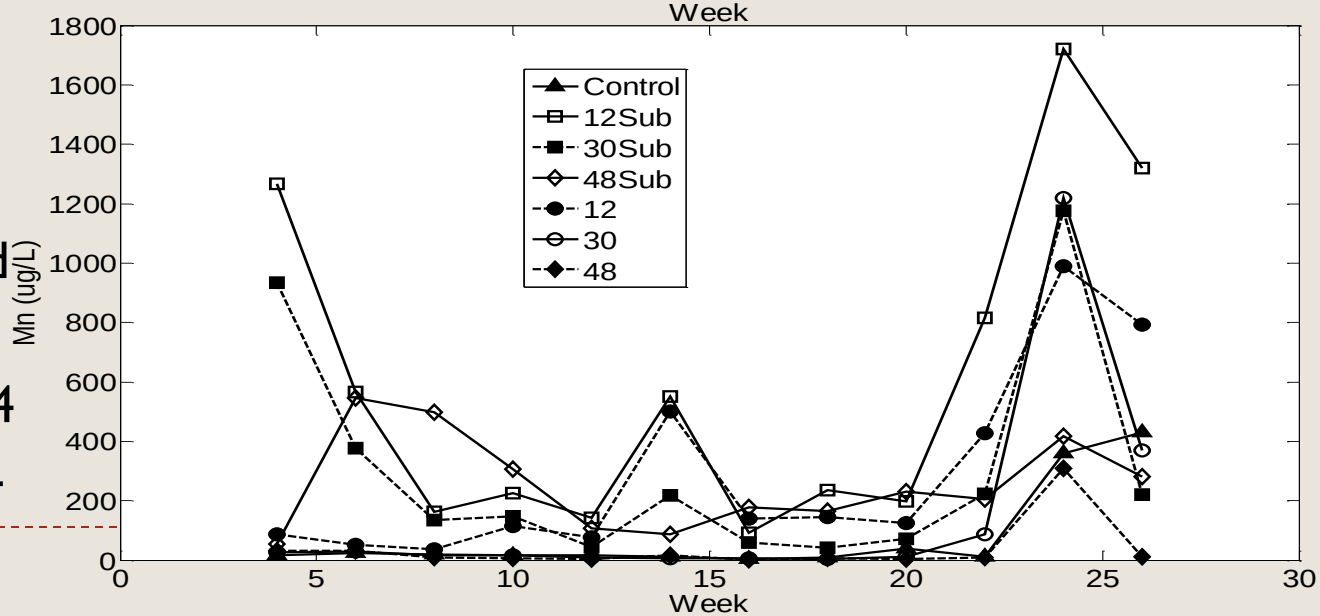




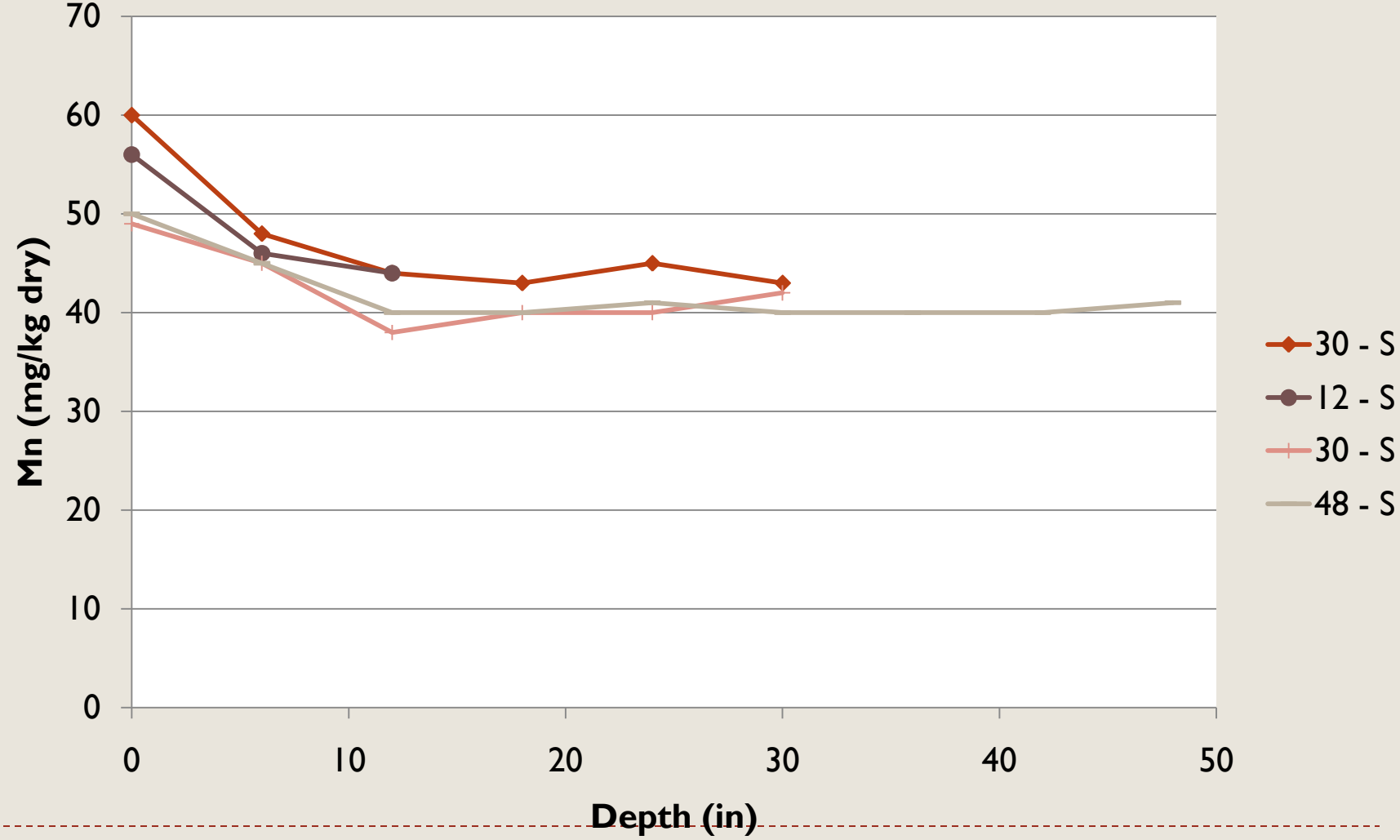
Mn Sand (top) Sandy Loam (bottom)

- Initial Mn sandy loam concentrations are 3x sand soils
- Significance for all depths, soil and sub
- No interactions effects
- Average effluent values (by increasing depth):
  - Sand: 109 ug/L, 5 ug/L, and 7 ug/L,
  - Sandy loam:290 ug/L, 150 ug/L, and 37 ug/L
  - Sub: 608 mg/L, 304 ug/L, and 256 ug/L





Mn Soil Concentrations by Depth



Laboratory Soil Column Evaluation of Treatment System

- Statistically determine the pollutant removal capacity of the volume of the overall soil column system for the various water quality parameters.
- Determine impact of soil depth and total soil volume to pollutant removal.
- Examine the influence of groundwater capillary rise on the depth of soil required for treatment of agricultural runoff.
- Find the degree of treatment variance between two defined soil types, sand and sandy loam, to determine if further detailed analysis is warranted.

Laboratory Soil Column Evaluation of Treatment System

- Significant difference for pollutant effluent concentrations:
  - Depth of 12 inches to those of greater depth
  - Soil type (except for alkalinity)
  - Submergence for Mn, Alkalinity, Nitrate, and COD
  - Interaction effects depth*soil and depth*submergence
- Depth performance: increase in depth = increase in treatment, up to 90% removal for many parameters at a depth over 12 inches
- Submerged columns typically had decreased removal performances
- Sand soil had greater pollutant removal percentages than sandy loam soils for almost all parameters
  - Sandy loam soils also had significant increases in Mn leaching
  - Soil physical properties have a significant impact on soil moisture and oxygen availability
    - high porosity, = high oxygen diffusion rate
  - Oxygen availability was theorized to be rate limiting in the nitrification process

Field and Laboratory Scale Comparison

- Similar trends for columns and field data
- Differences in the results can be explained by the experimental conditions
  - Higher treatment removal percentages are a result of the greater pollutant loadings
  - The MSU filter strips had a significant increase in soil clay content, reducing oxygen concentrations and impacting removal
  - Leaching of metals indicated anaerobic conditions within the field
  - As with sandy loam soils, the 12 inch sand columns had on average greater removal percentages than the filter strips at the small MI dairy site

Conclusions

- Manure produced the greatest concentrations of COD, BOD_5, ammonia, TKN, SO_4^-, solids, TOC, and Cl^-
- Average pollutant concentrations: feed sources < manure sources
  - due to large surface area (quantity) 29% of the drainage area,
- Average concentrations from feed were too great for treatment using agricultural filter strips
- Low pH values between 4 and 5 from feed sources impede biological treatment and burned the vegetation
- Water QUANTITY and dilution proved to be the determining factor in pollutant loading and allocation of management practices
- Management practices:
  - Proper upright silage filling practices
  - Bunker silos need to be covered and swept prior to precipitation and feed faces need to be maintained
  - If manure is a larger component than in this study, covering the manure prior to precipitation events or providing barriers such as berms or curbs can limit the transport of pollutants

Conclusions (con't)

- Sand soils have greater performance than sandy loam soils for a number of parameters
  - Increase in water holding capacity decreases oxygen diffusion
  - Backfilling filter strips with higher porosity soils can increase treatment of many parameters or potentially mechanically increasing soil porosity, or selecting vegetation that can increase oxygen diffusion and porosity
- BOD_5 removal requires a minimum depth of 30 inches for sand and sandy loam soils to reach a concentration below 30 mg/L
  - If groundwater is present within the system, it is recommended that the depth be increased to 48 inches
  - Appropriate site selection for filter strips at increased depth to groundwater will reduce groundwater impact.
- COD removal requires a minimum depth of 30 inches
  - BOD_5/COD ratios that indicate incomplete removal of biodegradable material in 12 inch columns.

Conclusions (con't)

- Removal of TKN and ammonia rely on nitrification and require 30 inches of treatment depth in sand and 30 inch soils but realize an even greater removal in 48 inch soils.
  - Nitrification rates are controlled by alkalinity availability, pH, temperature, and oxygen availability
  - Soils produce an excess of alkalinity and remain between the optimum pH, so if temperatures can be maintained between 5°C and 40°C, nitrification is based solely on oxygen
  - Increase oxygen within the treatment system to increase nitrification
- Potential implementation implications with nitrate and metal leaching

Future Research

- Evaluating nitrite build-up, including possible toxicity
- Dual soil treatment system (aerobic and anaerobic zone)
  - Possibilities include a defined clay layer to provide an anaerobic zone after aerobic treatment
- Measurement of dissolved oxygen under various treatment conditions
- Impact of soil moisture on pollutant removal
- Assessment of metal compounds (oxidation state)
- Life cycle of soil in terms of metal adsorption

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Thank You

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