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Soil Moisture Sensor Irrigation Controller Standardized Testing

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Outline

- Background
- Goal
- Methods
  - Materials
  - Process
- Testing
- Results

Background

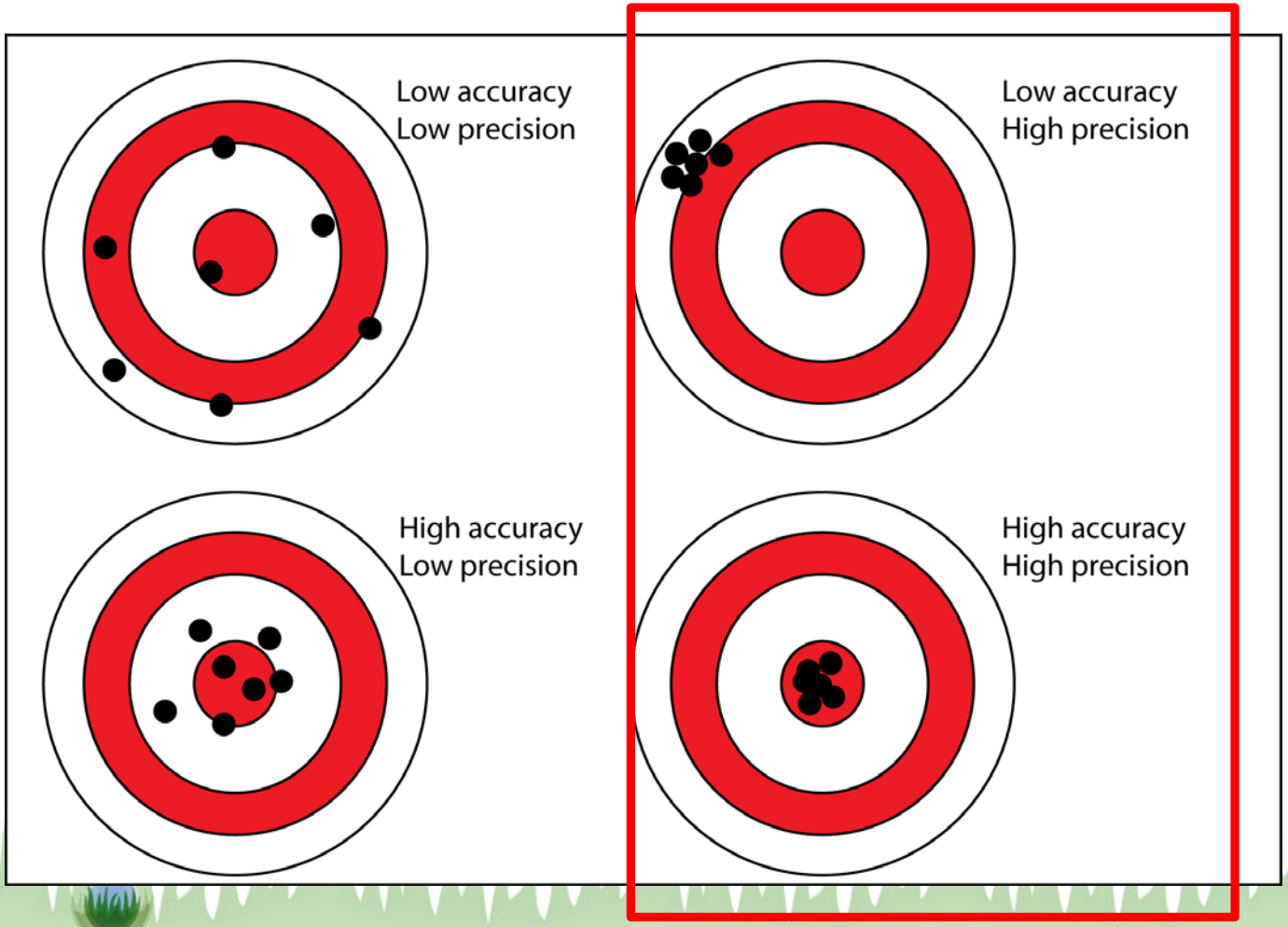
- Nov 2011 - EPA WaterSense WBIC spec
- Pre 2011 - SMS working group
- Late 2012 - ASABE X633, Testing Protocol for Landscape Irrigation Soil Moisture-Based Control Technologies formed
- Late 2013 - Draft standard based on dry down and accuracy

Accuracy Testing

History

- Nov 2011 – EPA WaterSense WBIC spec
- Pre 2011 - SMS working group
- Late 2012 - ASABE X633, Testing Protocol for Landscape Irrigation Soil Moisture-Based Control Technologies formed
- Late 2013 - Draft standard based on dry down and accuracy
- Spring 2014 - EBMUD coordination
- ~2014 - Precision metric developed
- Early 2018 - Design test ”media”
- May 2018 - MWD ICP testing funding

Precision


Low accuracy
Low precision
Low accuracy
High precision
High accuracy
Low precision
High accuracy
High precision

Test Questions

- Does response across moisture level vary? e.g. flat line response?
- Do readings change over time? 0 vs. 24 hr or longer?
- What is an acceptable deviation in precision?
- Do SMS function after freeze test?

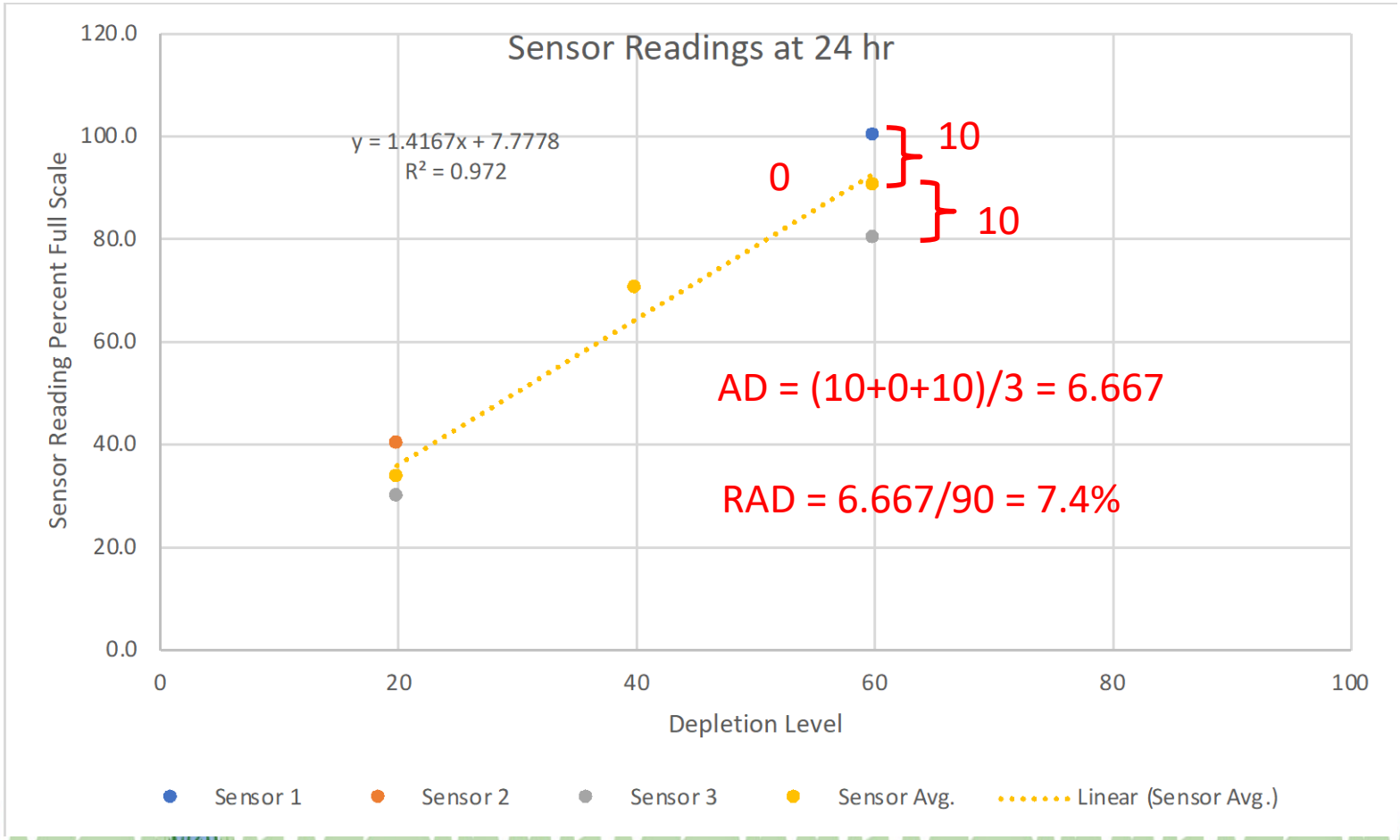
Analysis Background

- Test 4 brands
  - 3 moisture contents (depletion levels) relative to field capacity (FC)
  - 2 media types, coarse & fine “soil”
  - 2 water salinity levels
  - 3x2x2 = 12 test scenarios per brand
- Compare relative measurements (precision) of 3 SMS samples per brand at each moisture level

Metrics

- $Avg\ Deviation = \frac{\sum_{i=1}^{n} |\bar{x} - x_i|}{n}$
  - Averages distance from the mean for individual probes
  - Measure of precision but differing SMS scales varies results
- $Relative\ Avg\ Deviation = \frac{Avg\ Deviation}{\bar{x}}$
  - Normalizes average to account for different scales inherent in each sensor brand

AD, Avg. Deviation & RAD, Relative Avg. Deviation



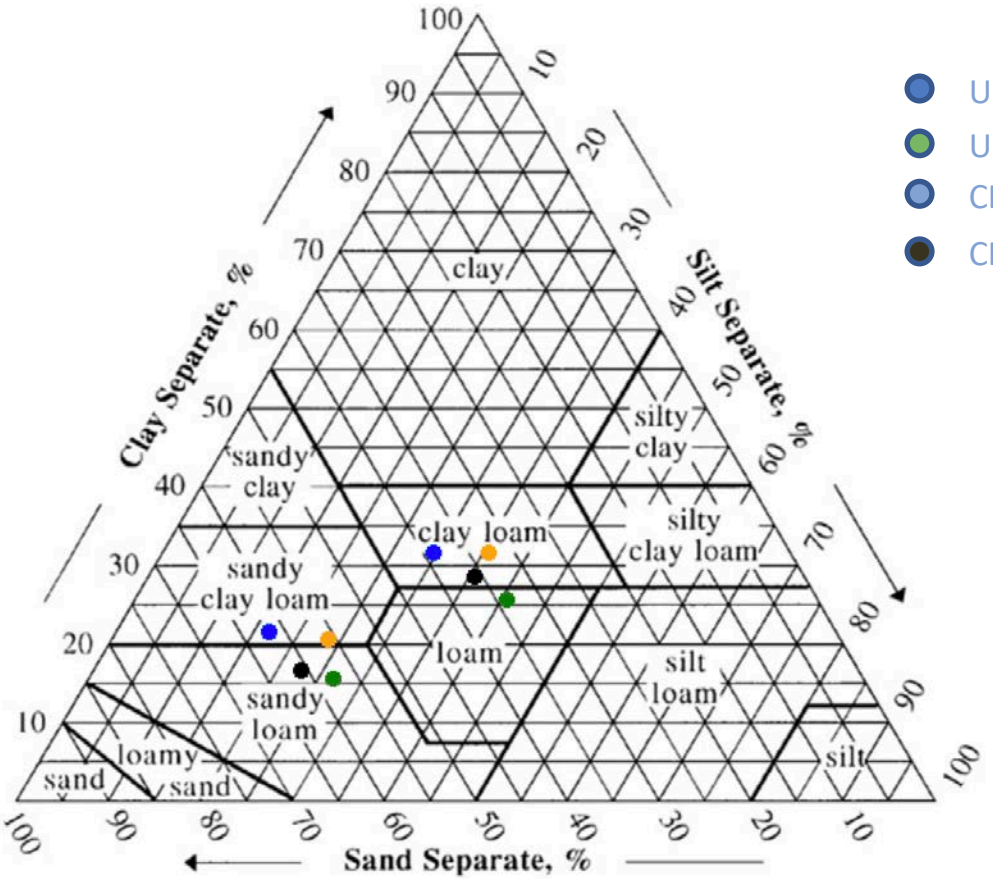
“Soil” Materials

- 60F fine silica sand
- 325 mesh silica flour
- Sodium bentonite 200 mesh powder

Media Mix

- Proportions (60F sand, 325 silica, clay)
- Coarse soil
  - 6:2:2 fraction by weight
  - Bulk density, Db = 1.4 g/cc
  - FC = 20%
- Fine soil
  - 1:1:1 fraction by weight
  - Bulk density, Db = 1.3 g/cc
  - FC = 32%

Particle Size Analysis



Media Salinity Testing

- Soil salinity determined from extraction
- Salinity varied from UF and CIT due to different source material
- Generally salinity increased from 0 to 3 dS/m water

Media Salinity Testing (fine)

- Water added to field capacity (32% by vol.)

Water Salinity (dS/m)	Soil Salinity (dS/m)
Air dry	1.48
0	1.59
1	1.67
2	1.74
3	2.08

Media Salinity Testing (coarse)

- Water added to field capacity (20% by vol.)

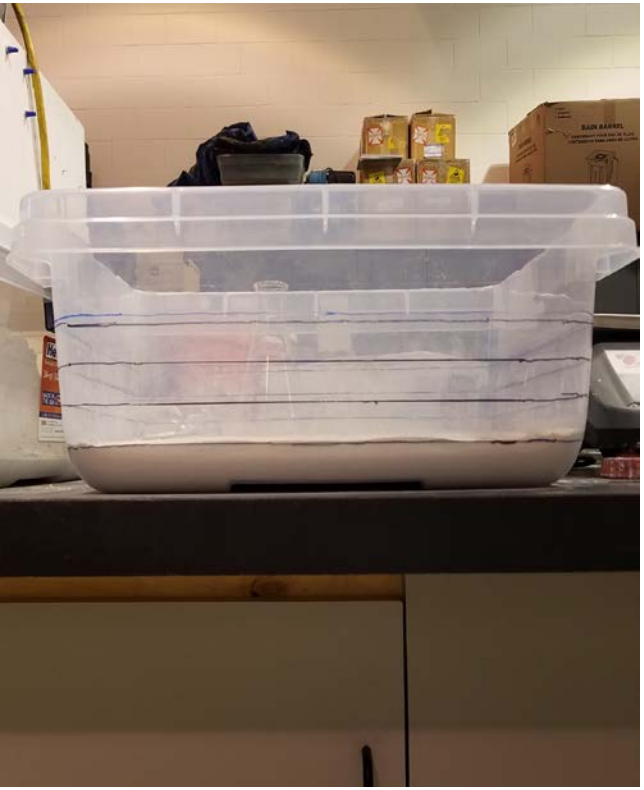
Water Salinity (dS/m)	Soil Salinity (dS/m)
Air dry	1.07
0	1.32
1	1.61
2	1.26
3	1.42

Procedure

- Determine container vol
- Determine SMS vol
- Dry media mass, M = V x Db
- Mix dry components & add water
- Pack containers with SMS & seal
- Weigh container
- Take enable/disable readings at 0 & 24 hr

Mixing Components

Packing Containers



Sensor Functionality

Test Matrix

Brand	Soil	Salinity
A	Coarse	0 dS/m
B		
C		
D		
A	Fine	0 dS/m
B		
C		
D		
A	Coarse	3 dS/m
B		
C		
D		
A	Fine	3 dS/m
B		
C		
D		

20%, 40%, 60% Depletion level for each combination

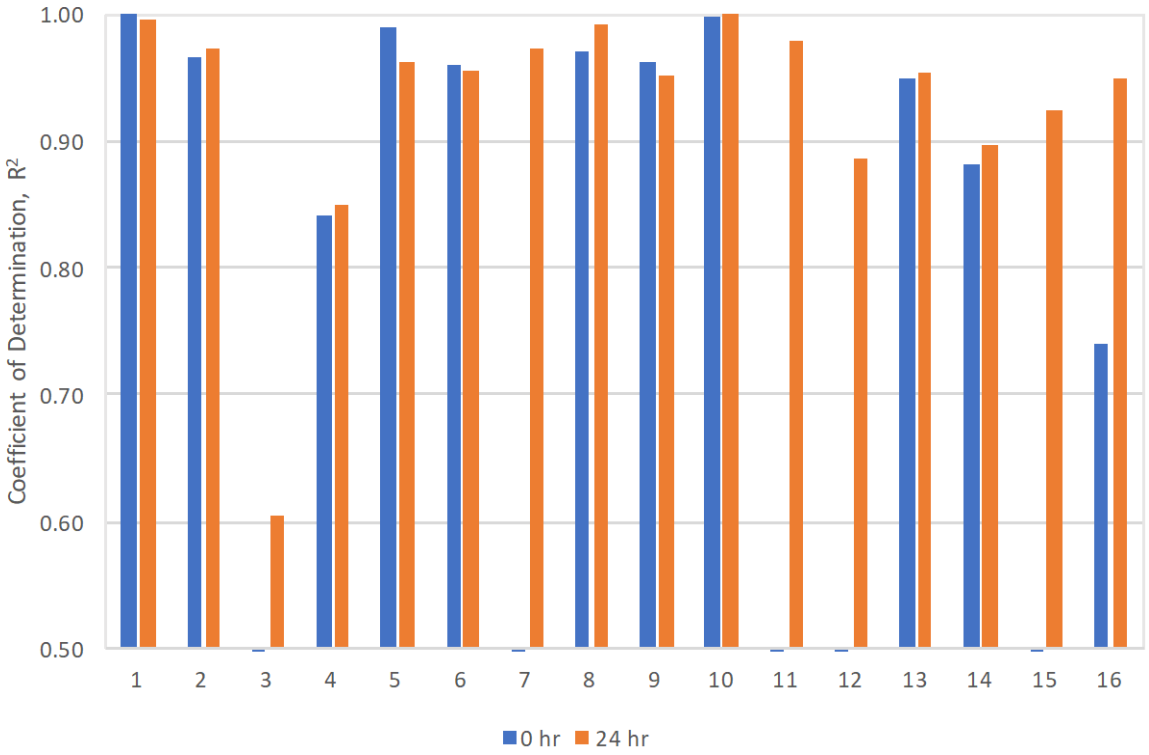
Freeze Test

- Fine media, 40% depletion, 0 dS/m
- Pre-test enable/disable
- Freeze container -18 C for 72 hrs
- Thaw to ambient temp for 24 hrs
- Post-test enable/disable

Table of Observed Regression Slopes – Sensor Reading

			Sensor Relative Reading			
Brand	**Soil**	**Salinity**	**Average Regression R^2**		**Regression Slope**	
			0 hr	24 hr	0 hr	24 hr
A	Coarse	0 dS/m	1.000	0.995	-0.095	-0.094
B			0.966	0.973	-0.504	-0.480
C			N/A	0.605	N/A	0.417
D			0.842	0.851	-0.397	-0.403
A	Fine	0 dS/m	0.988	0.963	-0.140	-0.132
B			0.960	0.956	-0.552	-0.538
C			N/A	0.972	N/A	1.417
D			0.971	0.992	-1.087	-1.214
A	Coarse	3 dS/m	0.962	0.951	-0.136	-0.136
B			0.998	0.999	-0.688	-0.661
C			N/A	0.980	N/A	-0.667
D			N/D	0.886	N/D	-0.436
A	Fine	3 dS/m	0.950	0.953	-0.259	-0.263
B			0.882	0.896	-0.526	-0.481
C			N/A	0.923	N/A	1.667
D			0.740	0.950	0.397	-0.624
Notes						
N/A, not applicable due to 24 hr equilibration period						
N/D, not determined since sensors did not register						

Sensor Reading R^2



Sensor Reading Absolute Slope

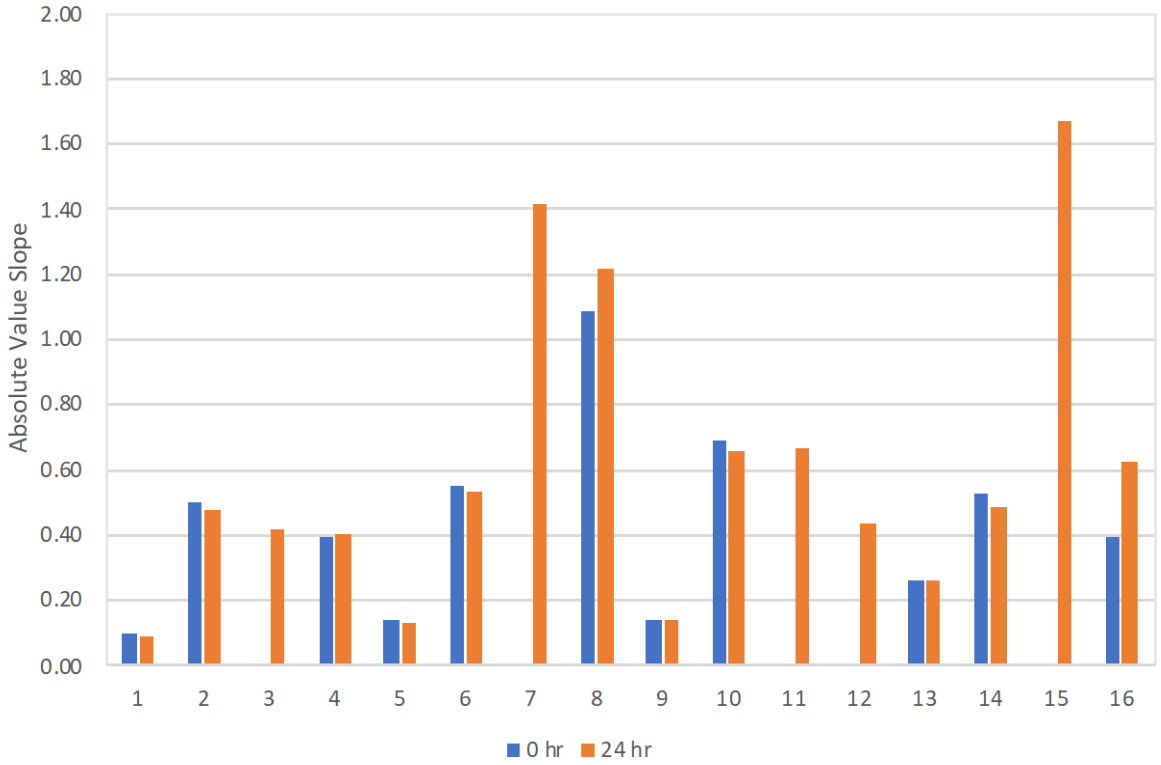
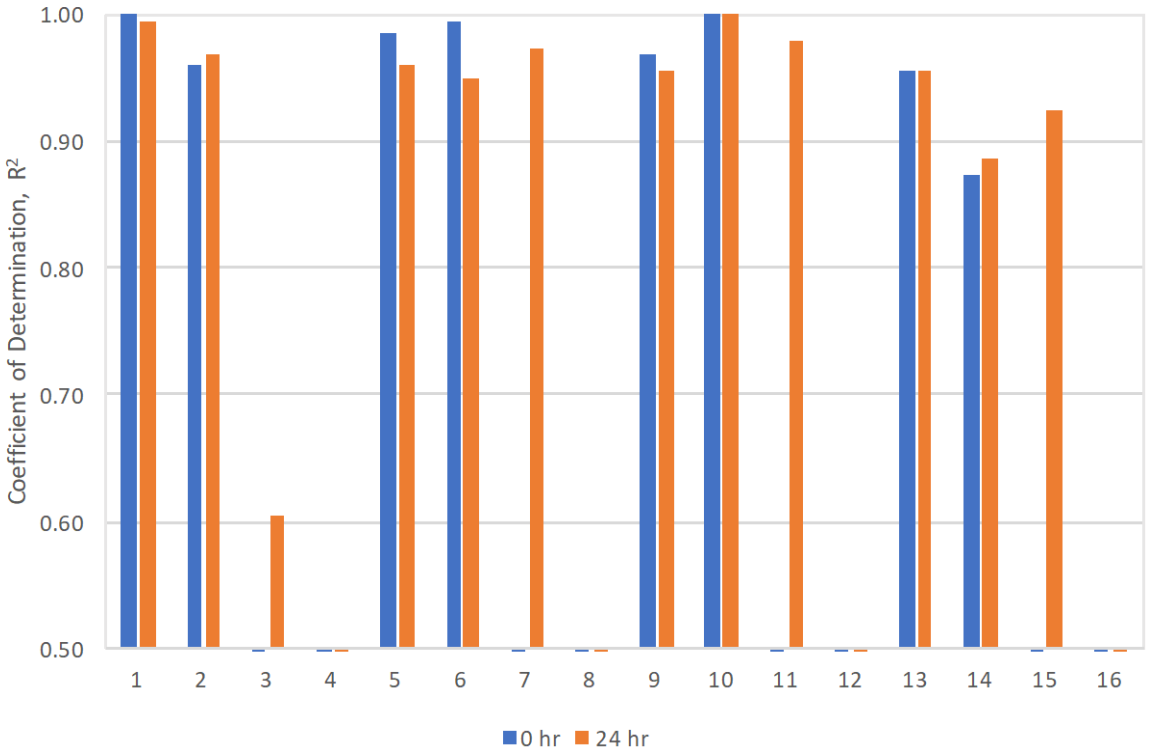


Table of Observed Regression Slopes – Irrigation Enabled

			Irrigation Enabled			
Brand	**Soil**	**Salinity**	**Average Regression R^2**		**Regression Slope**	
			0 hr	24 hr	0 hr	24 hr
A	Coarse	0 dS/m	1.000	0.993	-0.092	-0.088
B			0.961	0.967	-0.193	-0.183
C			N/A	0.605	N/A	0.042
D			N/D	N/D	N/D	N/D
A	Fine	0 dS/m	0.985	0.960	-0.138	-0.129
B			0.993	0.949	-0.211	-0.206
C			N/A	0.972	N/A	0.142
D			N/D	N/D	N/D	N/D
A	Coarse	3 dS/m	0.968	0.955	-0.133	-0.133
B			0.999	0.999	-0.260	-0.252
C			N/A	0.980	N/A	-0.067
D			N/D	N/D	N/D	N/D
A	Fine	3 dS/m	0.955	0.955	-0.254	-0.254
B			0.873	0.886	-0.202	-0.185
C			N/A	0.923	N/A	0.167
D			N/D	N/D	N/D	N/D
Notes						
N/A, not applicable due to 24 hr equilibration period						
N/D, not determined since sensors did not register						

Irrigation Enabled R^2



Irrigation Enabled Absolute Slope

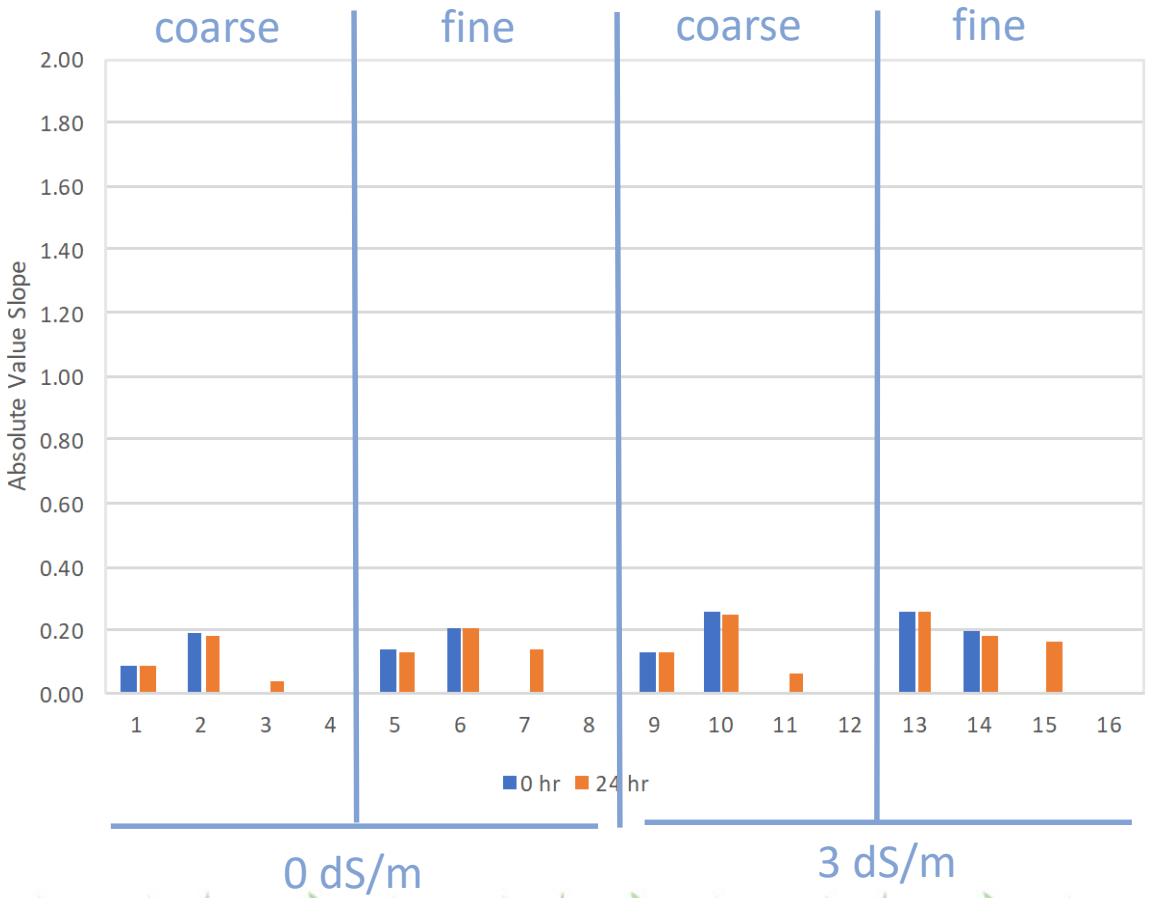
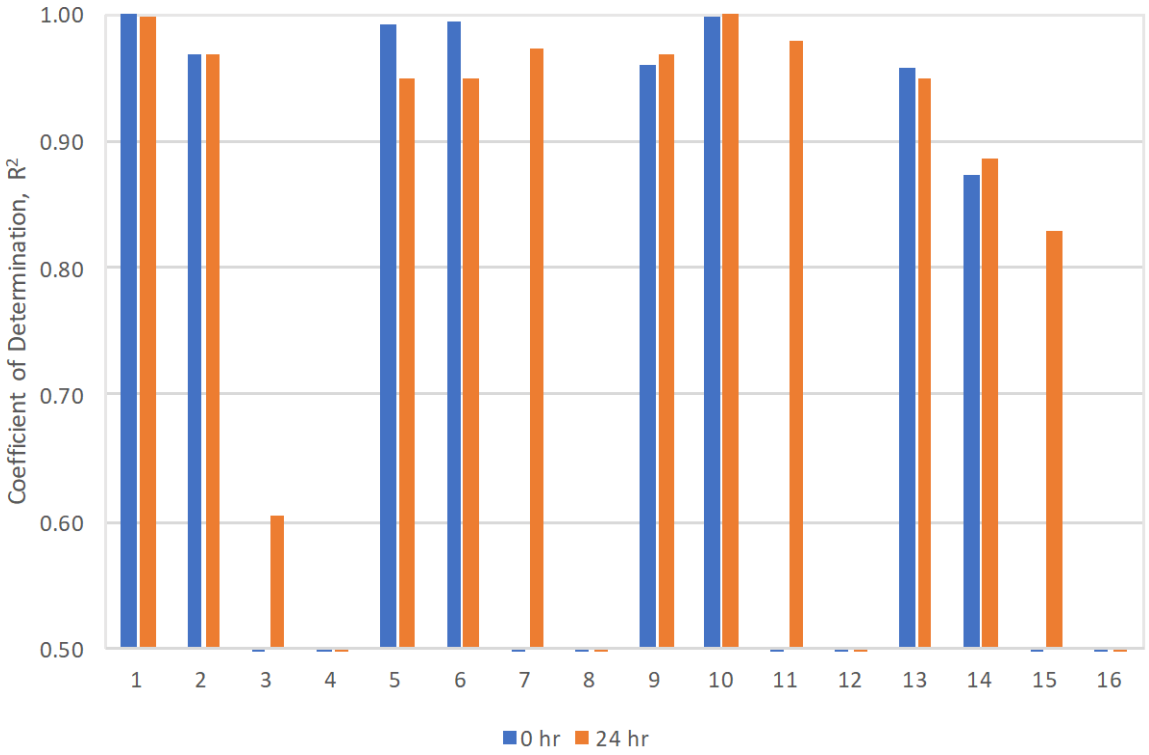


Table of Observed Regression Slopes – Irrigation Disabled

			Irrigation Disabled			
Brand	**Soil**	**Salinity**	**Average Regression R^2**		**Regression Slope**	
			0 hr	24 hr	0 hr	24 hr
A	Coarse	0 dS/m	0.999	0.997	-0.096	-0.092
B			0.968	0.967	-0.198	-0.183
C			N/A	0.605	N/A	0.042
D			N/D	N/D	N/D	N/D
A	Fine	0 dS/m	0.992	0.949	-0.138	-0.125
B			0.993	0.949	-0.211	-0.206
C			N/A	0.972	N/A	0.142
D			N/D	N/D	N/D	N/D
A	Coarse	3 dS/m	0.960	0.968	-0.129	-0.133
B			0.999	0.999	-0.262	-0.252
C			N/A	0.980	N/A	-0.067
D			N/D	N/D	N/D	N/D
A	Fine	3 dS/m	0.957	0.950	-0.250	-0.263
B			0.873	0.886	-0.202	-0.185
C			N/A	0.828	N/A	0.158
D			N/D	N/D	N/D	N/D
Notes						
N/A, not applicable due to 24 hr equilibration period						
N/D, not determined since sensors did not register						

Irrigation Disabled R^2



Irrigation Disabled Absolute Slope

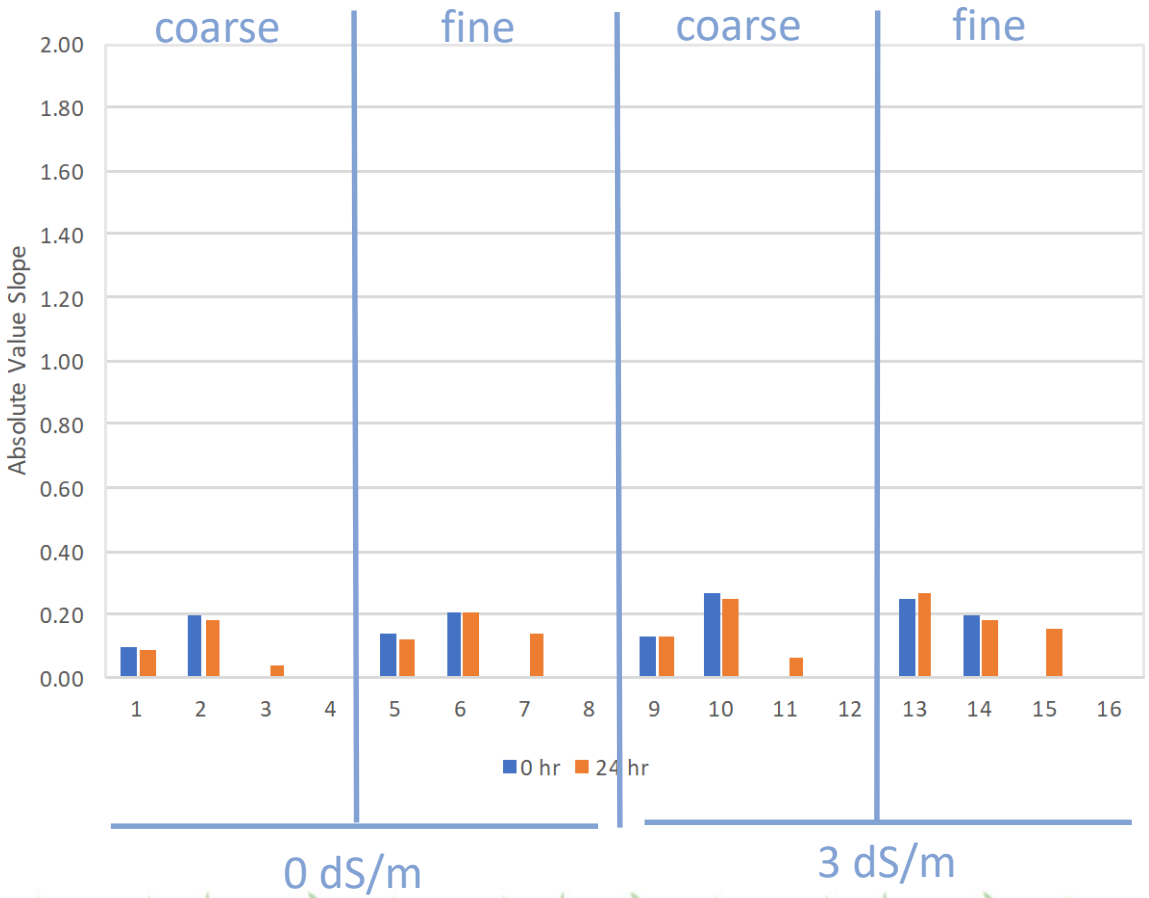
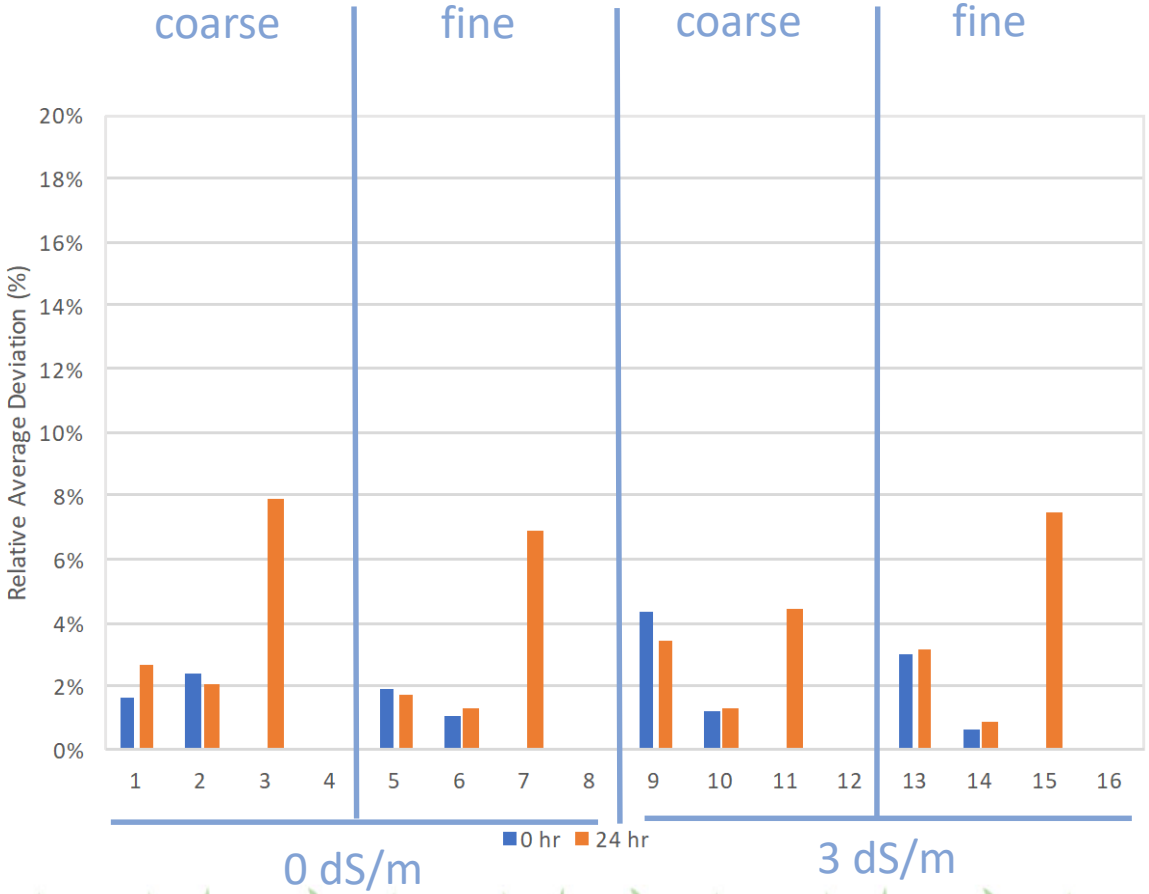


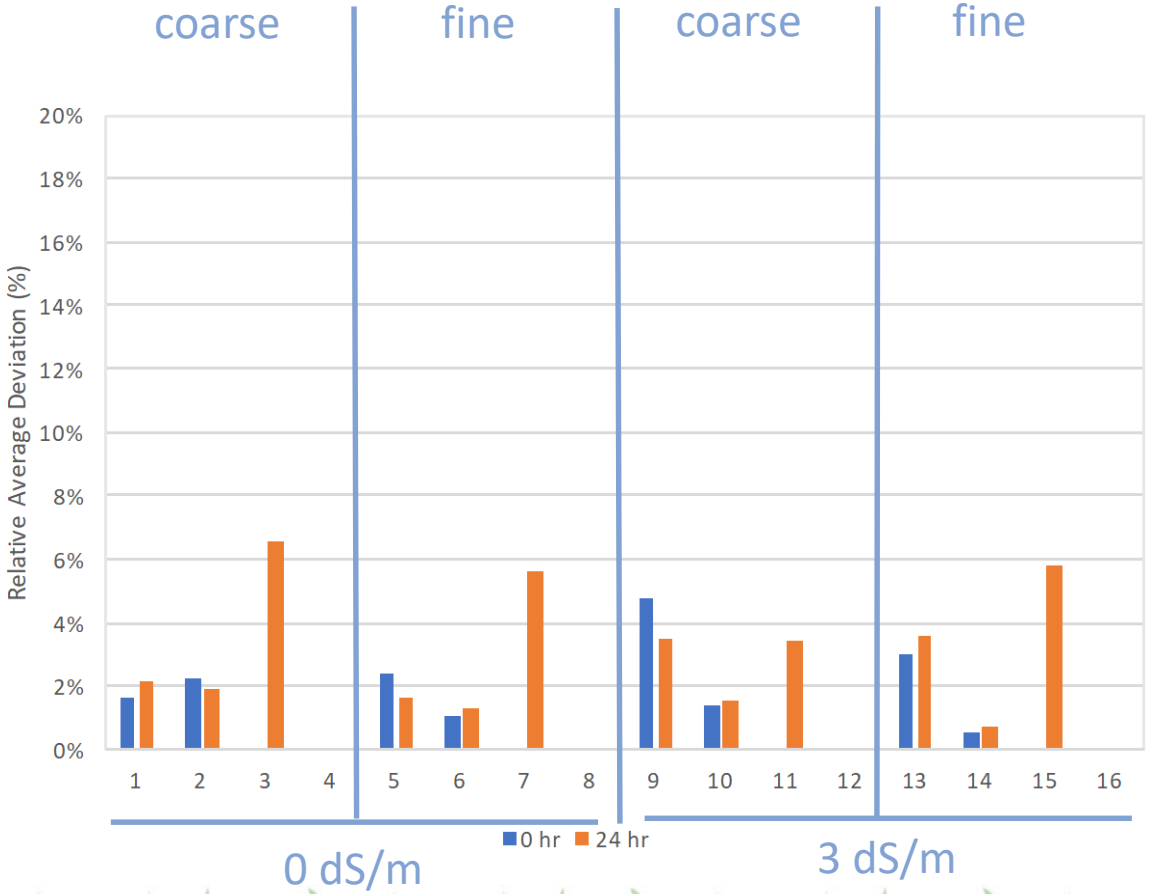
Table of Average RAD

			Average RAD across depletion levels					
Brand	**Soil**	**Salinity**	**Trigger ON**		**Sensor Reading**		**Trigger OFF**	
			0 hr	24 hr	0 hr	24 hr	0 hr	24 hr
A	Coarse	0 dS/m	1.6%	2.2%	1.7%	2.7%	1.7%	2.8%
B			2.2%	1.9%	2.4%	2.1%	2.2%	1.9%
C			N/A	6.5%	N/A	7.9%	N/A	10.1%
D			N/D	N/D	N/D	N/D	N/D	N/D
A	Fine	0 dS/m	2.4%	1.6%	1.9%	1.8%	2.0%	1.5%
B			1.0%	1.3%	1.0%	1.3%	1.0%	1.3%
C			N/A	5.6%	N/A	6.9%	N/A	9.1%
D			N/D	N/D	N/D	N/D	N/D	N/D
A	Coarse	3 dS/m	4.8%	3.5%	4.3%	3.4%	5.2%	3.0%
B			1.4%	1.6%	1.2%	1.3%	1.6%	1.6%
C			N/A	3.4%	N/A	4.4%	N/A	6.3%
D			N/D	N/D	N/D	N/D	N/D	N/D
A	Fine	3 dS/m	3.0%	3.6%	3.0%	3.2%	3.3%	2.9%
B			0.5%	0.7%	0.6%	0.9%	0.5%	0.7%
C			N/A	5.7%	N/A	7.5%	N/A	10.9%
D			N/D	N/D	N/D	N/D	N/D	N/D
Notes								
N/A, not applicable due to 24 hr equilibration period								
N/D, not determined since sensors did not register								

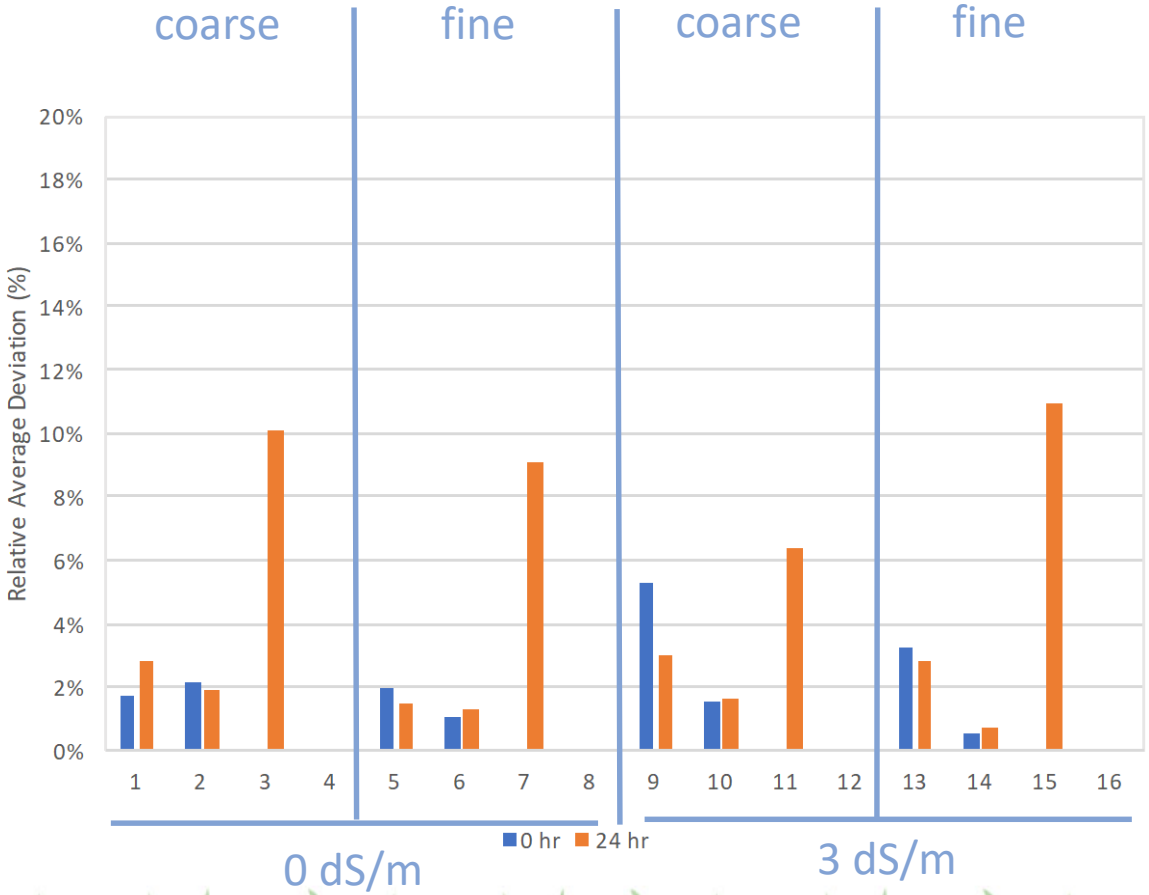
Average RAD Across Depletion Levels, Sensor Reading



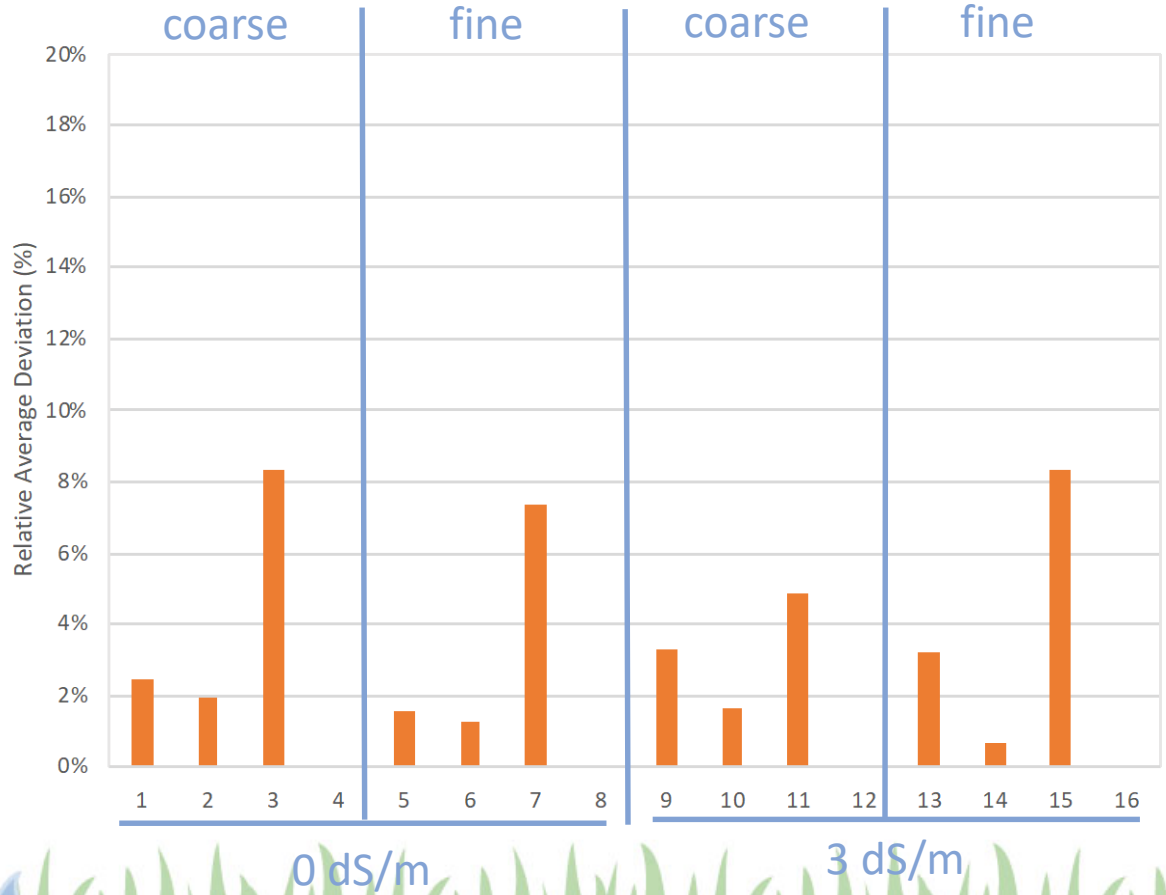
Average RAD Across Depletion Levels, Irrigation Enabled



Average RAD Across Depletion Levels, Irrigation Disabled



Avg RAD 0 & 24 hr Irrigation Enabled & Disabled



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