Phytoremediation of nitrate impacted soil and groundwater at a fertilizer facility in central Alberta

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Effects of Nitrate Contamination

- Toxic to humans
  - Limit in drinking water 10 mg/L NO_3 (USEPA)
- Water quality issues
  - Accelerated eutrophication
  - Aquifer contamination
- Soil quality issues
  - Increased electrical conductivity

Nutrients and EC

- Plant available nutrients are in the form of salts
- Ions in solution conduct electricity

↑ ions = ↑ EC

- EC used to represent soil salinity

Why Phytoremediation?

- Uses green plants to remediate impacted environmental media
- *In situ* or *ex situ*
- Cost effective
  - Low ongoing operation and maintenance costs
- Increased soil quality
- Driven by solar energy

Why Phytoremediation?

- Positive public perception
- Versatile
  - Treat range of soil types
  - Surface and groundwater
- Can be coupled with more aggressive conventional treatments

Limitations

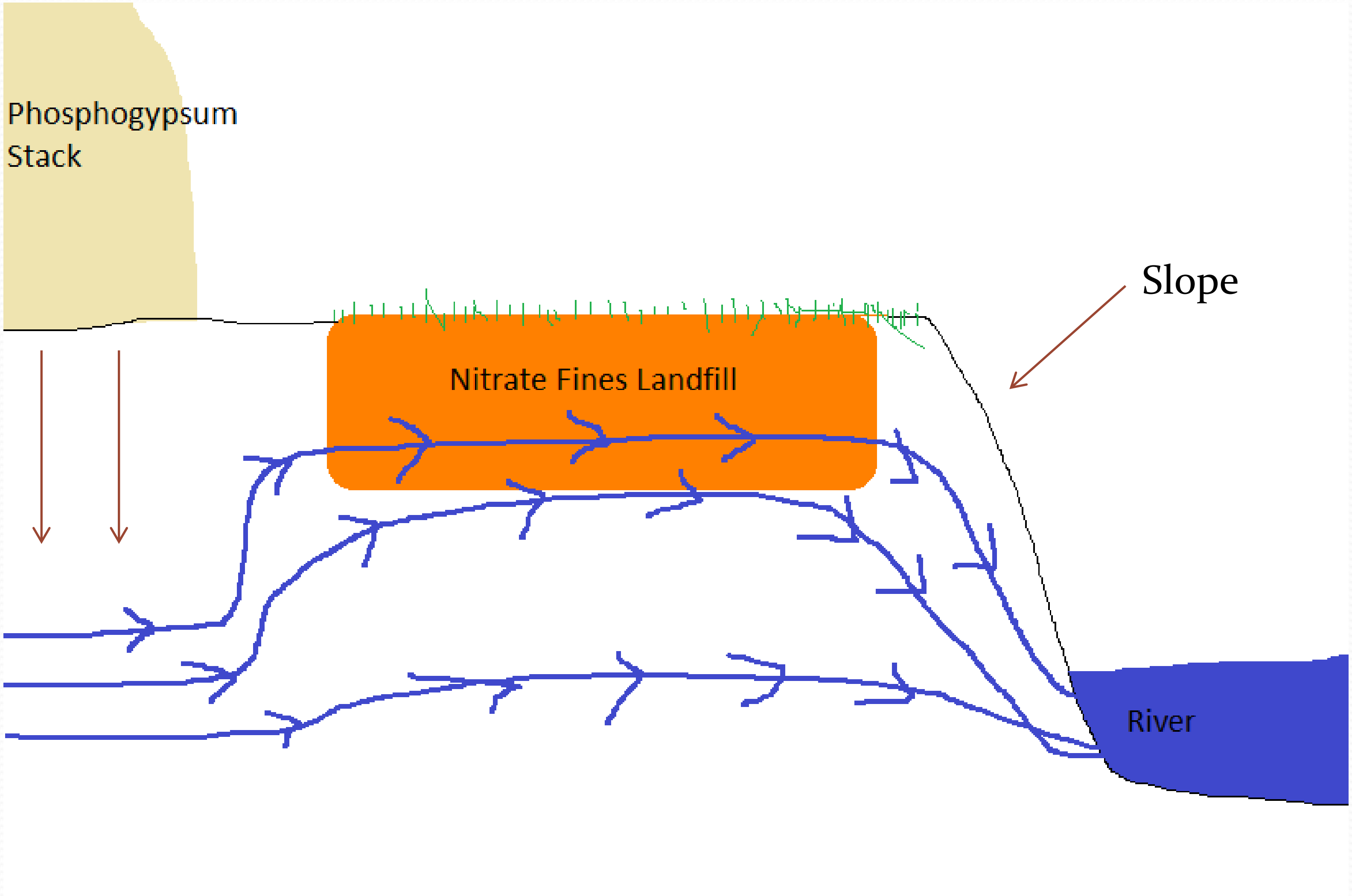
- Not successful if soil conditions or contaminant concentrations/characteristics phytotoxic
- Slower than some alternatives
- Seasonally dependent

Phytoremediation of Nitrogen

- Plant uptake of nitrogen – Mass Flow
  - Transpirational water uptake by plants
  - Water evaporation at soil surface
  - Percolation of water within soil profile
- Leads to movement of ions

Background - Nitrate Fines Landfill

Groundwater N concentrations up to 24,000 mg/L NH_4^+ and 7,000 mg/L NO_3^-


Phosphogypsum
Stack
Slope
Nitrate Fines Landfill
River

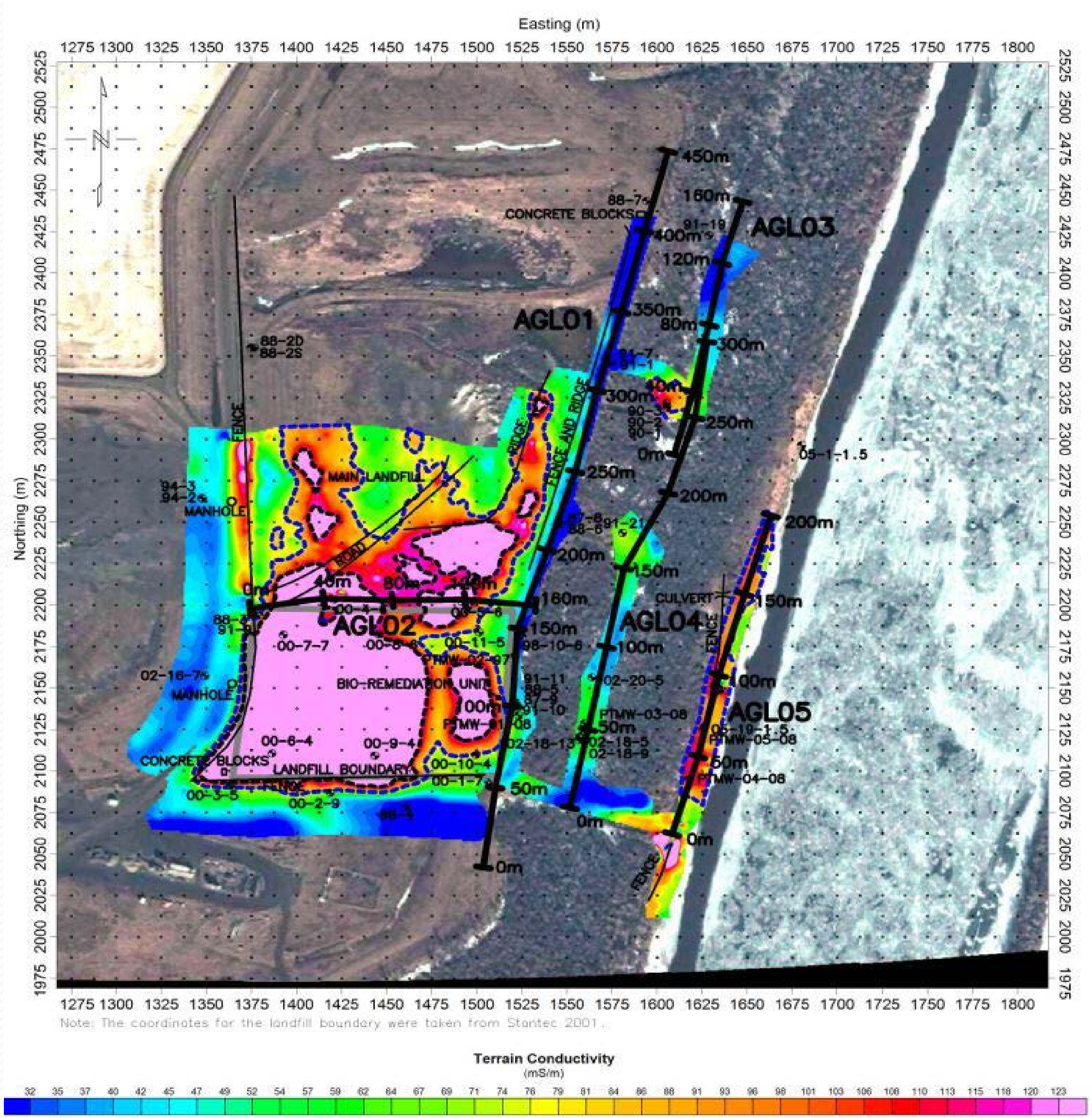
Research Objectives

- Determine viability of using Okanese poplar, willow, alfalfa and AC Saltlander grass to remediate nitrogen impacted soil and groundwater.
- Specific research objectives:
  - Evaluate which plant type most effective in removal of excess nitrogen compounds from impacted soil and groundwater.
  - Quantify upper limit of plant nitrogen tolerance.
  - Determine feasibility of using fertilizer impacted groundwater as an irrigation source.

Methodology

- Initial soil and groundwater sampling
  - EM/ERT survey
  - GW monitoring wells
  - Geoprobe

Geophysical Survey



WorleyParsons 2010

Vegetation Selection

Okanese poplar
2403 (Walker x
P. xpetrowskyana)

AC Saltlander
(*Agropyron spicatum x
Agropyron repens*

Willow
(*Salix bebbiana*)

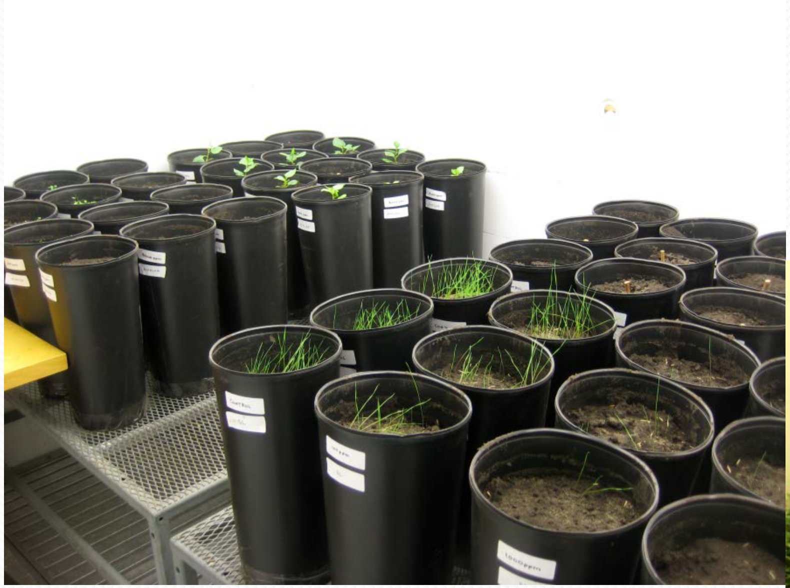
Alfalfa
(*Medicago sativa
var.* AC Nordica)

Phytoremediation of Nitrogen Impacted Soil

Objectives

- Characterize growth and survival for each plant type in nitrogen impacted soils.
- Identify an approximate upper limit of soil EC tolerance for each vegetation type.
- Investigate whether soil constituents other than nitrogen present in the landfill soil would effect plant growth.
- Determine which plant types are most efficient in the removal of excess soil nitrogen.
- Quantify the nitrogen balance within the environmental growth chamber system.

Trial 1 - Controlled Addition of NH_4NO_3 to Loamy Sand

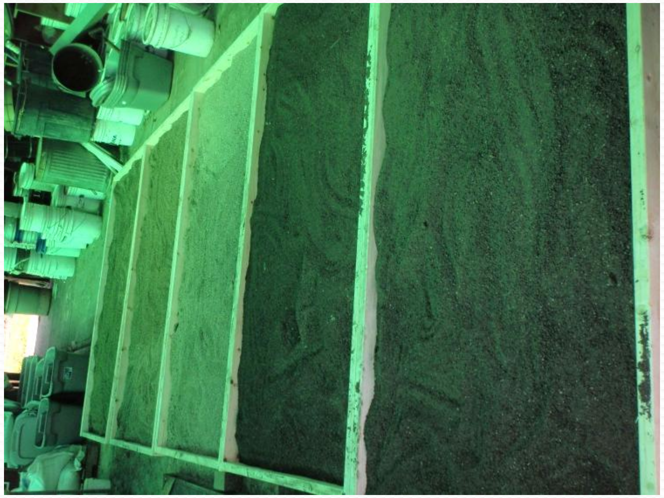


Treatments

- Control – 23.39 kg/ha
- 100 mg/kg NH_3NO_4 – 170 kg/ha
- 1000 mg/kg NH_3NO_4 – 1493 kg/ha
- 4000 mg/kg NH_3NO_4 – 5903 kg/ha

** Total Soil Mineral N

Trial 2 – Excavation and Remediation of Landfill Soil

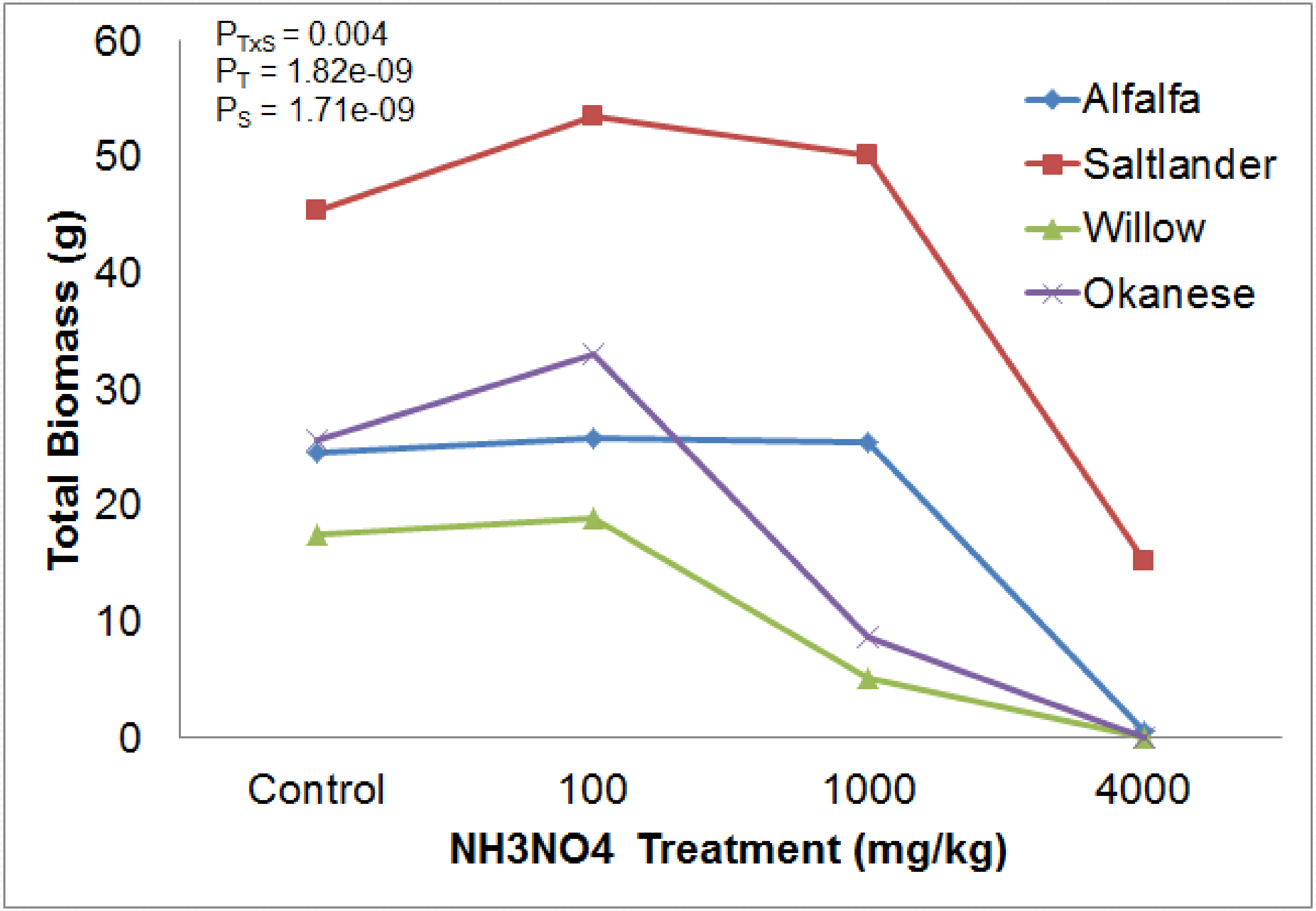


Treatments

Trial 1		Trial 2
100 mg/kg	→	Low (~ 100 mg/kg)
1000 mg/kg	→	Medium (~ 1000 mg/kg)
4000 mg/kg	→	High (~ 2500 mg/kg)

Results

Trial 1 - Tissue Biomass

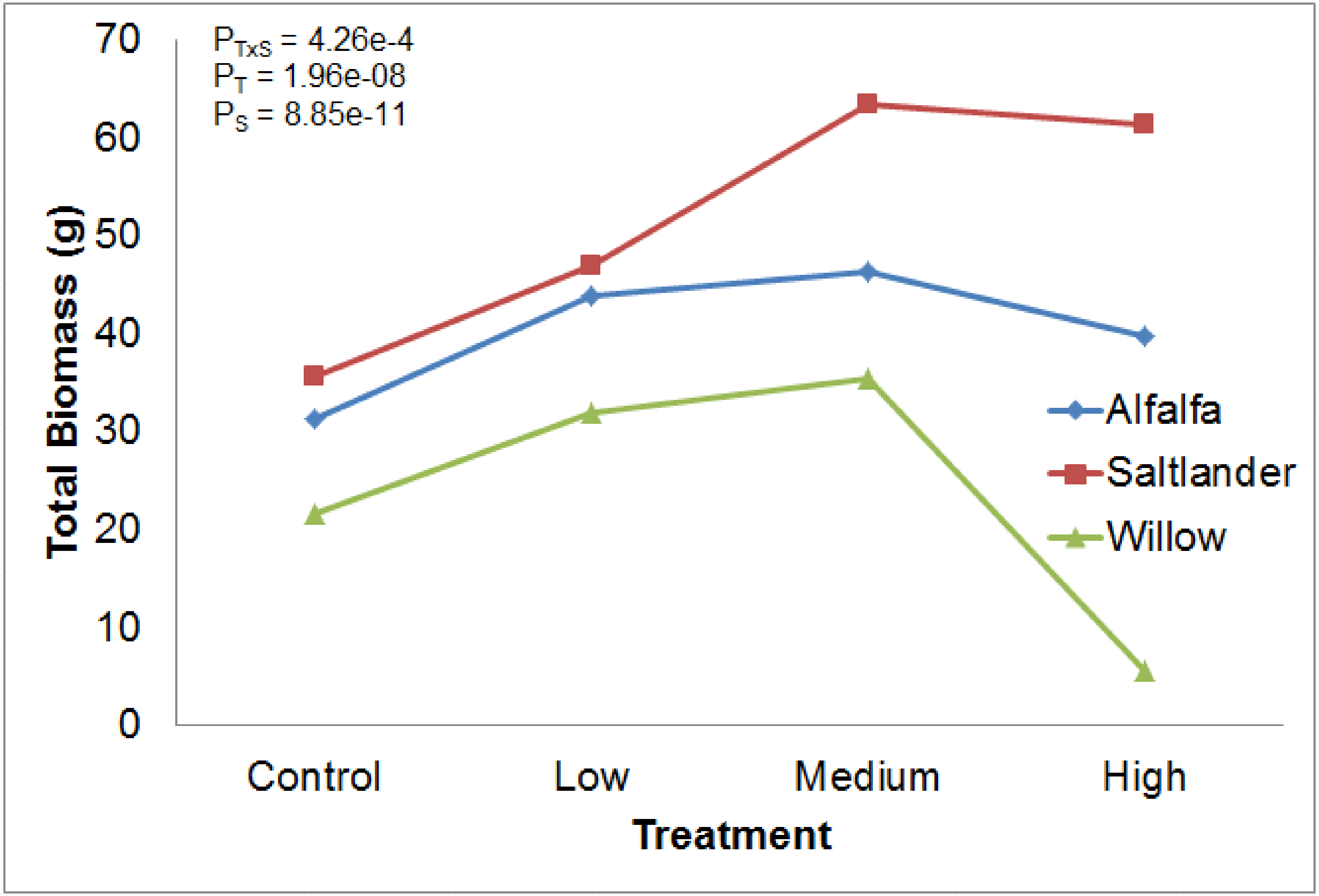



CONTROL


Willow – 1000 mg/kg NH4NO3

Willow – Control

Trial 2 – Tissue Biomass

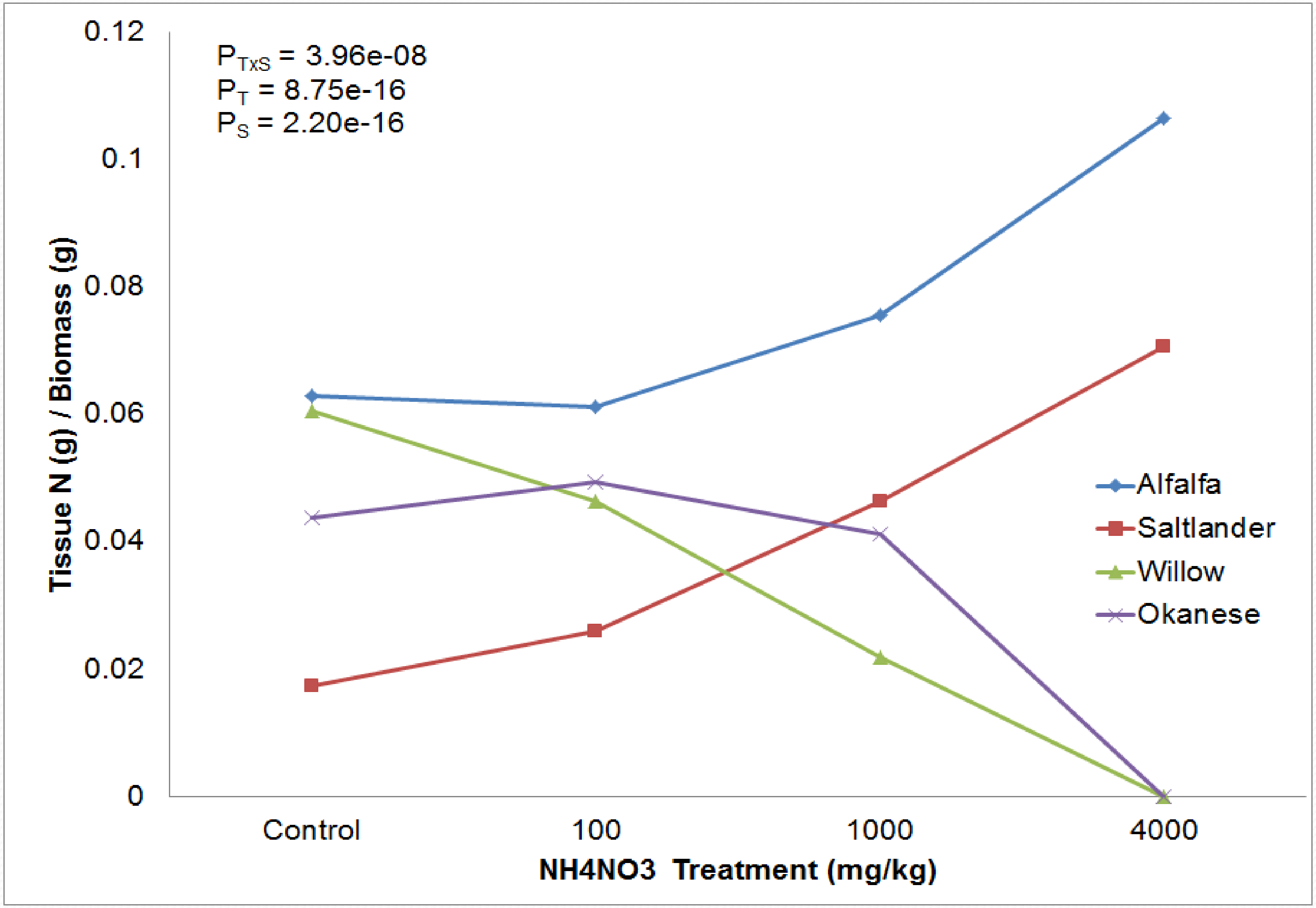



W-C3
SL-H3

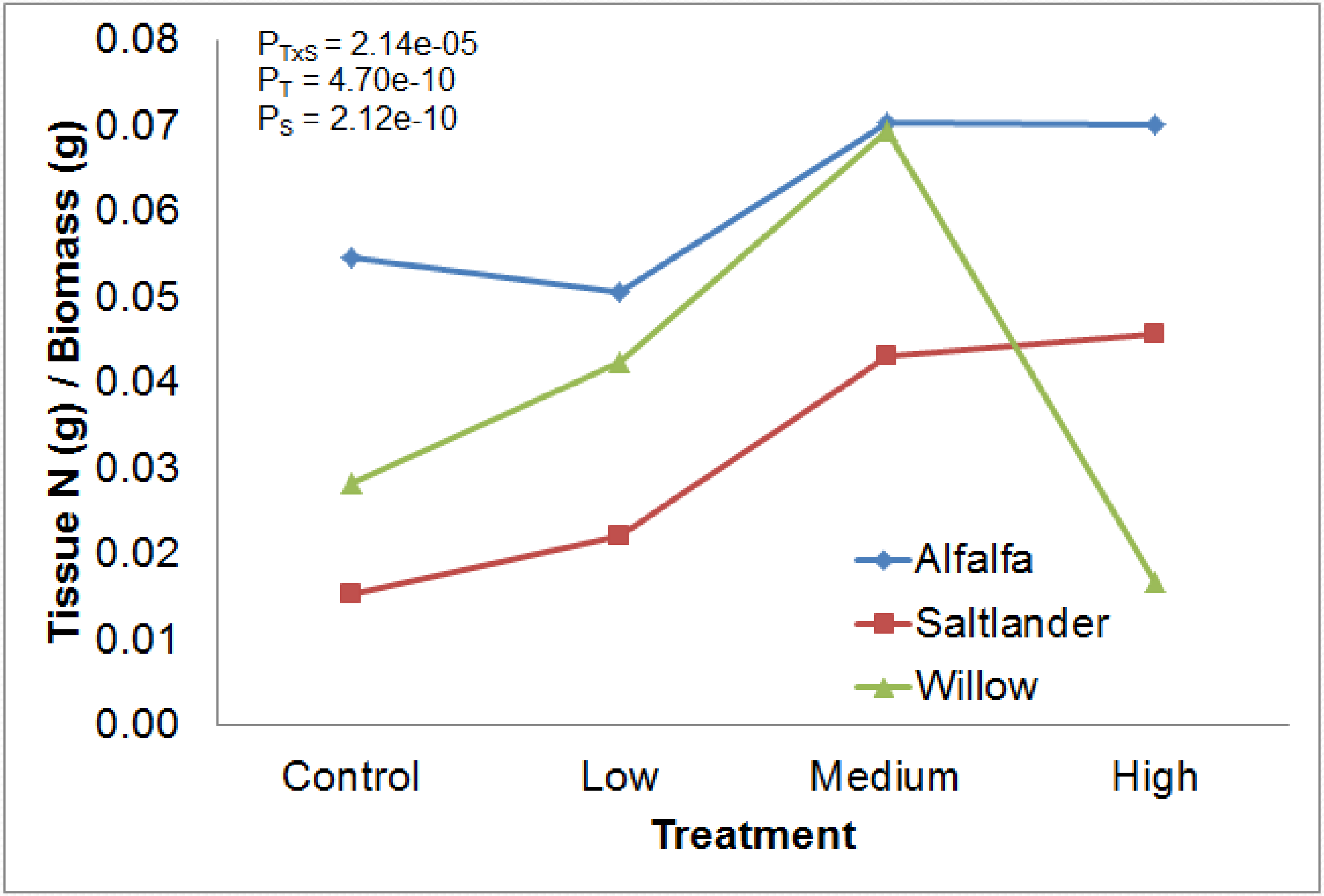

Biomass

- Similar trends in willow and Okanese, and in alfalfa and Saltlander
  - Similar mechanisms for salinity tolerance?
  - Woody plants – osmotic adjustment
  - Alfalfa and grass species – ion exclusion

Trial 1 - Plant N Uptake



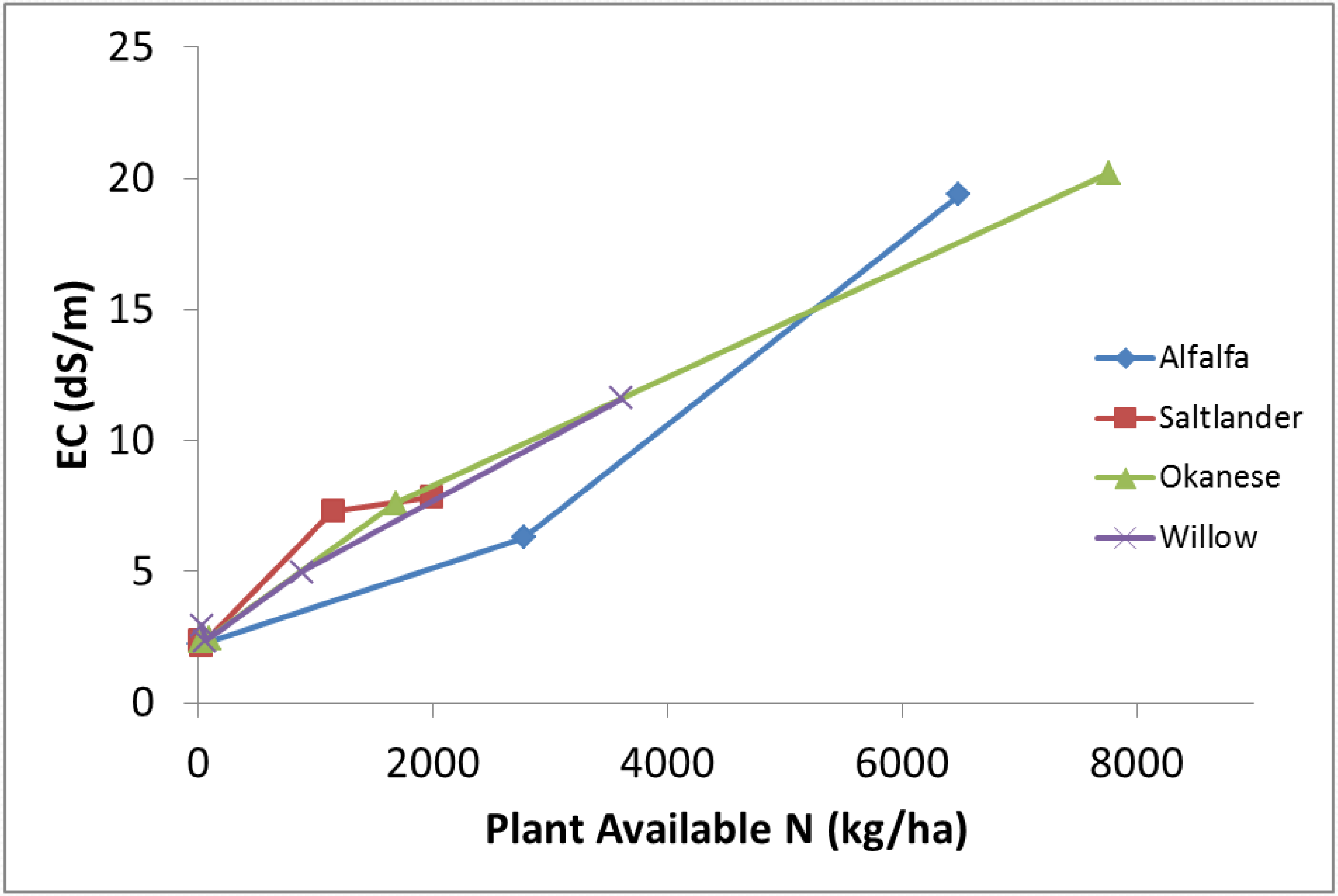
Trial 2 – Plant N Uptake



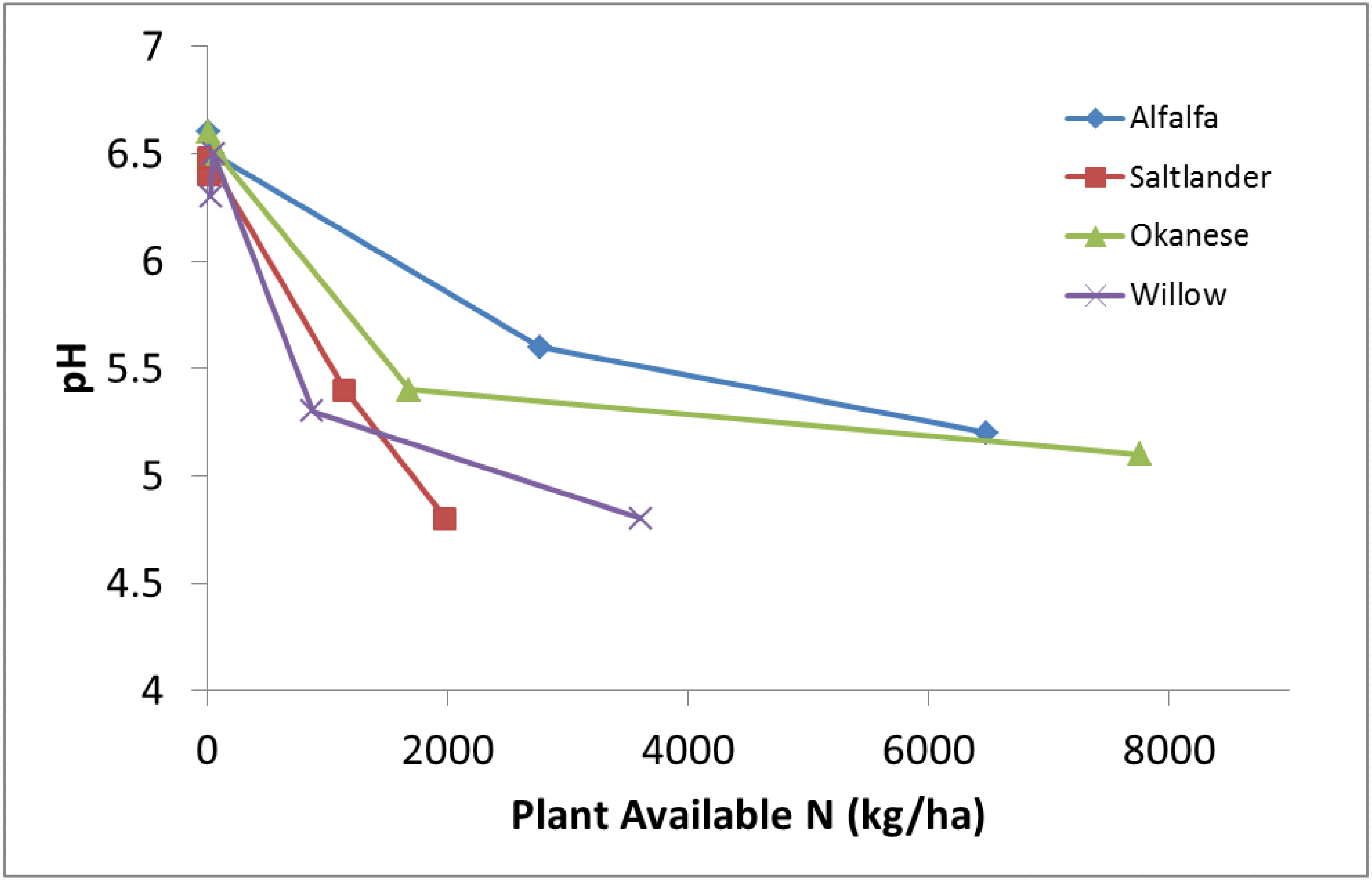
Plant N Uptake

- Willow and Okanese not capable of adapting well to saline conditions
  - Physiological drought
  - Decrease N uptake with increased EC
- Saltlander and alfalfa more tolerant

Trial 1: Post Trial Soils - EC



Trial 1: Post Trial Soils – pH



Nitrogen Balance

$\Delta N_a = N_f - N_i = NH_4NO_3$ addition + mineralization – plant removal – other losses

Rearranging results in the following relationship:

[mineralization - other losses] = ΔN_a – [NH_4NO_3 addition – plant removal]

* ΔN_a = Plant Available N, N_f = N final, N_i = N Initial

Nitrogen Balance Trial 1

Variety	Treatment	• N = N_f - N_i (kg/ha)	NH_4NO_3 Addition (kg/ha)	Plant Uptake (kg/ha)	[NH4NO3 Addition - Plant Uptake] (kg/ha)	[Mineralization - Other Losses] (kg/ha)
Alfalfa	Control	-8.04	0.00	10.29	-10.29	2.25
	100 mg/kg	-121.07	147.00	10.09	136.91	-257.98
	1000 mg/kg	-541.29	1470.00	12.48	1457.52	-1998.81
	4000 mg/kg	580.27	5880.00	23.82	5856.18	-5275.91
Saltlander	Control	-12.44	0.00	2.77	-2.77	-9.67
	100 mg/kg	-155.97	147.00	4.11	142.89	-298.86
	1000 mg/kg	-635.37	1470.00	8.02	1461.98	-2097.35
	4000 mg/kg	-3921.30	5880.00	14.39	5865.61	-9786.92
Okanese	Control	-3.47	0.00	8.61	-8.61	5.14
	100 mg/kg	-101.90	147.00	10.07	136.93	-238.83
	1000 mg/kg	50.48	1470.00	8.57	1461.43	-1410.95
	4000 mg/kg	-79.43	5880.00	0.00	5880.00	-5959.43
Willow	Control	1.77	0.00	12.07	-12.07	13.84
	100 mg/kg	-125.52	147.00	9.82	137.18	-262.71
	1000 mg/kg	-831.54	1470.00	4.42	1465.58	-2297.12
	4000 mg/kg	-2294.57	5880.00	0.00	5880.00	-8174.57

Results - Nitrogen Balance

- N additions/presence positively correlated to plant uptake for alfalfa and Saltlander, but negatively correlated for Okanese and willow

- N additions/presence negatively correlated to [mineralization – other losses] for all plant varieties indicating that the greater the addition of ammonium nitrate the greater the unaccountable nitrogen losses.

- Plant uptake negatively correlated to [mineralization – other losses] for alfalfa and Saltlander, but positively correlated for Okanese and willow.

Nitrogen Balance

- N loss greater than plant N uptake
  - High denitrification rates with high soil moisture contents
  - Soil water moderates oxygen diffusion
  - Some immobilization
    - Into microbial biomass due to high N and C excreted from roots

Role of Soil Clay Content?

- Similar trends in both trials
- Biomass development and N uptake overall higher in Trial 2
- Likely due to increased clay content
  - Higher CEC
  - Buffering capacity

Research Summary

- Coping mechanisms of alfalfa and Saltlander against salinity better suited than willow and Okanese poplar
- Phytoremediation may be more applicable to soils with higher clay contents
- N loss, likely due to atmospheric denitrification or immobilization, higher than plant N uptake
- Nitrate impacted groundwater phytotoxic to plants even when diluted

Application to Industry

- May use plants (Saltlander and alfalfa) in areas where nitrate impacts are below phytotoxic limits
- Expose to carbon sources and the atmosphere
  - Denitrification
  - Immobilization
- Saltlander may be invasive

Research Limitations and Future Research

- Better understanding of nitrogen balance
  - Organic N
  - Atmospheric release
- *In situ* response?
- Only one growing season
- Growth stage effects

Thank you
Questions?

NSERC CRSNG

Agrium

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Trial 1: Control Soil – Baseline Conditions

Analyte	Units	Results
Phosphorus (available)	kg/ha	117.6
Potassium (available)	kg/ha	336.0
Cation Exchange Capacity	meq/100g	18
pH	pH	6.7
Electrical Conductivity	dS/m	2.42
SAR		0.10
% Saturation	%	38
Calcium	kg/ha	932.4
Magnesium	kg/ha	92.4
Sodium	kg/ha	16.8
Potassium (soluble)	kg/ha	16.8
Chloride	kg/ha	42.0
Sulfate-S	kg/ha	84.0
Nitrate and Nitrite-N	kg/ha	23.4

Trial 1: Post trial soil conditions

	NH_4NO_3 Treatment (mg/kg)			
Alfalfa	Control	100	1000	4000
Nitrate-N (kg/ha)	9.80	43.9	1255.8	4965.3
Nitrite-N (kg/ha)	1.59	1.12	0.93	0.98
Ammonium-N (kg/ha)	3.97	4.34	1517.3	1517.5
EC (dS/m)	2.26	2.25	6.30	19.37
pH	6.6	6.5	5.6	5.2
Saltlander				
Nitrate-N (kg/ha)	9.80	14.0	1118.1	1689.3
Nitrite-N (kg/ha)	2.70	2.01	1.68	2.05
Ammonium-N (kg/ha)	0.50	3.22	24.22	290.7
EC (dS/m)	2.38	2.18	7.31	7.85
pH	6.4	6.48	5.4	4.8
Okanese				
Nitrate-N (kg/ha)	13.7	85.4	1675.3	5460.0
Nitrite-N (kg/ha)	1.54	1.35	1.82	0.89
Ammonium-N (kg/ha)	4.71	4.57	6.72	2304.4
EC (dS/m)	2.33	2.47	7.60	20.2
pH	6.6	6.5	5.4	5.1
Willow				
Nitrate-N (kg/ha)	29.4	56.5	877.3	2772.0
Nitrite-N (kg/ha)	1.82	0.84	1.68	1.49
Ammonium-N (kg/ha)	2.29	2.52	3.45	835.3
EC (dS/m)	2.95	2.36	4.97	11.6
pH	6.3	6.5	5.3	4.8

Trial 2- Baseline soil conditions: Nitrate Fines Landfill

		Results			
Analyte	Units	High	Medium	Low	Control
Nitrate-N	kg/ha	7560.0	3108.0	336.0	29.4
Nitrite-N	kg/ha	1.68	4.2	5.88	3.78
Phosphorus (available)	kg/ha	197.4	336.0	176.4	29.4
Sulfate-S	kg/ha	3943.8	1365.0	2944.2	210.0
Ammonium-N	kg/ha	3645.6	1402.8	17.22	24.78
Electrical Conductivity	dS/m	20.4	8.41	5.67	1.11
pH	pH	8.0	7.9	8.4	8.0

Trial 2 – Post trial soil conditions

	Treatment			
Alfalfa	Control	Low	Medium	High
Nitrate-N (kg/ha)	7.93	64.40	2892.3	4340.0
Nitrite-N (kg/ha)	2.38	2.47	1.82	2.33
Ammonium-N (kg/ha)	2.43	0.42	2.75	0.32
EC (dS/m)	0.93	3.80	8.08	10.55
Saltlander				
Nitrate-N (kg/ha)	7.93	4.20	3752.0	6766.7
Nitrite-N (kg/ha)	0.42	0.52	0.43	0.50
Ammonium-N (kg/ha)	0.13	0.00	1.00	0.37
EC (dS/m)	1.56	5.17	10.14	16.19
Willow				
Nitrate-N (kg/ha)	5.13	93.3	1918.0	5138.0
Nitrite-N (kg/ha)	2.71	2.99	2.29	2.52
Ammonium-N (kg/ha)	2.47	0.51	1.26	5141.5
EC (dS/m)	1.06	3.27	6.77	12.45

Groundwater Parameters

Analyte		Units	Results
Ammonia-N		mg/L	19,900
Kjeldahl Nitrogen	Total	mg/L	22,900
Nitrogen	Total	mg/L	32,200
Organic Nitrogen	Total	mg/L	3,000
Orthophosphate-P	Dissolved	mg/L	5,360
Organic Carbon	Total Nonpurgeable	mg/L	42.5
pH			6.92
Temperature		°C	22.4
Electrical Conductivity		µS/cm	111,000
Calcium	Dissolved	mg/L	<40
Magnesium	Dissolved	mg/L	<40
Sodium	Dissolved	mg/L	1,500
Potassium	Dissolved	mg/L	1,500
Iron	Dissolved	mg/L	2.4
Manganese	Dissolved	mg/L	<1
Chloride	Dissolved	mg/L	1,600
Nitrate-N		mg/L	9,300
Nitrite-N		mg/L	<1
Nitrate and Nitrite-N		mg/L	9,300
Sulfate (SO_4)	Dissolved	mg/L	22,600
Hydroxide		mg/L	<5
Carbonate		mg/L	<6
Bicarbonate		mg/L	13,300
P-Alkalinity	As $CaCO_3$	mg/L	<5
T-Alkalinity	As $CaCO_3$	mg/L	10,900
TDS	Calculated	mg/L	59,000
Hardness	Dissolved as $CaCO_3$	mg/L	<300
Ionic Balance	Dissolved	%	109