Lower Colorado River Multi-Species Conservation Program

Balancing Resource Use and Conservation

Laboratory Testing of Lassenite Pozzolan for Use as a Soil Amendment in Habitat Restoration

U.S. DEPARTMENT OF THE INTERIOR
BUREAU OF RECLAMATION

September 2011

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Lower Colorado River Multi-Species Conservation Program

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Lower Colorado River
Multi-Species Conservation Program
Bureau of Reclamation
Lower Colorado Region
Boulder City, Nevada
http://www.lcrmscp.gov

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Introduction

Previous habitat restoration at the Colorado River Indian Tribes' A'hakhav Preserve, (CRIT 9) and the Beal Lake Restoration Area on Havasu NWR has clearly shown that cottonwood and willow require much higher irrigation frequencies in sandy soils than in other soil textures due to the low water holding capacity of sand. Planting cottonwood and willow any distance from irrigation sources is problematic due to the time required to first saturate soils and then move irrigation water across large areas. Willows are particularly difficult to maintain under these conditions.

Restoration sites that are otherwise ideal for inclusion in the LCR MSCP may be excluded due to high pumping costs needed to maintain habitat for some covered species. Increasing soil moisture levels in general is desirable because it may increase habitat quality through natural establishment of native shrubs and groundcover within stands, thus increasing habitat diversity and vegetation density. Increased soil moisture would also contribute to increased tree vigor and survival which may increase insect populations, providing food for insectivorous birds, bats, and small mammals.

In 2006, Reclamation's Denver Technical Service Center conducted a literature and product search of various soil amendments that would possibly improve habitat restoration capabilities at sites containing sandy soils. This study will test the most promising soil amendment that emerged from that work, Lassenite Pozzolan (Lassenite). Lassenite[1] is mined in northern Nevada and has been marketed for use in golf course construction, largely in the deserts of Saudi Arabia. Testing by the distributor has shown it increases the moisture holding capacity of sand and, unlike organic materials, does not breakdown chemically (see Appendix 4). However, Lassenite has not been tested at lower application rates, at deeper rooting depths, or as a means to facilitate moving irritation water across large expanses of sandy soils.

Purpose

Through a series of experiments under laboratory conditions, Lassenite will be tested to determine its potential to improve the condition of sandy soils and increase the ability to create habitat at restoration sites that may be difficult to irrigate due to sandy soil conditions. If results of the experiments show that Lassenite increases the water retention of sand, decreases travel time of irrigation water across and through sand, and persists within the root zone of plants, it has the potential for lowering irrigation frequencies and amounts and therefore pumping costs. Lassenite could then be included in site preparation plans.

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[1] According to the supplier, Western Pozzolan, Lassenite Pozzolan is primarily amorphous silica formed in freshwater lakes from a combination of volcanic ash and diatoms.

Task I: Movement of Lassenite in Soil under Flood Irrigation Simulation

Introduction

The purpose of Task I is to determine if the Lassenite moves down through the soil profile during repeated flushing of water that simulate flood irrigation.

Methods

Four Plexiglas columns approximately 15" high and 15.5" inside diameter were filled with varying mixes of material. The columns were equipped with a bottom drain that could be opened or closed. A base plate immediately above the drain plate contained small holes (Figure 1a) to facilitate drainage throughout the overlying material. This plate was covered with a coarse filter paper to prevent loss of the sand during the test (Figure 1b).

Figure 1a. Column showing drain plate

Figure 1b. Columns at beginning of setup

Reports supplied by the Boulder City office[2] indicated the soil at the site of interest was approximately 97% sand, primarily fine textured. Since this test would rely on visual changes, it was important to use a material that was both similar in texture to the field and significantly different in color from the Lassenite, which is light tan. To meet these criteria, a very pure white sand was obtained from Reade

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[2] 1:Preliminary Analysis of CRIT 9 Revegetation Project: Bertin Anderson & Phillip Russel, Sept., 2001

2: Report of Analysis for Soil Samples: Bur. Of Reclamation Lower Colorado Regional Laboratory, #103107, Oct. 31, 2007

Advanced Materials that had an average grain size of about 150 μm (fine sand)(Figure 2). Figure 3 illustrates the difference in color and texture between the sand and the Lassenite. Figure 4 illustrates the range of mixes used in the study relative to the extremes of 100% sand or 100% Lassenite. For this study, a range of color shades was established for scoring purposes: 0 = pure white sand, indicating no migration of Lassenite; 5 = darkest color possible if all the Lassenite in the column were mixed with the sand.

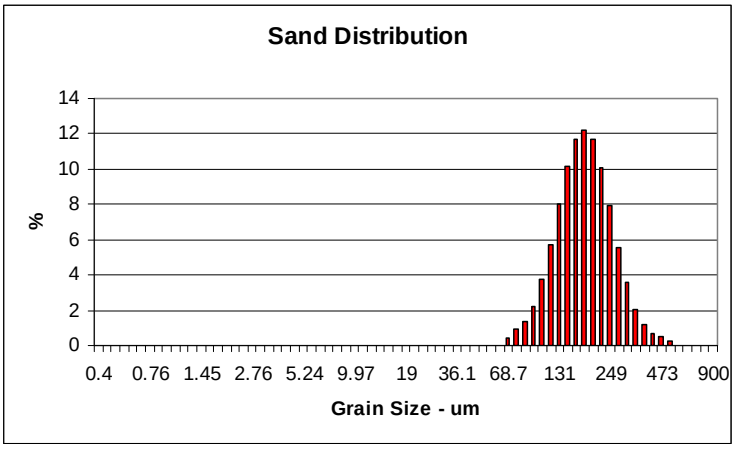


Figure 2. Grain Size Distribution of white sand (plotted from Coulter Particle Size Analyzer)

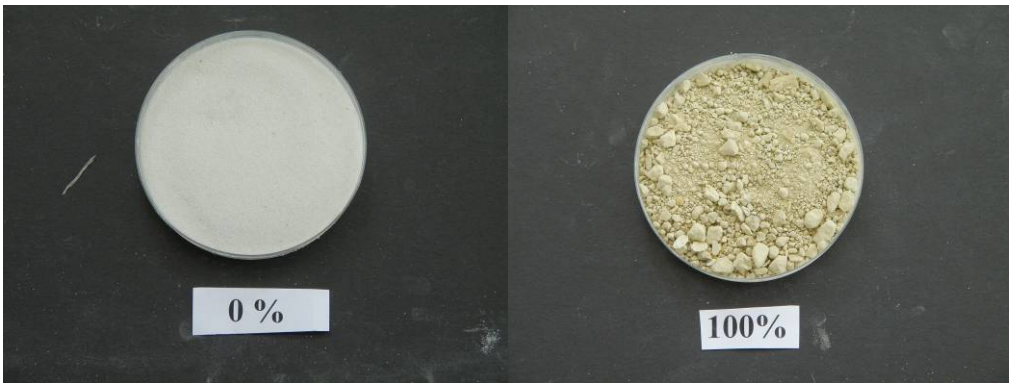


Figure 3. White Sand on Left; 100% Lassenite on Right

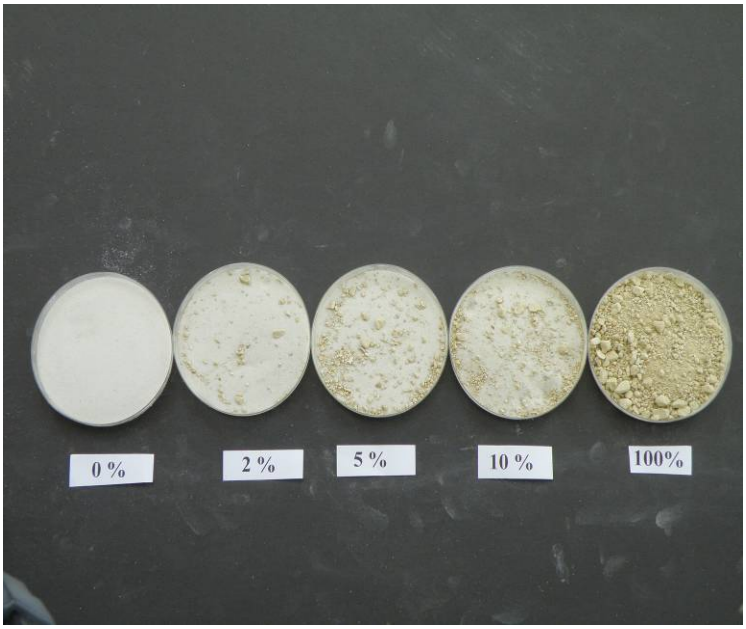


Figure 4. Range of Mixtures were 0% Lassenite on left to 100% Lassenite on right

Column 1 was filled with pure sand to act as the control. Columns 2, 3 & 4 had 3" of pure sand at the bottom. These mixes were chosen to bracket potential mixes to be used in the field. The upper 9" consisted of the following dry weight mixes: Column 2, 98% sand, 2% Lassenite; Column 3, 95% sand, 5% Lassenite; Column 4, 90% sand, 10% Lassenite.

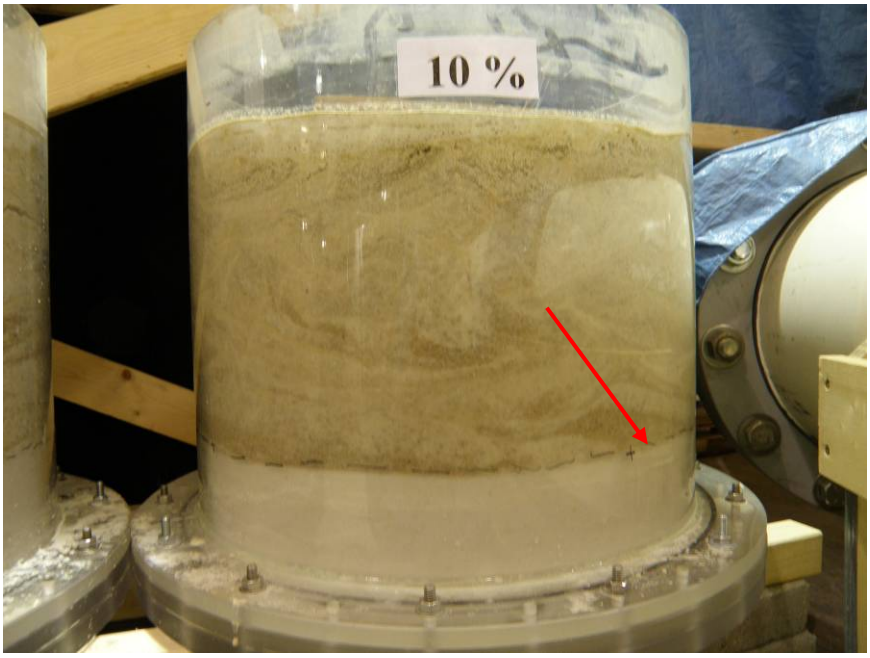


Figure 5. Lower 3" of sand at red arrow; upper 9" of 10 % Lassenite/Sand Mix

Prior to mixing, both the sand and Lassenite were dry. The appropriate mixture for each column was created on a dry-weight basis and mixed before putting it in the column. The columns required a total of approximately 150 lbs. of sand and sand/Lassenite mix. Each column was filled to 12”, leaving 3” of open space at the top. Once the pure sand was placed in the column, it was leveled and smoothed out. A line was then placed around the outside of the column defining the top of the sand (Figure 5). The sand/Lassenite mix was carefully placed on top of the sand so as not to disturb the upper sand surface. No compaction was attempted.

Water was added to each column from a tank placed above the column (Figure 6). Each tank was outfitted with a hose extending to the top of the column, ending with a fine spray nozzle (Figure 7) to prevent erosion while adding the water. During the initial soaking of Replicate A, the drainage valves were closed to measure the amount of water needed to saturate the material.[3] This resulted in high initial moisture readings. Later readings were taken with the valves open.

[3] In this context, saturation is defined as: ‘No additional water will soak into the sample. Any water added will remain on top of the sample as free water.’

Figure 6. Packed columns prior to saturation

Figure 7. Fine spray nozzle attached to end of hose to prevent erosion.

Humidity during the tests ranged from 24% to 37%, and temperature from 67°F to 69°F .[4] Initial saturation of all columns required 12 L – 13 L of water, approximately one pore volume. Two complete sets of 5 flushes (Replicates A and B) were run through each column.

To begin the flushing tests after initial saturation, water was added to each column at a rate to maintain 2”-2.5” of head while soaking into the sand/mix. This continued for 30 minutes while capturing and measuring the drainage. The amount of drainage per flush varied from 5.6 L to 14.5 L. Total amounts flushed through each column were as follows:

Column 1 (Sand)	Replicate A = 50.9 L	Replicate B = 52.5 L
Column 2 (2% Mix)	Replicate A = 38.1 L	Replicate B = 45.2 L
Column 3 (5% Mix)	Replicate A = 40.2 L	Replicate B = 52.2 L
Column 4 (10% Mix)	Replicate A = 36.3 L	Replicate B = 39.6 L

Although the main objective of Task I was to determine movement of Lassenite, moisture readings were also taken immediately prior to and after each flushing, and about once a day for 5 – 7 days, until the

[4] Readings were the average of 2 hygrometer/thermometer gauges (see upper left of Figure 6).

next flushing event (Appendix 1). The moisture readings were taken by inserting a probe into the center of the column at 6” (center of the sand/Lassenite mix) and 9” (underlying sand).

At the end of five flushes, the sand/Lassenite mix was carefully removed down to the interface with the pure sand layer and the sand was visually inspected for any Lassenite that may have migrated downward. The 3” sand layer was removed ½” at a time and inspected for any migrated material.

Results

Both macro- (Figure 8) and micro- visual inspections (Figures 9-11) of the sand below the mixes indicated that no migration of the Lassenite occurred in any of the columns. There were minor irregularities in the boundary surface due to compaction as the columns became saturated that contained very small inclusions of Lassenite, but no Lassenite was visible at ½” below the interface i.e. there was 0% movement of the Lassenite into the sand layer (Figures 4, 8-11).

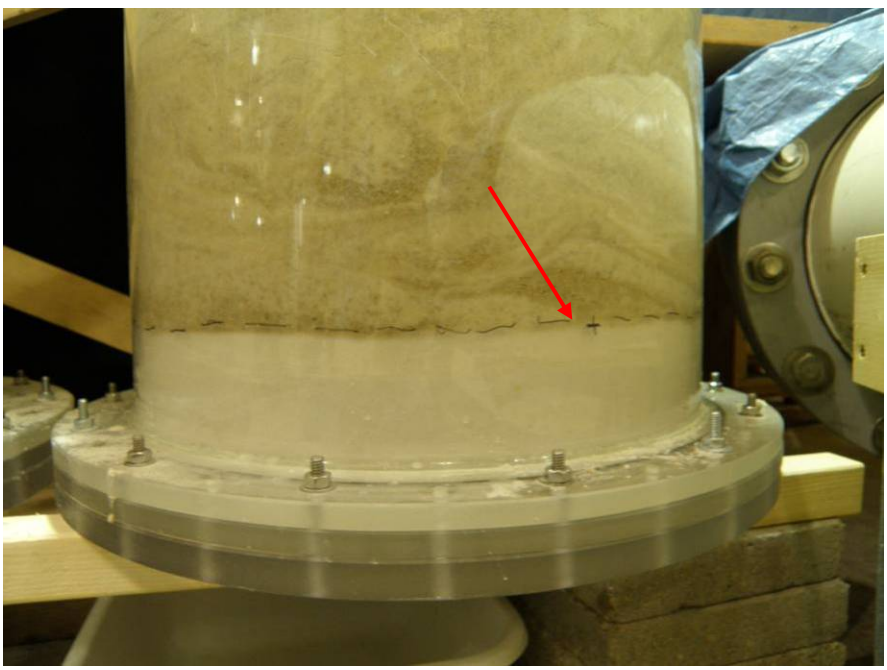


Figure 8. 10% sand/Lassenite mix after 5 flushes, with sharp demarcation between lower sand & upper mix shown by red arrow.

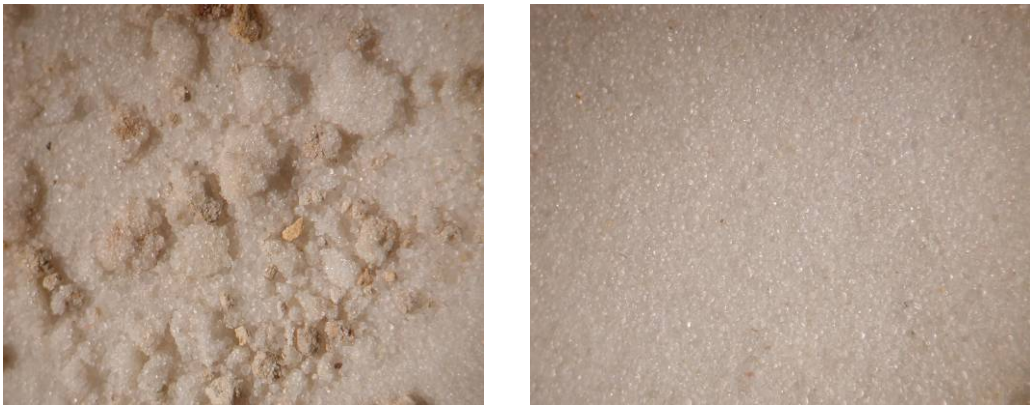


Figure 9. Microscopic view of sand from interface of 2% mix on left; sand ½" below interface on right

Figure 10. Microscopic view of sand from interface of 5% mix on left; sand ½" below interface on right

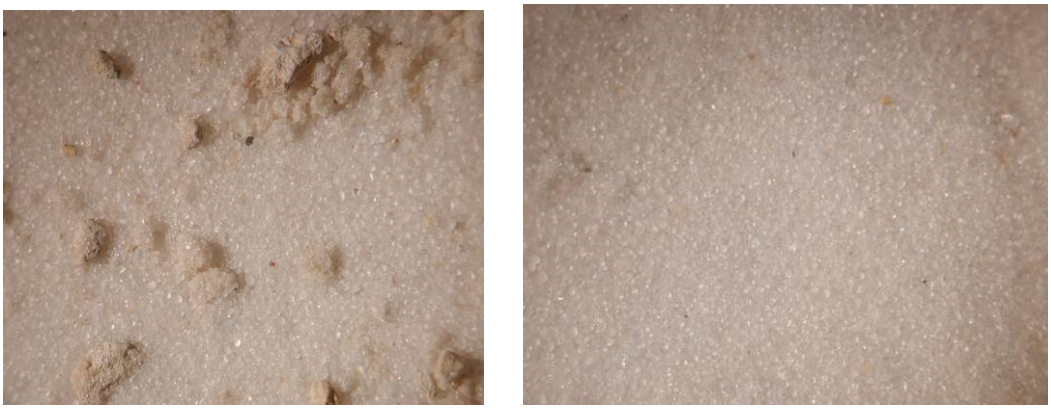


Figure 11. Microscopic view of sand from interface of 10% mix on left; sand ½" below interface on right

While the determination of soil moisture levels was not the primary purpose of Task I, the data does show an increase in soil moisture in the columns with increasing percentages of Lassenite (F= 41.6, df = 3,3, P= 0.006) (Figure 12). However, Lassenite did not affect trends in soil moisture through time (F = 1.04, df = 3,3, P = 0.488), differences in soil moisture between depths (F = 1.75, df = 3,3, P = 0.329) and trends in soil moisture through time between depths (F= 1.19, df = 3,3, P = 0.445) (see Appendix 1, Task I Analysis).

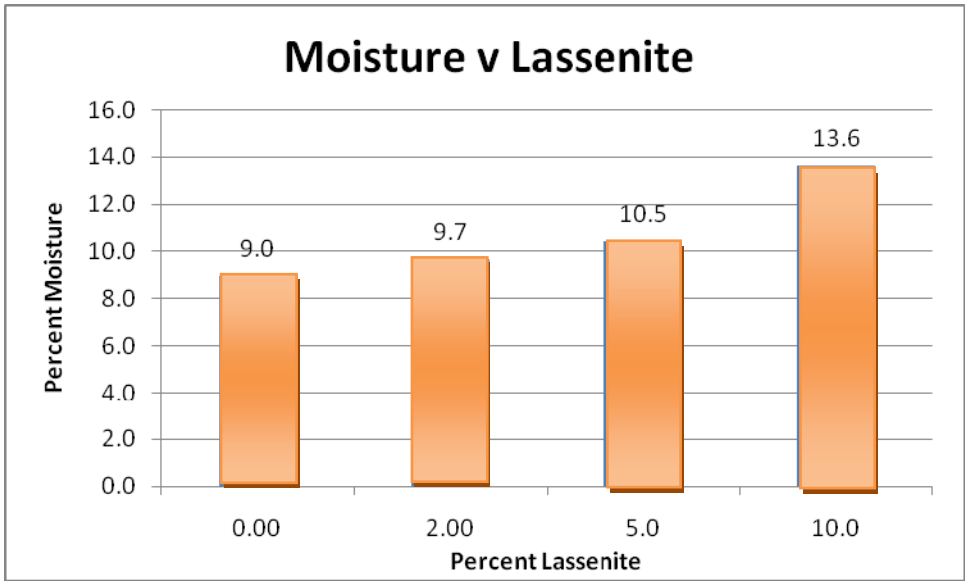


Figure 12. Percent soil moisture increased with increasing percent Lassenite in the soil mixtures.

Discussion

The Lassenite did not migrate under flushing conditions in sand of similar size and gradation to that of the potential field area and would therefore not be expected to do so when applied in the field. Available water content (AWC), is what is left after gravitational water has drained from soils, and is a measure of the amount of water in a soil that is potentially available to plants (Plant Available Water). The 5% and 10% mixes increased the soil moisture to levels above the Plant Available Water content of sand alone, which is approximately 10% (http://ceeldorado.ucdavis.edu/files/45069.pdf). Under lab conditions, soil moisture increased with increasing percentages of Lassenite in the mix (Figure 12). Sensors placed throughout the columns showed a clear difference in soil moisture between treatments.

Task II: Determine soil moisture effects of Lassenite at various application rates at the surface, upper root zone and at measured distances horizontally from the water source.

Introduction

The purpose of Task II was to compare the performance of Lassenite mixed with sand at 2%, 5% and 10% proportions to a control consisting of 100% sand. The moisture holding capacity was tested to determine if moisture within the treatment areas increased, and if so, to determine how long after irrigation the mixes retained moisture. Moisture levels adjacent to the treatment area were also tested to determine how the each mixture of Lassenite affected 100% sand at various distances from the application area of each trough.

The material used in Task II was commercially available sand obtained in the Denver area and selected to be a close match to sandy soils on the lower Colorado in size distribution. Gradation of the sand is shown in Figure 13. This sand was used to fill the 100% sand troughs and as the sand in the mixed troughs. All mixes were made on a weight basis. After the completion of Task II, the troughs were emptied, and the material was discarded.

As a reference to the moisture contents in Task II, the following general criteria are provided: Field capacity (FC) approximates the amount of water that is held in soil after it has been fully wetted and all gravitational water has been drained away. In practice, field capacity is reached 1-2 days after heavy rainfall or irrigation ceases. In sands, this is generally between 7% - 17%. Available water content (AWC), or what is left after gravitational water has drained, is a measure of the amount of water in a soil that is potentially available to plants, and in sands this is normally considered to be moisture content of 5% - 10%. Moisture contents below AWC for a particular material are defined as the Permanent Wilting Point (PWP), and for sands are considered to be between 2% and 7%.

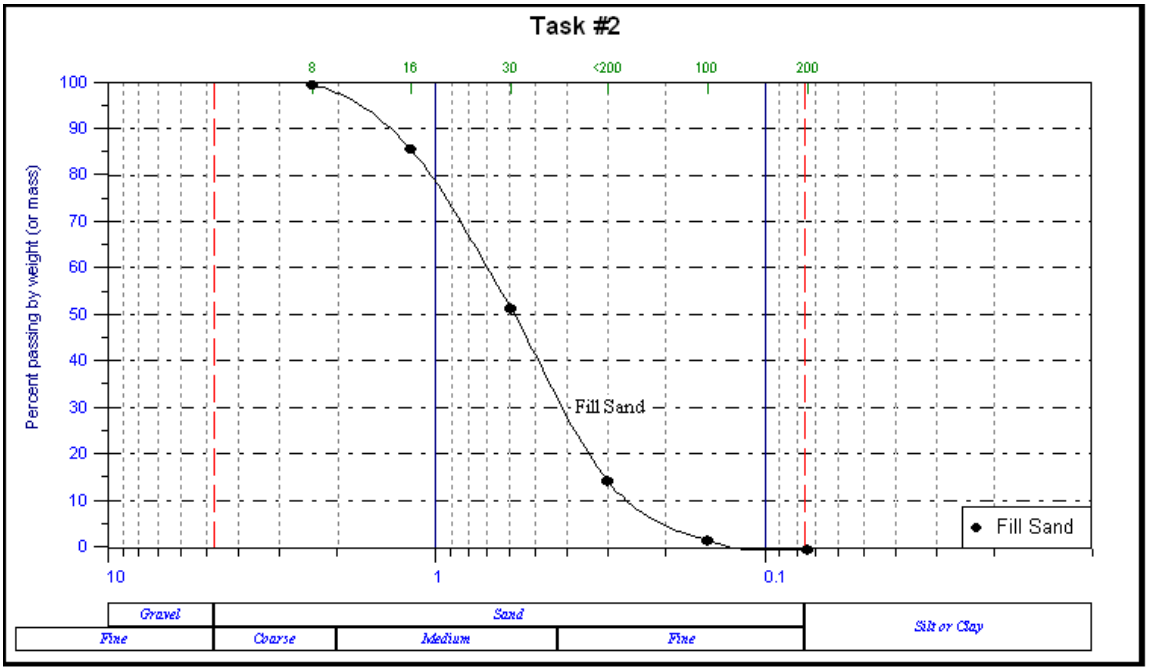


Figure 13. – Gradation of fill sand used for Tasks II & III.

Moisture sensors used were Decagon Devices, Inc., EC-5 (Figure 14). These sensors measure volumetric water content (VWC), as opposed to gravimetric water content. Decagon states that most saturated soils have a VWC of 40–60%, and in-house laboratory testing of these sands indicated their saturation level was 40-45%. Product information supplied by Decagon indicates these sensors have a VWC measurement range of 0-100%, sensor accuracy of 3%, with resolution of 0.1%. In-house testing indicated a standard deviation between sensors of less than 1% at 10% moisture and 1.8% at 40% moisture.

Figure 14. Moisture sensors used in Tasks I, II, and III.

Methods

A series of four troughs, 6’ long, 3’ deep and 1.5’ wide, were constructed (Figure 15) with 2 bottom drains in each trough. A 3” layer of gravel was placed in the bottom of each trough extending 2’ from the end where water would be applied (Figure 16). One trough was filled to the 3’ level with only sand as a control. In the other 3 troughs, 100% sand was placed up to the 18” level. Above that and at the same end as the gravel, treatments mixes extended outward 2’ (Figure 17). The treatments were 2%, 5%, or 10% Lassenite. The Lassenite mix was placed only at one end of the trough in order to test its effect on the moisture levels in the surrounding sand. Seven sensors were horizontally centered at various distances and depths from the water source, as shown in Figure 18 and Table 1.

Figure 15. Task II troughs, 6'L x 1.5W x 3'D.

Figure 16. 3" gravel pack in bottom of trough.

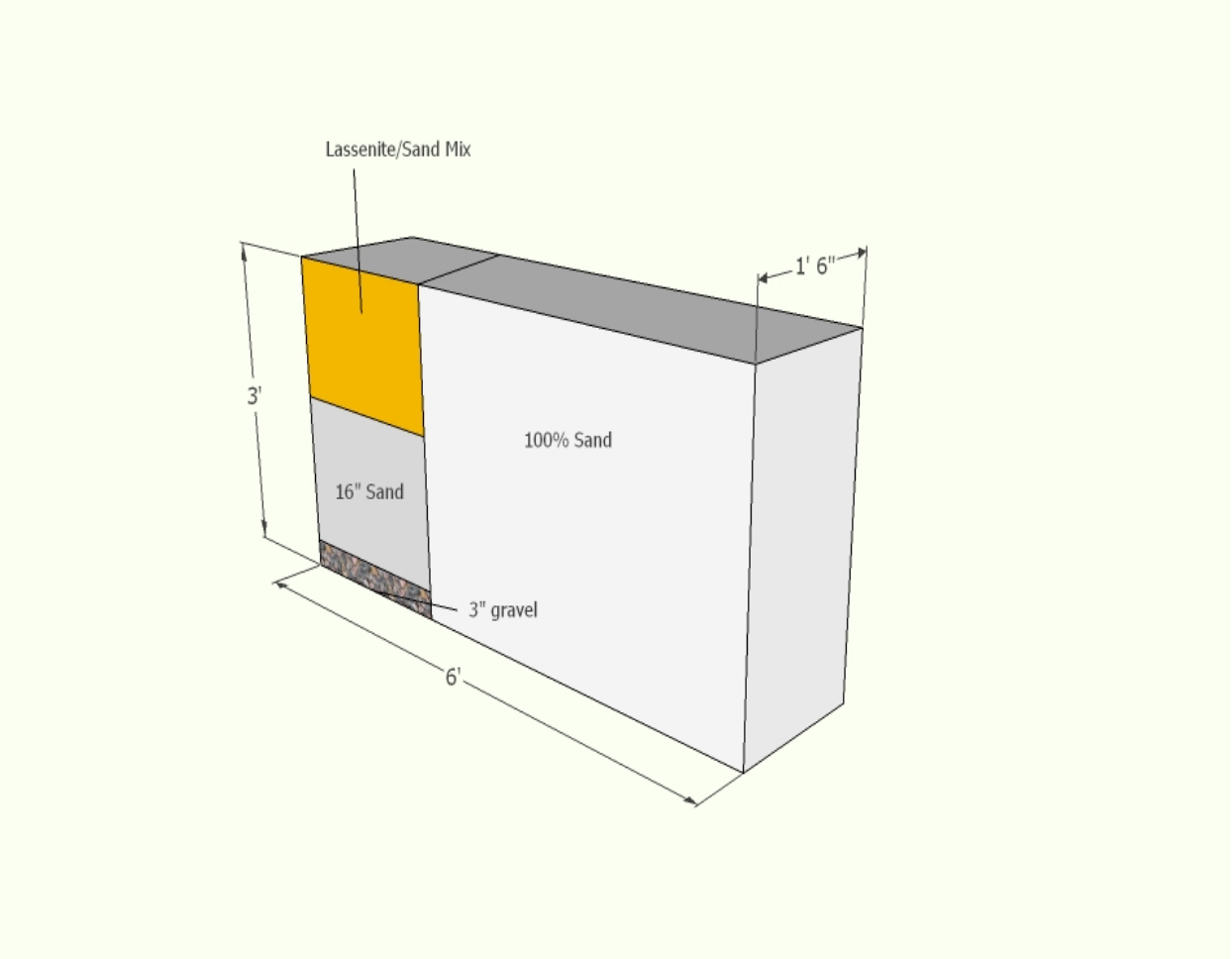


Figure 17. Configuration of Task II troughs. The treatment area is shown in orange.

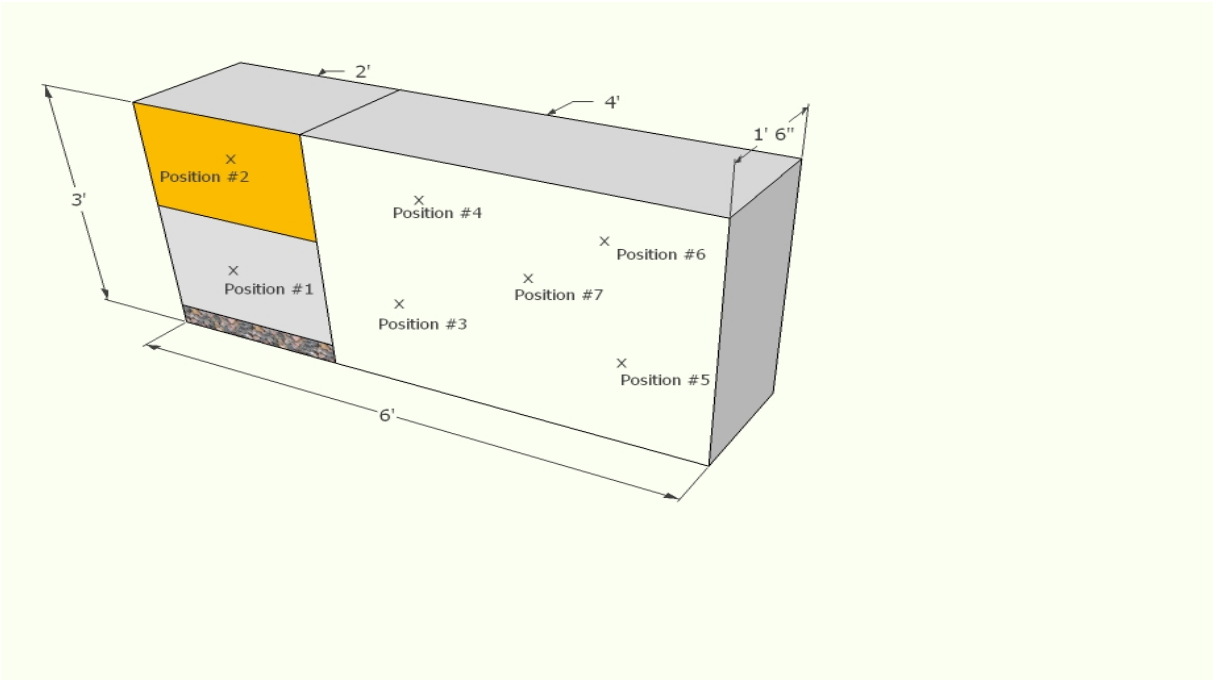


Figure 18. Sensor positions for Task II. Position 2 is within the treatment area in Troughs 2 (2% Lassenite), 3 (5% Lassenite), and 4 (10% Lassenite). Sensors placed in Positions 1, 3, 4, 5, 6 and 7 were to detect effects of the Lassenite on adjacent sand. Trough 1 was a control filled with 100% sand.

Sensor Location			Sensor #s by Trough # and Treatment Mixes			
Position	**Distance**	**Depth**	**Trough #1**	**Trough #2**	**Trough #3**	**Trough #4**
			100 % Sand	2% Lassenite/Sand mix	5% Lassenite/Sand mix	10% Lassenite/Sand mix
#1	1’	2’	1	8	15	22
#2	1’	9”	2	9	16	23
#3	3’	2’	3	10	17	24
#4	3’	1’	4	11	18	25
#5	5’	2’	5	12	19	26
#6	5’	1’	6	13	20	27
#7	4’	1.5’	7	14	21	28

Table 1. Distances and depths of the sensors placed in the troughs in Task II.

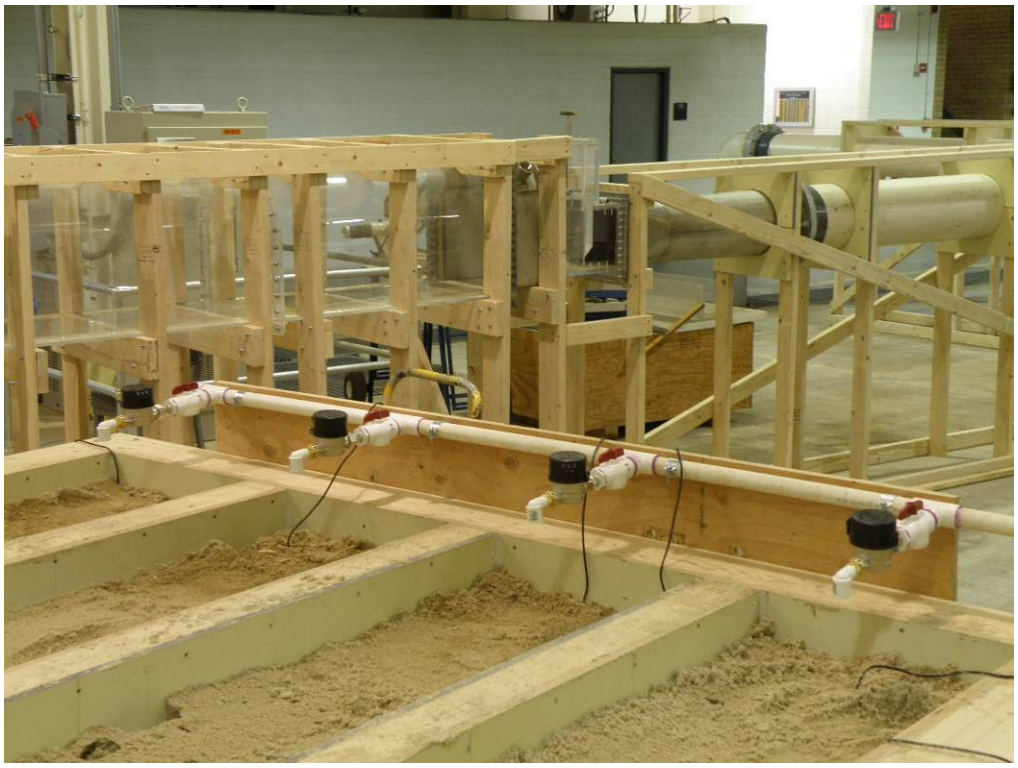


Figure 19. Water input manifold.

A manifold was attached to one end of the troughs for the application of water. Above each trough was a valve fitted with a flow meter (Figure 19) that measured the output to 0.1 gallons.

Attached to the valves was a short length of hose with a sprinkler to allow for a gentle application of the water to prevent erosion (Figures 20 and 21). Water was only added above the first 2’ of each trough and its dispersal downward and outward from that point was monitored with the sensor array. Water was not added along the entire length of the trough in order to determine the effect of the Lassenite on the moisture of the surrounding sand.

Figure 20. Sprinkler setup used for Task II.

Figure 21. Water source for Task II.

The bottom drains were closed and water was added to each trough until saturation[5] was achieved, as determined by the moisture readings from the sensors. This required between 57 and 58 gallons per trough. The drains were then opened and the moisture was monitored over the course of the next month. At the end of the month, the troughs were emptied, refilled, and the test was replicated. Graphs of each sensor performance and data for Replicates A and B are included in Appendix 2.

Results

Analysis was performed on data collected *after* saturation was achieved within each trough and the drains were opened. The soil moisture was monitored and recorded from the time the drains were opened until the experiment ended approximately 30 days later (Figures 22 & 23). Temperature and humidity were not controlled during the experiments, but existing conditions were recorded. Temperature and humidity during the 30 day period after the drains were opened is in Appendix 2, Tables 2-1 and 2-2. Temperatures ranged from 62-66° F and humidity ranged from 29-47%.

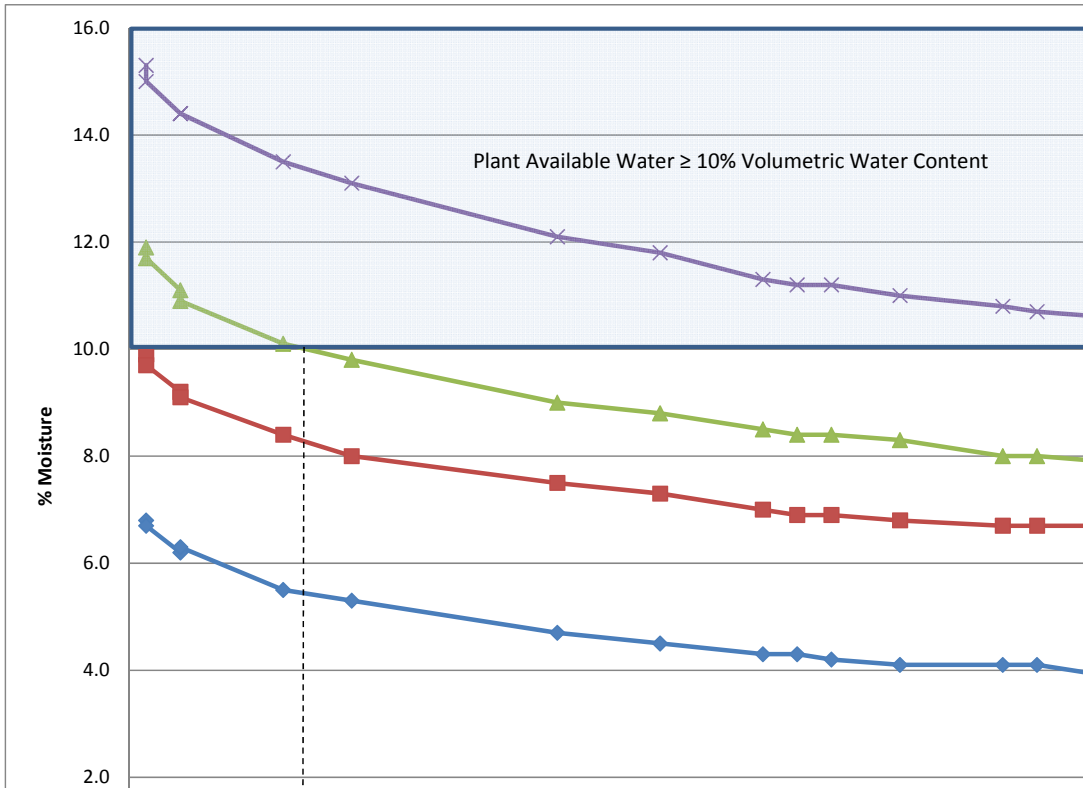


Figure 22. Percent Soil Moisture over Time, Replicate A. On April 8, 2010 the soil within the troughs was completely saturated and the drains were opened. All data presented in this figure is from position #2 within each trough (9 inches below the surface). Neither, the control trough (Sand) or the 2% mixture could retain plant available water. However, the 5% mixture held plant available water for 6 days after the drains were opened, and the 10% mixture held plant available for the entire duration of the experiment (33 days).

[5] Defined here as free water at the surface of the trough.

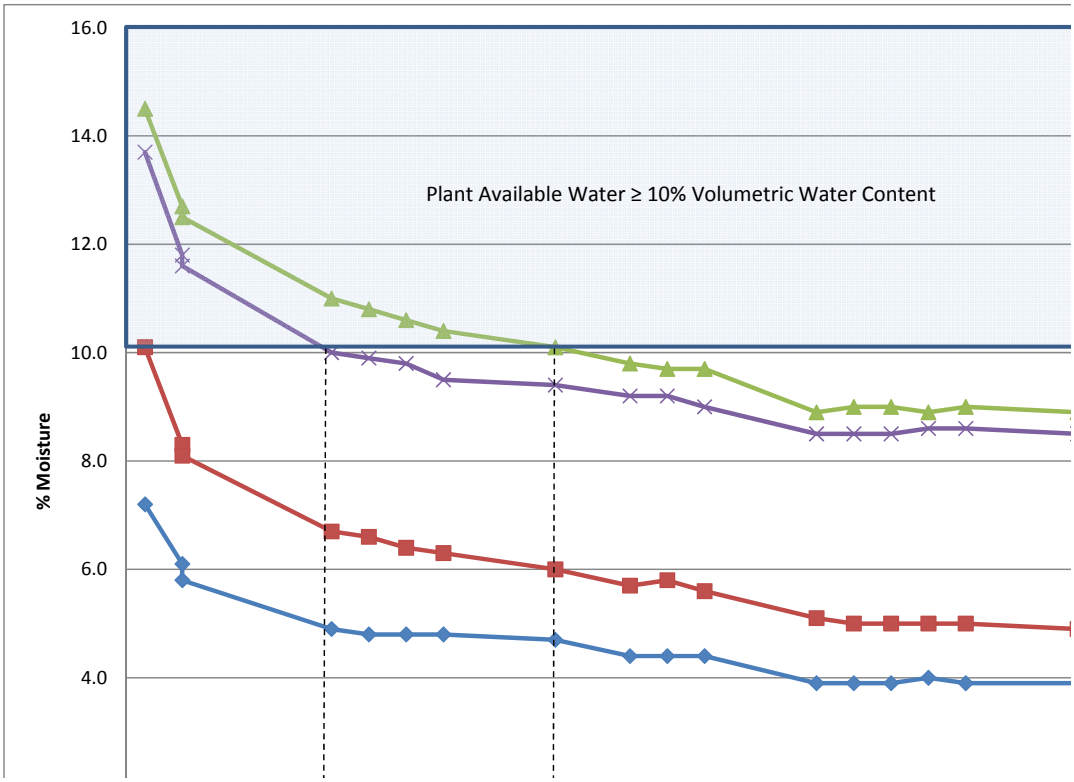
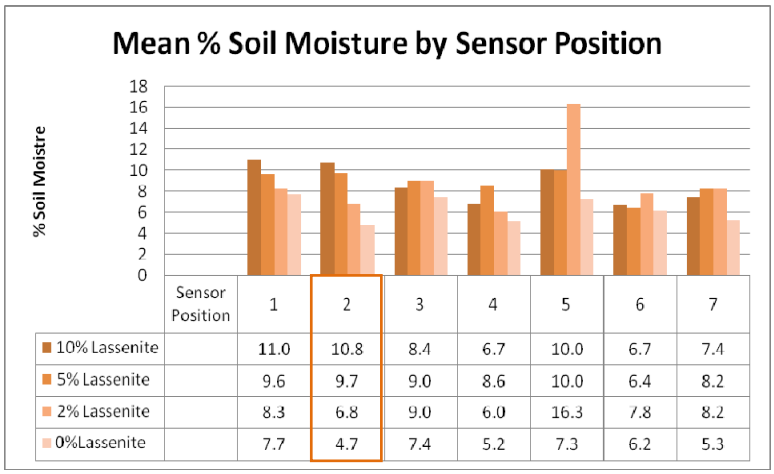


Figure 23. Percent Soil Moisture over Time, Replicate B. On May 27, 2010 the soil within the troughs was completely saturated and the drains were opened. All data presented in this figure is from position #2 within each trough (9 inches below the surface). Neither the control trough (Sand) or the 2% mixture could retain plant available water. However, the 10% mixture held plant available water for 5 days after the drains were opened, and the 5% mixture held plant available water for 11 days.

Data from this "drying out" phase is shown below the yellow line in Tables 2-1 and 2-1, Appendix 2. When the soil moisture data from all sensors within each trough was analyzed using ANOVA, the addition of Lassenite had no significant effect on the soil moisture *of the adjacent sand* at any distance[(1) overall soil moisture ($F = 2.14$, $df = 3,3$, $P = 0.27$); (2) trends in soil moisture thru time ($F = 0.68$, $df = 3,3$, $P = 0.62$); (3) distribution of soil moisture among sensors ($F = 1.53$, $df = 18,18$, $P = 0.19$), or (4), trends in soil moisture thru time among sensors ($F = 1.75$, $df = 18,18$, $P = 0.12$)] (See Appendix 2, Analysis Task II).



	Sensor Position	1	2	3	4	5	6	7
10% Lassenite		11.0	10.8	8.4	6.7	10.0	6.7	7.4
5% Lassenite		9.6	9.7	9.0	8.6	10.0	6.4	8.2
2% Lassenite		8.3	6.8	9.0	6.0	16.3	7.8	8.2
0%Lassenite		7.7	4.7	7.4	5.2	7.3	6.2	5.3

Figure 24. Mean soil moisture increased with increasing Lassenite percentages, but was statistically signifcant only at Sensor Position 2 (results outlined in orange).

Soil moisture did increase with increasing percentages of Lassenite (Figure 24). However, only Sensor Position 2 was *within* the treatment areas of each trough (see Figure 18), the other sensors were placed at various distances from the application site to determine the effect of Lassenite on adjacent 100% sand areas. An ANOVA test detected a significant difference based on sensor position within each trough (Table 2). When the data from just Sensor Position 2 in each trough was analyzed with Tukey's Test to compare the effect of the Lassenite at the different application rates, results significantly differed for both the 5% (P =0.04) and 10% (p= 0.026) mixes when compared to the control troughs containing 100% sand. Analysis of the data from the each of the other 6 Sensor Positions did not detect a significant difference when compared to the control trough (Table 3).

Sensor Position	F (df 3,3)	P Value
1	1.80	0.32
2	15.54	0.025
3	0.62	0.65
4	2.58	0.23
5	0.72	0.60
6	0.68	0.62
7	2.14	0.28

Table 2. ANOVA Results by Sensor Position

Comparison	0% vs 2%	0% vs 5%	0% vs 10%	2% vs 5%	2% vs 10%	5% vs 10%
P Value (df 3,3)	0.26	0.042	0.026	0.19	0.094	0.76

Table 3. Tukey's Tests Comparing Means of 4 Lassenite Treatments at Sensor 2

Discussion

With the intent of determining if the use of Lassenite for restoration purposes is economically feasible, the proportions used in the mixes were chosen to determine the *least* amount of Lassenite that could have a significant effect on irrigation amounts and frequencies. Task II was designed to test not only the soil moisture within the treatment areas, but also throughout the trough to determine how far from the application site Lassenite could be expected to have an effect. Figures 2-3a&b in Appendix 2 graph the responses of the sensors at Position 2, located in the treatment areas. These results are similar to what is expected of the product based on the literature available. However, no effects of Lassenite resulted when all sensor positions are analyzed together. This is because there were 6 sensors within each trough located in 100% sand and only one in the treatment area, at Sensor Position 2. The results of the sensors in 100% sand essentially "swamped" the results from Sensor Position 2.

The 5% and 10% mixtures demonstrated under laboratory conditions the ability to retain soil moisture at levels above the Plant Available Water Content of sand alone, which is approximately 10% (http://ceeldorado.ucdavis.edu/files/45069.pdf) (Figures 22, 23, and 24). Based on the results of this analysis, it is recommended that a minimum of 10% Lassenite Pozzolan by volume be used in further demonstrations in the field to amend sandy soils. Results from these experiments are based on laboratory conditions i.e. temperatures and humidity levels are not what is found at potential field sites on the lower Colorado River. However, the product has been used in desert environments to develop golf courses in Saudi Arabia (Appendix 4) where conditions are similar to the LCR.

Task III: Determine if Lassenite decreases the amount of time water is transported across and through sand, and if it slows drying time, during simulated flood irrigation events

Introduction

For a full description of materials and equipment used in Task III, see Methods and Figures for Task II.

Methods

The same troughs used for Task II were expanded to 12' long and an additional drain was added so that there were drains at 3', 9', and 11' from the water source[6]. Two troughs were filled with sand and two were filled with a mix of the sand and 5% Lassenite (by weight) to a height of 3'. Troughs 1 and 2 were 100% sand, and Troughs 3 and 4 contained a 5% Lassenite mix. The mixing was done using a 1 cubic yard concrete mixer (Figure 25). The 4 cu.yds. of material needed to fill the 2 mixed troughs were combined and dumped into the troughs by means of a forklift dump cart (Figure 26) so that the material in those two troughs was as uniform as possible. The 100% sand troughs were filled the same way.

Figure 25. Concrete mixer used for Task 3

[6] All distances are referenced from the end of the troughs with the water input.

Figure 26. Filling troughs for Task 3.

After the material was loaded into the troughs, it was leveled to the 3’ mark (Figures 27 & 28) and all moisture sensors were placed in the sand troughs and in most positions in the mixed troughs (Tables 2 and 3, and Figure 29).

In the 5% mixed troughs, a furrow 6” wide and 6” deep was created using a wooden form (Figures 30 and 31) and filled with 100% Lassenite (Figure 32). This furrow was placed to determine if it would facilitate the movement of water across the 12’ trough. The remaining sensors were then placed directly in the furrows, for a total of 21 sensors in each trough (See Table 2 for specific locations).

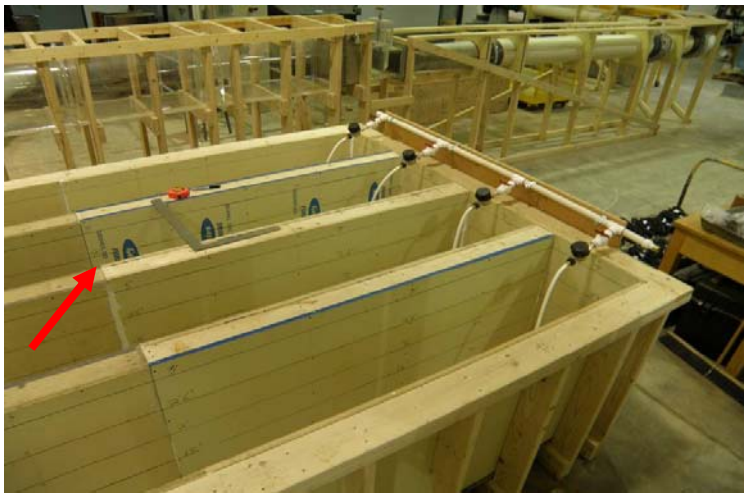


Figure 27. Empty troughs with 3’ level marked.

Figure 28. Filled & leveled trough.

		Sensor Numbers by Position in Troughs				
Trough #	Fill Material	Position 1*	Position 2*	Position 3*	Position 4*	Position 5*
1	Sand	1-4	5-7(left) 8-10 (right)	11-12 (left) 13-14 (right)	15-18	19-21
2	Sand	22-25	26-28 (left) 29-31 (right)	32-33 (left) 34-35 (right)	36-39	40-42
3	5% Mix	43-46	47-49 (left) 50-52 (right)	53-54 (left) 55-56 (right)	57-60	61-63
4	5% Mix	64-67	68-70 (left) 71-73 (right)	74-75 (left) 85,77 (right)	78-81	81-84

Table 2. Sensor numbers and Positions by Trough, Task III.

Note: All sensor numbers within a position increase from the water source toward the end of the trough, except for sensor #85 which was a substitute.

***Position 1 - In furrow, 3" deep, @ 3',6',9', 11.5'**

***Position 2 – Parallel to furrow, midway between side and furrow, 3" deep, @ 3',6',9'**

***Position 3 – Parallel to furrow, midway between side and furrow, 9" deep, @ 4',8'**

***Position 4 – Directly beneath furrow, 9" deep, @ 3',6',9', 11.5'**

***Position 5 – Directly beneath furrow, 12" deep, @ 4', 8',11'**

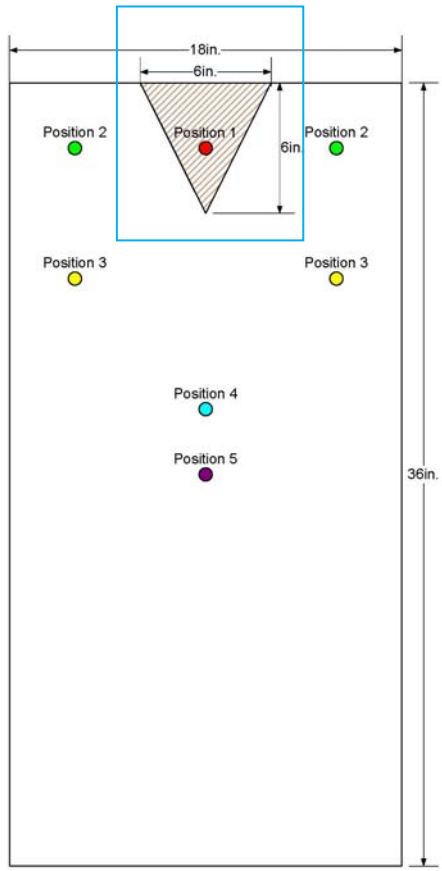


Figure 29. Cross-section of trough showing sensor positions (area in blue box is in Figure 31).

Position	Depth of Sensor	Distance of sensors from water source
1	3 inches	3 ft, 6 ft, 9ft, 11.5 ft
2	3 inches	3 ft, 6 ft, 9ft
3	9 inches	4 ft, 8 ft
4	9 inches beneath furrow	3 ft, 6 ft, 9 ft, 11.5 ft
5	12 inches beneath furrow	4 ft, 8 ft, 11 ft

Table 3. Sensor positions and locations within troughs (depth and distance from water source).

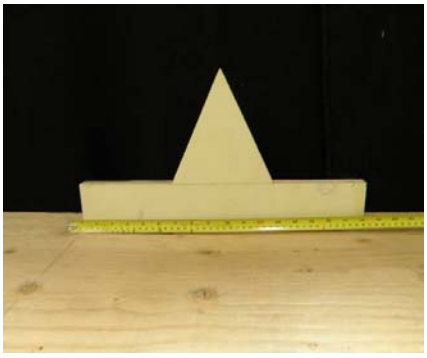


Figure 30. Furrow template.

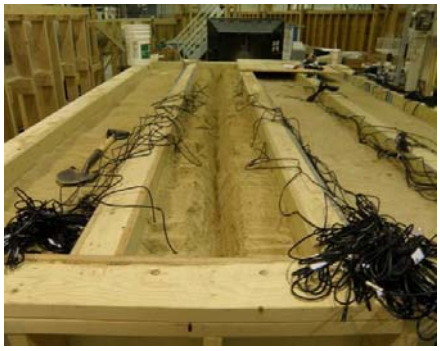


Figure 31. Furrow prior to filling with Lassenite (See Figure 29).

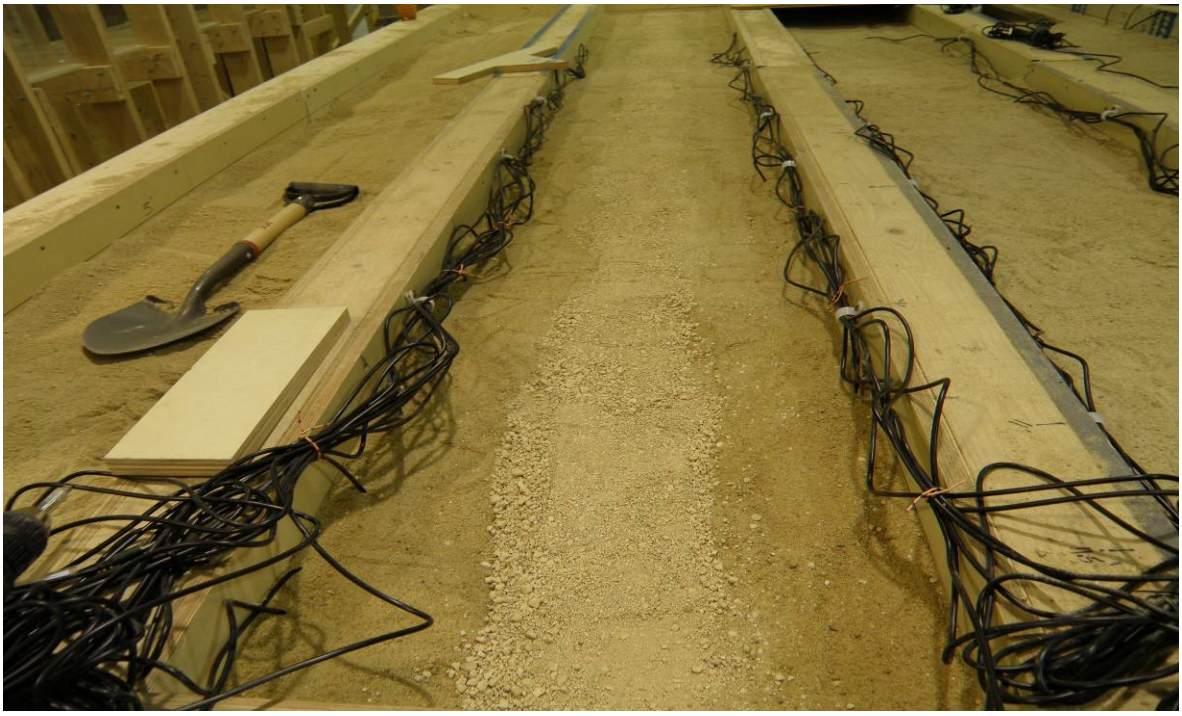


Figure 32. Furrow filled with Lassenite prior to start of Task 3.

Each trough was outfitted with a flow meter, as in Task II, but the sprinklers were removed to provide a direct flow at the end of the troughs to simulate flood irrigation. Gravel was placed on top of both the sand and mixed troughs for a distance of approximately 18” to prevent erosion while water was applied (Figure 33).

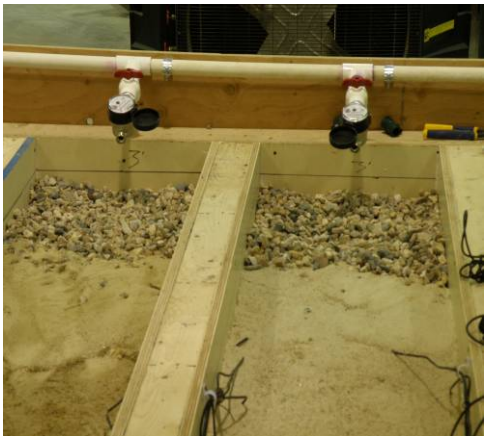


Figure 33 - Gravel for erosion control.

Figure 34. Wetting of troughs prior to Task 3.

Initial readings were taken to document moisture levels prior to the start of the test. The test was to consist of 5 irrigation events, one day apart for 5 consecutive days. One week prior to the start of the five irrigation events the material in the troughs was saturated (Figure 34) to enhance settling of the material for more uniform packing. Water was applied evenly over the length of the trough (during this phase only) until water began to drain from the bottom drains. This required 102 gallons over the course of about 30 minutes. The same amount of water was then applied to each of the three other troughs at the same rate. The troughs were then left for one week to stabilize.

One result of the initial saturation was that approximately 2' of test soil nearest the flow meters settled 3 to 4 inches (Figure 35), while the rest of each trough settled about 1 inch. Figure 36 shows the difference between a trough that settled after wetting, and one that has not yet had water applied (note the 3' line on the inside of the troughs).

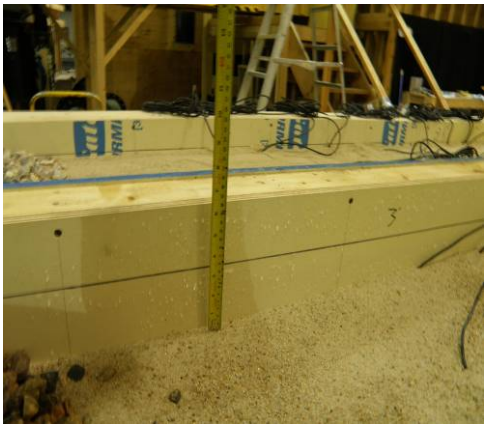


Figure 35. Compacted end after settling.

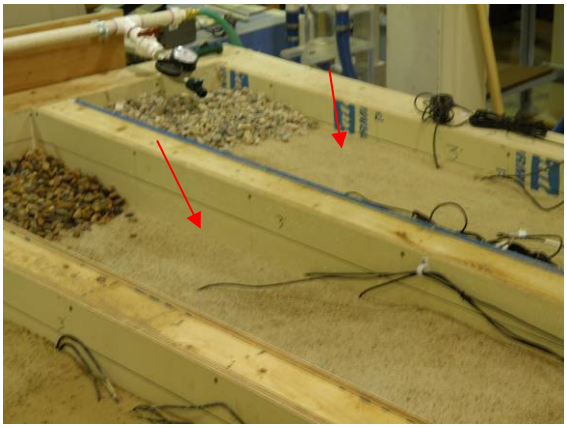


Figure 36. Compacted vs. uncompacted soil in troughs.

Additional sand or Lassenite mix was added in the first 2' of the length of the trough to bring the level of material up to maintain a level surface. It was felt this would not affect the tests because the first sensors were located 3' from that end.

Testing began one week after the material in the troughs was completed saturated. Water was added to one Lassenite trough through the flow meter at the rate of approximately 2.5 - 3 gallons/minute. The test was designed to run until water reached the end of the trough and the sensor at the 11.5' position in the furrow began to show an increase in moisture. This amount of water, at this rate, would then be applied to all troughs each day. Trough 4 was arbitrarily chosen as the standard and the valve was opened (Figure 37). After 10 minutes and 25 gallons, the water had reached the end of the trough and the 11.5' sensor was showing an increase in moisture. Therefore, 25 gallons over the course of approximately 10 minutes was added to each trough each day for a total of 5 consecutive days (i.e. 5 irrigation events). Moisture readings were taken prior to each test, and 15 minutes after the flow of water ceased. Additional readings were taken for a period of 2 weeks after the last 'irrigation' event. All data are included in Appendix 3.

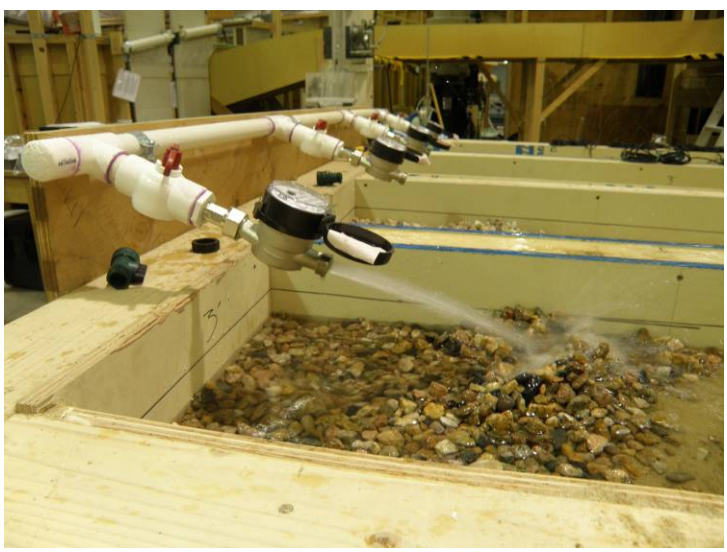


Figure 37. Addition of Water for Task 3.

Results

After adding 25 gallons of water to the first trough (5% Lassenite mix with 100% Lassenite furrow), the sensor at 11.5' showed an increase in soil moisture in approximately 10 minutes. Both troughs with the Lassenite mixes and the furrow of 100% Lassenite consistently moved water to the end with every 25

gallons. With each “irrigation event”, the water ponded at the surface over the entire length of the trough (Figure 38) and required 5-10 minutes to percolate into the material until no visible water was present at the surface. During the same tests in the sand troughs, the surface water only reached distances between 4’8” to 6’10” (Figure 39).

Figure 38. Two troughs on right are 5% Lassenite mix, showing extent of water movement during test.

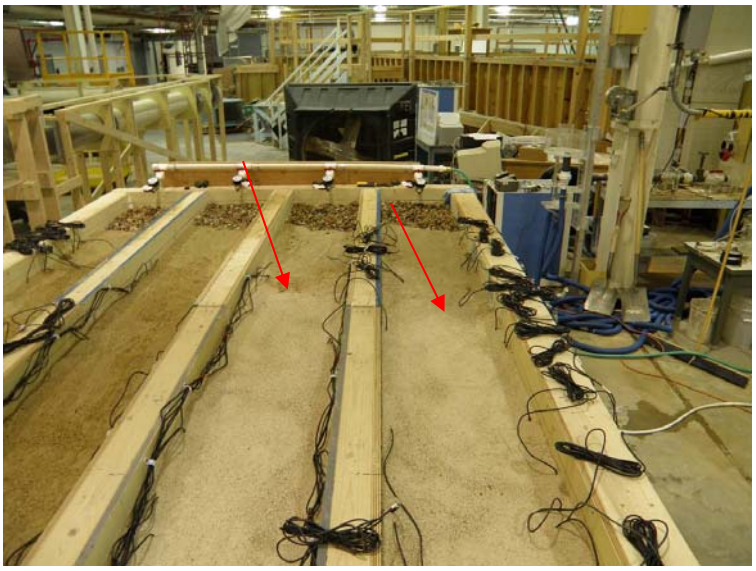


Figure 39. Wet areas of two control (sand) troughs on right during test. Note red arrows showing where dampness ends.

As can be seen in the graphs in Appendix 3, Figures 3-2 through 3-5, the sensors located directly in the 100% Lassenite furrows (Position 1) consistently showed an increase in moisture responses along the entire length of the trough. Beyond 3' from the water source, there was little to no response from sensors in the equivalent positions in the control (sand) troughs (Figure 40). The sand troughs retained very little moisture at any distance from the water application site (Figures 40 and 41) either immediately after irrigation (Figure 40) or during the drying out phase (Figure 41).

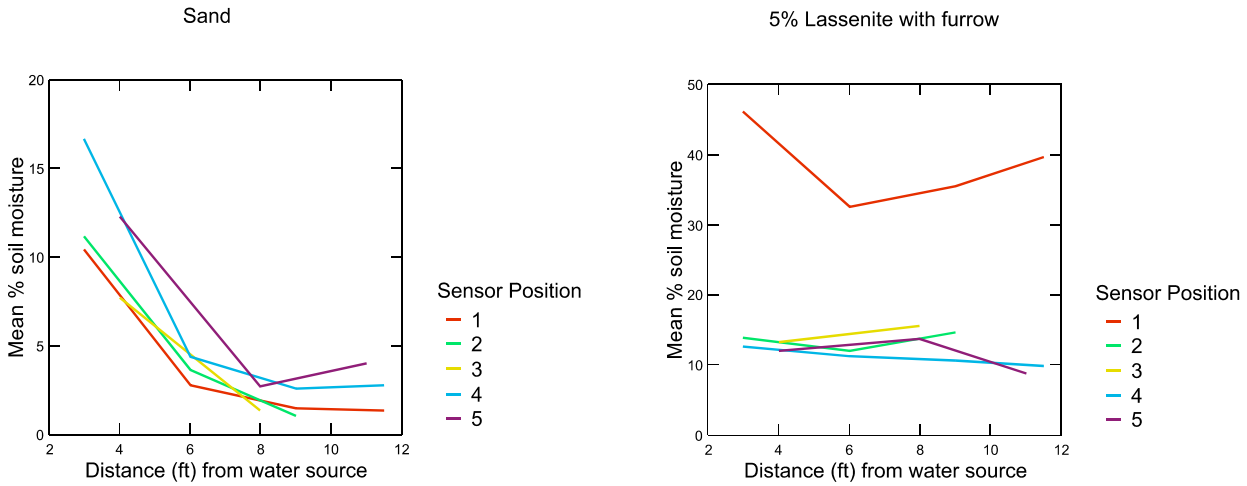


Figure 40. Soil moisture monitored by distance from the water source, immediately after irrigation (See Column for Post-irrigation Data, Table 3-1, Appendix 3). At Sensor Position 1, directly within the furrow, moisture levels dropped below 5% only 5-6 feet from the water source in the control trough (sand), while moisture in the treatment trough remained over 30% the entire length of the trough, approximately 11.5' (5% Lassenite with furrow).

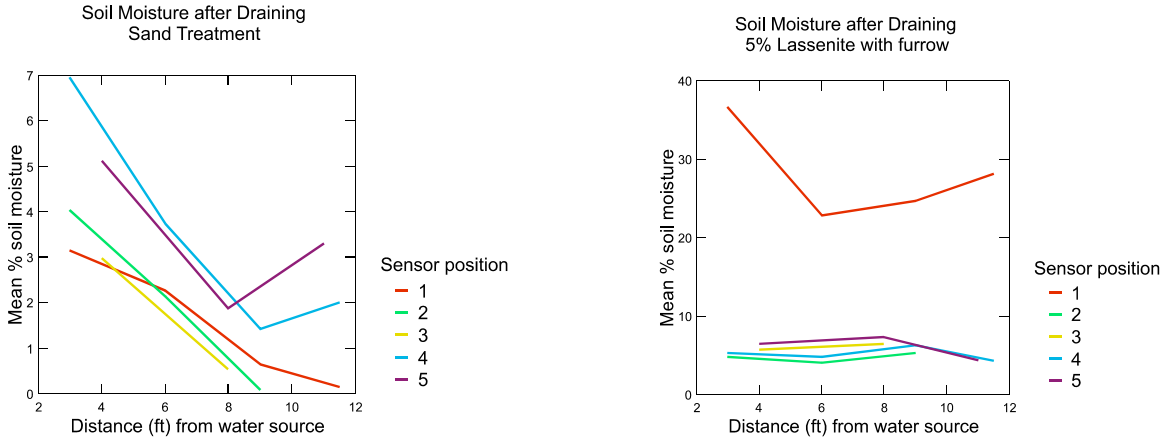


Figure 41. Soil moisture monitored by distance from the water source during the drying out phase. Mean moisture levels decreased sharply in the control troughs at Sensor Position 1. Mean moisture levels at Sensor Position 1 in the treatment trough remained over 20% the entire length of the trough, approximately 11.5' (5% Lassenite with furrow). The rise in moisture at 8-9 feet may result from water pooling in the lower regions of the trough before draining.

Five days after the final irrigation event, soil moisture content within the 100% Lassenite furrows was still high, ranging from 23.6% to 46.9% ($\bar{x}$ = 38.2) (Appendix 3, Table 3.1). At that point, the Lassenite-filled furrows still appeared wet (Figure 42). At the same position within the control troughs (100% sand), soil moisture ranged from 0% to 21.8% ($\bar{x}$ = 5.7%). Twelve days after the last irrigation, moisture content within the 100% Lassenite furrows ranged from 12.5-30.2% ($\bar{x}$ = 20.8%). At the same time and position in the sand troughs, moisture levels ranged from 0% to 2.4% ($\bar{x}$ = 0.4%) (Appendix 3, Figure 3-1).

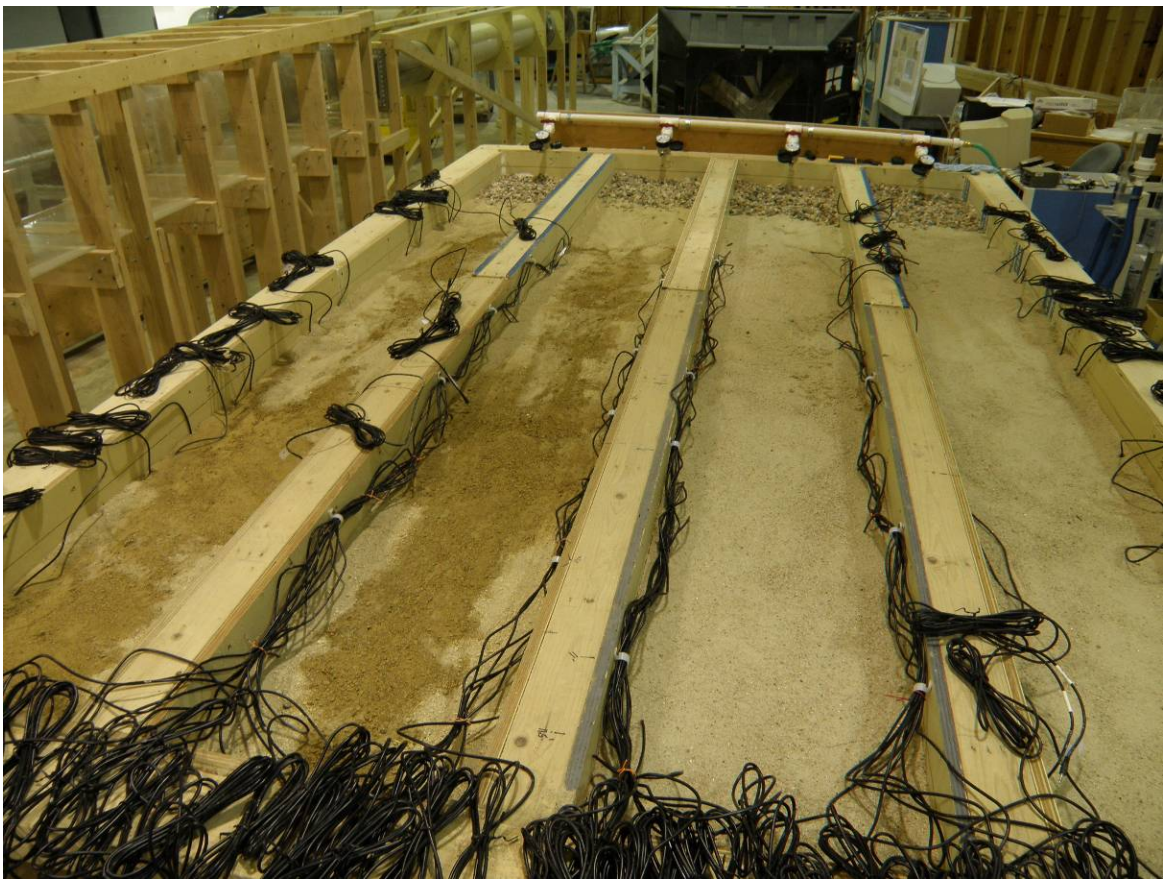


Figure 42. One week after the last application of water, 100% sand in the 2 troughs on the right; Lassenite filled furrows, with 5% mix on the left.

Results of the sensors analyzed separately after the final irrigation event in Task III (during the drying out period) are in Appendix 3, Data Analysis Task III. Lassenite mixtures did not affect the overall soil moisture ($F = 19.1$, df = 1,1, $P = 0.14$) or the trends in soil moisture through time ($F = 6.63$, df = 1,1, $P = 0.236$). However, there was a highly significant difference due to the Lassenite on the distribution of soil moisture among sensors ($F=12.3$, df = 20,20, $P < 0.001$), i.e. moisture levels were significantly different due to the location of the sensor in the trough. There was also a highly significant difference in trends in soil moisture through time among sensors ($F = 5.57$, df = 20,20, $P < 0.001$).

An analysis of the variance (see ANOVA, Appendix 3, Data Analysis Task III) on data from sensors grouped by position showed that the distribution of soil moisture among sensors was significantly affected by the Lassenite ($F=95.5$, $df=4,4$, $P<0.001$). Lassenite treatments were then analyzed to determine the degree of Lassenite effect due to sensor position in the trough. Position 1 had a weak effect due to Lassenite ($F=64.5$, $df= 1,1$, $P=0.079$) while the effect at Position 5 was slightly more significant ($F=64.5$, $df = 1,1$, $P = 0.027$). When analyzed to determine the effect due to position in the trough *over time*, Positions 3 ($F=541$, $df = 1,1$, $P = 0.027$) and 5 ($F=47.1$, $df=1,1$, $P= 0.092$) showed significance, although the effect at Position 5 was weak.

Discussion

While the 5% mixed troughs did in some cases retain a higher moisture level outside the 100% Lassenite furrows than the sand troughs, the greater benefit appears to be in the increased movement of water to the far end of the trough during an irrigation event, as shown in Figures 38-42. In every irrigation event, water quickly moved down the length of the 100% Lassenite furrow in the mixed troughs and only slowly percolated downward. For example, sensors at Position 2 (lateral to and 9' from the point of application) in the sand troughs barely show a rise in moisture when water was added during the first 5 days (100 hours), while the equivalently placed sensors in the treatment troughs show a large spike and continue to show higher moisture levels with time (Figure 42). Results indicate movement of the water during the irrigation events seemed to be consistent across the width of the troughs, indicating that the furrow was transmitting the water efficiently throughout the mixed material laterally, and downward percolation was much slower than in the sand troughs (see soil moisture graphs from each sensor position in Appendix 3).

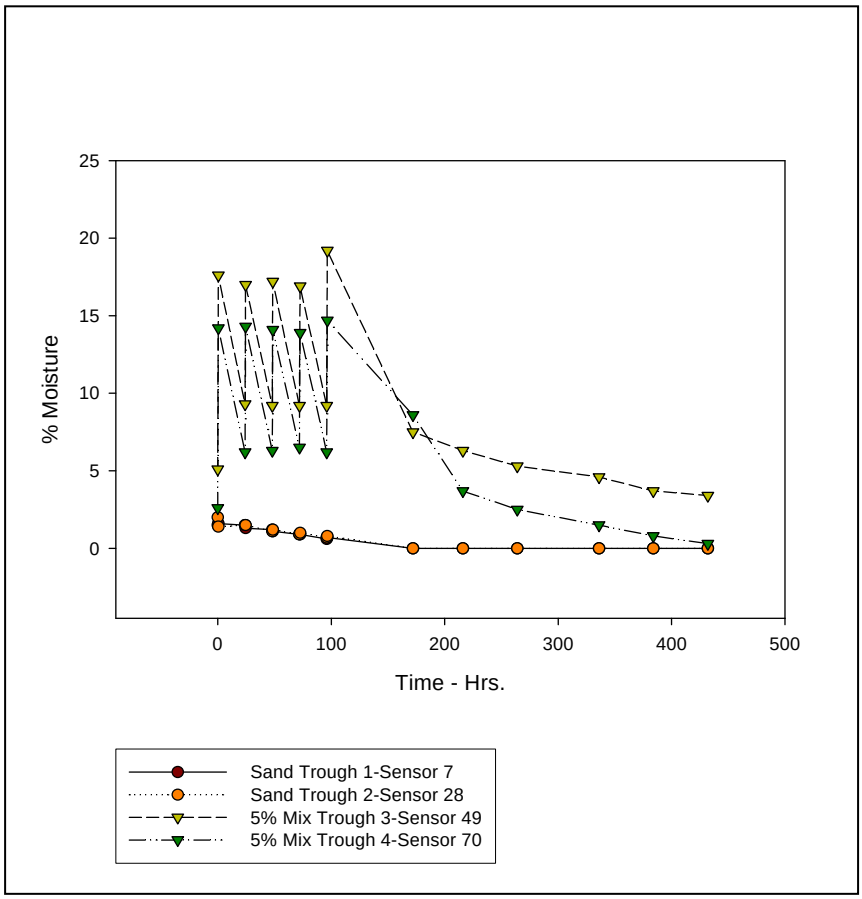


Figure 42. At Sensor Position 2, 9' from the water source, Sensor Numbers 49 and 70 record an increase in soil moisture immediately after water is added to the trough followed by a slow decrease over time. Sensor Numbers 7 and 28 in the control trough do not register any change in soil moisture.

Summary and Conclusions

Overall, the Lassenite performed well under laboratory conditions: there was no evidence that it would migrate through the sand during irrigation events, it greatly enhanced the movement of the water across the trough and mixes retained moisture for longer periods of time than sand, with moisture retention generally increasing with higher percentage mixes. There was little evidence that a mixed zone had any influence outward into a sand zone, however. There was some evidence in Task I that in a contained situation the sand maintained a higher moisture level underneath the Lassenite mixes. However, this effect was not seen in Task II where the sand underneath the mixes was in direct contact with other sand.

Based on the laboratory performance of Lassenite, this amendment may reduce the amount of water used in irrigation and the time required to irrigate, thus lowering the overall costs of irrigation. Testing

showed that high percentage mixes of Lassenite retained moisture longer than surrounding sand. The inclusion of scattered patches of Lassenite within habitat may improve conditions for the southwestern willow flycatcher by providing areas of moist soil and/or standing water. In addition, installing "pathways" of Lassenite throughout a restoration area may enhance the movement of water and increase soil moisture retention along the pathway.

These results concur with the product information available from the product manufacturer (Appendix 4). Lassenite is a commercial product that is sold as a soil amendment to increase moisture retention and reduce the frequency of watering, among several other purposes. Testing has been conducted on it by others previous to this study that also confirm its moisture holding properties (Appendix 4). Although these tests have been conducted under higher humidity and lower temperatures than is normally found on the lower Colorado River, this product has been in used under similar environmental conditions in Saudi Arabia in the development of golf courses (Appendix 4). It is recommended that demonstrations of Lassenite be continued in the field to determine its performance when exposed to the harsh climate of the lower Colorado River.

Appendices

Appendix 1, Task I Data and Analysis

	Column Leachate Data														
Notes	Hours since Start	Column #1- 0% Mix	Column #1- 0% Mix	Column #2 - 2%Mix	Column #2 - 2%Mix	Column #3 - 5% Mix	Column #3 - 5% Mix	Column #4 - 10 % Mix	Column #4 - 10 % Mix	% Humidity	Temperature - F	Column #1	Column #2	Column #3	Column #4
START TEST #1		% Moisture - 6" Depth	% Moisture - 9.5" Depth	% Moisture - 6" Depth	% Moisture - 9.5" Depth	% Moisture - 6" Depth	% Moisture - 9.5" Depth	% Moisture - 6" Depth	% Moisture - 9.5" Depth			Amt.Drained-L	Amt.Drained-L	Amt.Drained-L	Amt.Drained-L
Start 11-12-09															
Started Saturation	0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	31	68				
Saturated	22	10.9	11.3	16.0	17.5	19.2	22.5	24.8	49.9	32	67				
End of 1st Flush	24	8.2	10.3	10.2	13.9	9.7	13.5	12.3	15.7	35	68	11.8	8.2	8.6	8.2
11/16/2009	90	8.2	9.8	12.4	14.6	14.2	19.2	15.4	18.3						
11/16/2009	97	8.9	10.4	12.1	15.5	14.0	18.1	16.9	19.7						
11/17/2009	114	8.3	9.2	11.7	14.6	11.8	16.7	15.6	21.0						
11/18/2009	140	7.1	9.0	8.7	14.8	13.2	14.7	15.0	19.4						
End of 2nd Flush	141	9.0	10.6	10.5	13.7	10.9	15.1	12.3	18.3	36	68	6.1	6.8	5.6	6.2
11/19/2009	168	8.2	10.5	9.8	13.4	11.5	12.6	14.3	16.6						
11/20/2009	193	7.3	10.0	8.5	12.9	9.5	14.7	11.8	15.1						
11/23/2009	264	7.8	10.1	8.4	13.1	9.1	15.6	11.6	16.2						
End of 3rd Flush	265	9.0	10.8	9.5	11.0	9.5	12.3	14.5	17.5	28.0	66.0	9.2	8.2	8.2	6.1
11/24/2009	289	8.5	10.4	7.8	10.0	8.9	11.5	9.7	13.7						
11/25/2009	311	7.5	10.0	7.4	9.5	7.8	10.5	11.4	13.4						
11/27/2009	361	7.6	10.0	7.5	9.4	7.3	11.0	12.0	15.1						
11/30/2009	432	5.1	9.9	7.4	10.6	7.3	10.1	10.9	14.2						
End of 4th Flush	433	9.1	10.0	10.0	13.0	10.1	11.5	11.5	13.4	28.0	68.0	11.8	7.9	9.3	9.0
12/1/2009	457	9.6	10.5	9.4	10.8	10.5	12.8	10.4	11.8						
12/2/2009	481	8.8	10.1	9.4	11.2	10.5	12.4	14.3	15.7						
12/3/2009	505	7.3	9.7	7.8	9.5	8.3	10.2	11.7	15.4						
12/4/2009	529	7.4	9.6	7.2	10.5	7.5	9.5	9.5	12.2						
12/7/2009	601	2.3	7.3	1.4	7.5	0.7	3.8	8.1	7.8						
End of 5th Flush	602	8.7	9.4	10.2	11.9	10.4	12.8	15.3	13.9	24.0	68.0	12.0	7.1	8.5	6.9
12/8/2009	625	8.0	9.3	8.6	11.6	8.2	10.7	9.3	11.1						
12/9/2009	649	7.5	8.9	5.7	8.8	7.1	9.7	10.4	13.1						
END OF TEST #1															
	Average	7.9	9.9	9.1	12.1	9.9	13.0	12.9	16.6						
START TEST #2															
Start 12-18-09															
		0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0						
Saturated		11.1	10.4	11.2	15.1	14.8	19.1	22.3	25.6						
End of 1st Flush	1	8.2	8.6	15.1	9.0	8.9	9.5	11.9	17.8	30.0	68.0	12.1	14.5	12.1	9.0
12/21/2009	73	7.2	8.2	13.7	11.1	11.0	12.8	16.8	18.8						
12/22/2009	97	5.5	8.1	10.5	12.4	10.0	13.3	15.0	18.1						
12/23/2009	121	5.5	8.1	10.2	11.8	11.1	11.7	14.6	16.4						
End of 2nd Flush	122	7.4	8.0	7.9	9.0	8.3	9.7	9.8	14.1	34.0	69.0	12.7	9.6	12.4	8.7
12/24/2009	163	7.8	8.4	8.8	9.6	9.6	9.7	10.8	13.4						
12/28/2009	242	0.3	3.6	1.4	8.3	2.7	7.7	8.8	8.9						
1/4/2010	410	0.1	4.3	0.5	5.1	3.2	4.7	10.0	9.7						
End of 3rd Flush	411	10.0	11.3	8.7	8.8	8.6	10.1	11.0	12.5	32.0	68.0	8.4	8.1	7.8	7.6
1/6/2010	458	9.7	11.7	7.8	8.7	9.0	9.7	11.8	10.7						
1/7/2010	482	9.3	11.2	8.1	9.5	9.3	9.6	11.9	13.7						
1/8/2010	506	9.0	11.4	8.6	9.7	9.1	9.9	13.4	10.9						
1/11/2010	578	8.4	11.8	7.9	9.6	9.3	9.5	11.8	13.5						
1/12/2009	598	8.5	10.7	7.6	9.4	9.2	9.3	11.4	11.0						
End of 4th Flush	599	10.1	11.1	7.7	9.6	8.1	9.5	8.7	10.2	34.0	67.0	10.2	7.2	10.6	8.1
1/14/2010	621	9.5	11.9	8.0	8.8	8.0	9.5	10.9	12.5						
1/15/2010	646	9.4	11.3	7.6	8.8	8.5	9.7	11.1	13.2						
1/19/2010	741	8.1	10.8	7.8	9.3	9.0	9.9	9.6	11.7						
End of 5th Flush	742	9.7	11.1	7.7	9.3	8.4	9.6	10.5	11.0	37.0	67.0	9.1	5.8	9.3	6.2
1/20/2010	765	9.6	11.5	7.9	9.4	8.8	9.2	10.2	11.1						
1/21/2010	789	10.3	11.0	8.2	8.5	8.2	9.3	9.5	10.6						
1/22/2010	813	9.8	11.7	7.9	9.4	9.0	10.2	9.7	11.5						
1/25/2010	885	8.8	11.5	7.9	10.1	9.4	9.9	10.7	11.0						
END OF TEST #2															
	Average	8.1	9.9	8.3	9.6	8.8	10.1	11.8	13.2						

Table 1-1. Data, Task I.

Data Analysis, Task I

AOV table: Dependent variable = soil moisture, arcsin transformed to normalize

Sources of variation

Replicates (blocks, r = 2)

Lassenite mixture (t = 4)

Hours elapsed during experiment, independent of water flushes (continuous variable,

transformed 1/h to straighten, n = 25 in both blocks)

Sensor depth (s = 2)

Factor tested	Tested against	Result
(1) Lassenite	Block X Lassenite	F = 41.6, df = 3,3, P = 0.006
(2) Lassenite X Hours	Block X Lassenite X Hours	F = 1.04, df = 3,3, P = 0.488
(3) Lassenite X Depth	Block X Lassenite X Depth	F = 1.75, df = 3,3, P = 0.329
(4) Lassenite X Hours X Depth	Block X Lassenite X Hours X Depth	F = 1.19, df = 3,3, P = 0.445

Lassenite mixtures affected (1) overall soil moisture but did not affect (2) trends in soil moisture thru time, (3) differences in soil moisture between depths, or (4) trends in soil moisture thru time between depths.

Appendix 2, Task II Data, Graphs & Analysis

Date	Time of Reading	Sensor # 1	Sensor # 2	Sensor # 3	Sensor # 4	Sensor # 5	Sensor # 6	Sensor # 7	1" @3'	1"@5'	Sensor # 8	Sensor # 9	Sensor # 10	Sensor # 11	Sensor # 12	Sensor # 13	Sensor # 14	1"@3'	1"@5'	Sensor # 15	Sensor # 16	Sensor # 17	Sensor # 18	Sensor # 19	Sensor # 20	Sensor # 21	1"@3'	1"@5'	Sensor # 22	Sensor # 23	Sensor # 24	Sensor # 25	Sensor # 26	Sensor # 27	Sensor # 28	1"@3'	1"@5'	Humidity	Temp. - F
3/29/2010	1:00 PM	7.9	4.8	7.8	5.3	7.5	5.9	6.4	0.0	0.0	5.8	7.8	8.7	5.9	7.0	6.3	8.6	0.0	0.0	6.5	7.9	7.6	8.2	8.5	7.5	5.8	0.0	0.0	9.1	10.8	6.9	7.9	5.3	6.1	6.9	0.0	0.0	31	66
3/29/2010	2:00 PM	18.0	10.8	7.8	5.3	7.4	6.0	6.3	0.5	0.0	12.7	15.8	8.6	5.9	6.9	6.2	8.5	0.0	0.0	16.9	17.7	7.6	8.0	8.5	7.5	5.8	0.0	0.0	8.8	22.7	6.9	7.6	6.0	6.1	7.0	0.0	0.0	31	66
3/30/2010	10:00 AM	9.8	7.2	7.7	5.4	7.4	6.2	6.2	0.0	0.0	7.4	9.9	8.7	5.8	6.9	6.1	8.3	0.0	0.0	8.2	11.2	7.7	8.1	8.6	7.3	5.3	0.0	0.0	10.2	14.6	7.4	7.7	5.9	5.9	6.9	0.0	0.0	32	67
3/31/2010	8:00 AM	9.7	6.7	7.3	5.3	7.5	6.3	6.1	0.0	0.0	6.9	9.4	8.7	5.8	6.8	5.9	8.2	0.0	0.0	7.8	10.4	7.7	8.1	8.8	7.3	5.6	0.0	0.0	9.7	14.3	7.3	7.5	5.7	5.8	6.8	0.0	0.0	34	66
3/31/2010	1:00 PM																																					38	66
3/31/2010	2:00 PM	15.1	9.4	7.5	5.8	7.6	6.3	6.0	4.8	0.0	11.1	13.7	8.8	5.8	7.1	5.8	8.1	2.2	0.0	12.0	14.7	7.8	8.1	8.9	7.2	5.6	0.8	0.0	16.6	20.3	7.3	7.5	5.8	5.8	6.8	0.5	0.0	38	66
4/1/2010	9:30 AM	11.1	6.6	8.1	5.5	8.5	6.5	6.0	2.0	0.0	10.4	10.1	11.2	5.6	8.9	5.9	8.2	2.5	0.0	10.3	11.0	9.3	8.1	11.1	7.1	5.6	1.7	0.0	12.7	15.0	8.2	7.3	6.4	5.6	6.7	0.0	0.0	39	68
4/1/2010	10:00 AM																																						
4/1/2010	1:00 PM																																						
4/2/2010	10:00 AM	17.0	6.9	10.5	5.2	15.8	6.3	5.9	3.6	0.0	33.2	10.2	39.9	5.7	38.2	5.4	8.7	1.6	0.0	32.5	11.2	35.5	9.4	37.0	7.0	6.4	3.3	0.0	27.5	15.7	15.3	9.8	19.2	6.3	8.2	3.3	2.0	34	68
4/2/2010	1:00 PM																																					33	68
4/2/2010	2:00 PM	41.6	10.1	39.3	5.2	41.1	6.4	6.1	3.2	0.0	35.4	15.4	40.9	5.6	37.5	5.5	18.2	1.2	0.0	38.9	16.9	39.8	9.1	36.6	7.0	25.5	0.7	1.6	29.3	25.7	40.9	9.2	41.4	6.1	17.1	2.0	2.1	33	68
4/5/2010	10:00 AM	41.4	5.9	39.0	4.7	41.3	5.9	7.8	0.0	0.0	36.2	9.9	41.6	5.7	38.6	5.4	14.7	0.0	0.0	39.8	10.4	40.0	8.0	37.2	7.1	15.1	0.0	0.0	29.3	15.1	41.0	7.9	41.5	5.8	36.3	0.0	0.0	33	68
4/5/2010	1:00 PM																																					33	68
4/5/2010	2:00 PM	42.5	9.2	40.2	4.7	40.3	5.8	37.3	0.0	0.0	34.9	29.7	41.6	6.7	39.2	6.2	41.7	0.7	0.0	39.6	16.4	39.7	16.9	37.0	22.5	42.5	0.3	0.0	40.8	25.8	40.9	11.9	41.5	6.0	40.9	0.3	0.0	32	68
4/6/2010	11:00 AM	42.7	8.1	40.3	5.1	40.6	6.4	37.2	0.0	0.0	35.8	12.9	42.1	7.0	38.9	6.4	41.4	0.0	0.0	40.4	12.0	39.7	9.9	37.3	10.8	42.3	0.0	0.0	40.7	16.8	41.3	9.3	41.7	6.3	40.9	0.0	0.0	33	68.0
4/7/2010	9:00 AM	42.8	7.6	40.4	5.2	40.8	6.9	37.5	0.0	0.0	36.1	12.5	42.4	6.8	39.2	6.1	41.5	0.0	0.0	40.9	11.3	39.7	8.9	37.7	9.4	42.5	0.0	0.0	40.6	15.6	41.5	8.2	41.4	6.0	41.1	0.0	0.0	34	68.0
4/7/2010	10:00 AM																																						
4/7/2010	11:00 AM	43.2	41.4	39.1	41.0	41.3	39.6	38.6	4.3	5.1	36.3	40.3	42.5	40.3	39.9	40.7	41.8	15.1	11.9	40.9	45.2	40.6	41.4	37.4	39.8	42.0	12.2	8.5	41.0	40.7	40.9	42.3	42.5	39.5	41.9	14.6	7.1	34	68.0
4/7/2010	1:00 PM	43.2	41.0	39.1	40.8	41.2	39.6	38.4	8.0	7.8	35.9	40.3	42.4	40.2	40.1	40.7	41.9	11.0	9.1	40.9	45.0	40.7	41.3	37.3	39.7	42.6	9.7	9.1	41.0	40.2	41.1	42.0	42.7	40.6	41.8	9.7	7.1	33	68.0
4/7/2010	1:00 PM Saturation - Opened Bottom Drains - ~57 gal.																																						
4/8/2010	8:00 AM	10.3	6.8	10.6	8.2	10.2	9.2	7.6	3.7	3.3	9.1	9.9	10.2	7.1	9.0	9.1	9.8	4.2	4.1	9.0	11.9	9.6	9.3	9.2	8.0	9.0	3.8	2.0	10.8	15.3	9.3	9.4	11.3	8.2	5.7	4.1	2.5	34	68
4/8/2010	1:00 PM	10.1	6.7	10.2	8.0	9.8	8.6	7.3	2.1	3.0	8.8	9.7	9.7	6.9	8.9	8.8	9.5	2.1	4.0	8.6	11.7	9.3	9.0	8.9	7.8	6.3	2.6	2.2	10.5	15.0	8.9	8.9	10.8	7.8	8.4	2.9	3.0	33	68.0
4/9/2010	9:00 AM	9.2	6.2	9.3	7.3	9.0	7.9	6.8	2.0	1.5	7.9	9.2	8.3	6.3	8.1	7.9	8.7	2.4	1.5	8.2	11.1	8.5	8.2	8.6	7.2	7.9	2.7	1.1	10.1	14.4	8.3	8.3	9.8	7.2	7.7	1.7	1.2	30	66.0
4/9/2010	1:00 PM	9.2	6.3	9.2	7.2	8.9	8.0	6.7	2.4	1.7	7.8	9.1	9.0	6.2	8.1	7.9	8.7	1.4	1.1	8.1	10.9	8.4	8.2	8.5	7.2	7.8	2.2	2.0	10.0	14.4	8.3	8.1	9.9	6.8	7.7	2.2	1.2	29	66.0
4/12/2010	8:00 AM	8.2	5.5	8.1	6.2	8.1	6.9	5.7			6.8	8.4	8.2	5.6	6.9	7.0	7.7			7.3	10.1	7.4	7.3	7.7	6.6	6.7			9.4	13.5	7.4	7.2	8.9	6.3	6.7			31	68.0
4/14/2010	9:00 AM	7.9	5.3	7.7	5.8	7.8	6.5	5.6			6.5	8.0	7.8	5.3	6.8	6.6	7.1			7.1	9.8	7.1	7.0	7.4	6.3	6.4			9.1	13.1	7.2	6.8	8.4	5.9	6.3			30	64.0
4/20/2010	9:00 AM	7.3	4.7	7.1	5.2	6.9	5.9	5.0			5.8	7.5	7.2	4.7	6.2	5.8	6.4			6.4	9.0	6.5	6.3	6.8	5.8	5.6			8.5	12.1	6.5	6.1	7.6	5.2	5.7			50	64.0
4/23/2010	8:00 AM	7.1	4.5	6.9	4.9	6.8	5.6	4.9			5.7	7.3	7.1	4.5	6.1	5.5	6.1			6.2	8.8	6.4	6.1	6.7	5.6	5.4			8.4	11.8	6.4	5.8	7.5	5.0	5.6			44	63.0
4/26/2010	1:00 PM	6.9	4.3	6.8	4.6	6.8	5.7	4.8	0.0	0.0	5.6	7.0	7.2	4.1	6.1	5.1	5.8	0.0	0.0	6.2	8.5	6.3	5.8	6.6	5.4	5.2	0.0	0.0	8.4	11.3	6.4	5.6	7.6	4.6	5.4	0.0	0.0	38	64.0
4/27/2010	1:00 PM	6.9	4.3	6.8	4.5	6.8	5.5	4.7	0.0	0.0	5.7	6.9	7.2	4.1	5.4	5.0	5.7	0.0	0.0	6.2	8.4	6.3	5.7	6.6	5.3	5.1	0.0	0.0	8.4	11.2	6.4	5.5	7.4	4.5	5.3	0.0	0.0	39	64.0
4/28/2010	1:00 PM	7.0	4.2	6.8	4.5	6.7	5.2	4.7	0.0	0.0	5.6	6.9	7.2	4.1	6.1	5.0	5.7	0.0	0.0	6.2	8.4	6.3	5.7	6.6	5.4	5.1	0.0	0.0	8.4	11.2	6.4	5.5	7.3	4.6	5.3	0.0	0.0	33	65.0
4/30/2010	1:00 PM	6.9	4.1	6.8	4.4	6.8	5.1	4.6	0.0	0.0	5.6	6.8	7.1	3.9	6.2	4.8	5.6	0.0	0.0	6.2	8.3	6.3	5.6	6.6	5.2	5.0	0.0	0.0	8.4	11.0	6.3	5.3	7.4	4.4	5.1	0.0	0.0	31	62.0
5/3/2010	1:00 PM	6.8	4.1	6.7	4.1	6.7	5.0	4.1	0.0	0.0	5.7	6.7	7.1	3.8	6.1	4.6	5.4	0.0	0.0	6.2	8.0	6.3	5.5	6.6	4.9	4.5	0.0	0.0	8.4	10.8	6.3	5.1	7.4	4.2	5.1	0.0	0.0	33	63.0
5/4/2010	1:00 PM	6.9	4.1	6.7	4.1	6.7	5.0	4.5	0.0	0.0	5.6	6.7	7.2	3.8	6.1	4.6	5.4	0.0	0.0	6.2	8.0	6.3	5.5	6.7	5.1	5.0	0.0	0.0	8.4	10.7	6.3	5.0	7.4	3.3	5.1	0.0	0.0	30	64.0
5/6/2010	1:00 PM	6.9	3.9	6.7	4.0	6.7	5.0	4.5	0.0	0.0	5.7	6.7	7.2	3.7	6.1	4.5	5.4	0.0	0.0	6.2	7.9	6.2	5.4	6.7	5.0	4.8	0.0	0.0	8.4	10.6	6.3	5.0	7.4	4.1	5.1	0.0	0.0	44	64.0
5/7/2010	1:00 PM	6.9	3.9	6.7	3.9	6.7	4.9	4.4	0.0	0.0	5.7	6.6	7.2	3.6	6.1	4.4	5.3	0.0	0.0	6.1	7.8	6.3	5.3	6.6	4.9	4.8	0.0	0.0	8.4	10.5	6.3	4.9	7.3	3.9	5.0	0.0	0.0	47	62.0
5/10/2010	1:00 PM	6.9	3.6	6.6	3.9	6.7	4.6	4.4	0.0	0.0	5.6	6.4	7.1	3.5	6.1	4.3	5.1	0.0	0.0	6.1	7.8	6.3	5.2	6.6	4.9	4.2	0.0	0.0	8.4	10.5	6.3	4.7	7.3	3.9	5.0	0.0	0.0	34	64.0
End of Test																																							

Table 2-1. Task II Data, Replicate A

Date	Time of Reading	Sensor # 1	Sensor # 2	Sensor # 3	Sensor # 4	Sensor # 5	Sensor # 6	Sensor # 7	1" @3'	1"@5'	Sensor # 8	Sensor # 9	Sensor # 10	Sensor # 11	Sensor # 12	Sensor # 13	Sensor # 14	1"@3'	1"@5'	Sensor # 15	Sensor # 16	Sensor # 17	Sensor # 18	Sensor # 19	Sensor # 20	Sensor # 21	1"@3'	1"@5'	Sensor # 22	Sensor # 23	Sensor # 24	Sensor # 25	Sensor # 26	Sensor # 27	Sensor # 28	1"@3'	1"@5'	Humidity	Temp. - F
5/20/2010	7:30 AM																																					43	65
5/20/2010	10:00 AM	18.0	7.6	12.7	10.1	16.9	10.7	9.6	5.2	6.6	37.9	10.2	37.4	8.3	46.6	10.7	19.8	6.2	6.1	39.4	16.8	40.1	8.5	40.5	8.8	18.9	6.9	3.7	36.7	14.9	31.4	8.5	41.8	16.8	10.1	0.0	0.4	45	66
5/21/2010	7:00 AM	24.2	6.1	15.9	6.9	32.1	7.7	7.8	2.5	2.9	21.8	7.7	35.6	8.1	41.1	10.6	13.0	4.4	4.5	39.5	12.8	39.5	5.8	40.2	7.1	16.3	3.8	2.8	36.7	11.2	34.7	8.6	41.7	9.0	11.3	1.4	0.0		
5/21/2010	7:30 AM																																						
5/21/2010	1:00 PM	40.3	7.3	39.4	7.5	38.8	7.9	18.8	2.3	2.1	40.3	9.1	36.7	8.3	40.5	10.7	41.4	6.0	1.6	40.4	15.1	40.3	6.1	39.9	9.6	37.7	3.7	2.2	37.1	13.9	39.0	11.1	41.3	10.0	40.4	0.2	1.3	43	66
5/24/2010	7:00 AM	40.2	6.7	39.1	6.9	38.8	8.1	20.3	0.0	0.0	40.1	6.9	36.9	8.5	40.8	11.1	41.7	3.3	0.1	40.0	11.8	40.6	5.6	38.9	8.3	37.4	1.0	0.0	37.6	11.2	38.9	9.8	41.3	9.8	41.0	0.0	0.0	38	68
5/24/2010	7:30 AM																																					30	68
5/24/2010	1:00 PM	41.0	14.4	39.7	12.8	38.8	16.5	37.2	1.7	0.6	40.8	9.0	36.6	12.1	41.0	15.0	42.1	3.0	0.0	41.1	23.0	40.0	8.2	38.9	27.8	37.7	1.0	0.0	38.7	24.1	39.3	40.1	40.5	20.4	41.2	0.2	0.0		
5/25/2010	7:00 AM	41.2	12.8	40.0	12.0	38.8	15.5	37.4	0.9	0.0	41.0	24.1	37.9	12.3	40.3	15.2	42.3	2.5	0.0	41.4	16.4	40.4	7.1	38.8	18.2	38.0	0.3	0.0	38.8	16.7	39.7	31.1	40.8	15.7	41.4	0.0	0.0	30	64
5/25/2010	7:30 AM																																						
5/25/2010	1:00 PM	41.4	38.9	39.0	38.6	39.3	39.9	38.0	5.4	5.1	41.7	29.6	38.5	40.2	41.6	39.9	41.9	0.3	0.0	41.2	41.7	40.8	32.2	39.3	42.8	38.2	0.1	0.0	38.7	42.9	38.7	40.9	41.0	40.4	41.6	0.5	0.0		
5/26/2010	10:00 AM																																					44	66
5/26/2010	1:00 PM	41.6	39.6	38.7	38.7	39.5	40.1	38.3	13.0	10.1	41.9	42.3	38.2	40.5	41.7	40.2	41.8	2.4	2.5	41.6	41.4	40.9	32.1	39.6	42.7	38.0	0.7	0.0	38.9	42.5	39.0	40.8	41.1	40.4	41.5	5.6	3.5		
5/26/2010	1:15 PM																																						
5/27/2010	2:00 PM	41.7	40.5	39.4	39.7	40.1	40.9	38.5	41.9	44.7	41.9	42.5	38.3	40.6	42.0	39.4	41.9	40.5	34.6	42.1	42.0	41.2	41.1	39.7	41.8	38.4	43.8	39.0	39.3	43.1	40.1	41.0	41.7	40.1	41.3	41.7	41.1		
5/27/2010	7:00 AM	41.7	39.5	39.1	39.1	40.0	40.3	38.5	39.2	37.7	42.0	42.3	38.6	40.5	41.9	39.6	42.0	35.7	32.7	42.1	41.4	41.3	41.1	39.5	42.0	38.2	43.2	32.2	39.1	42.6	39.7	40.7	41.7	39.7	41.2	38.8	29.3	47	66
5/27/2010	7:00 AM	*Saturated - Opened Drains ~ 57 gal*																																					
5/27/2010	2:00 PM	11.4	7.2	11.4	8.4	10.9	9.6	8.3	3.9	4.5	41.3	10.1	38.2	12.0	40.4	14.3	42.0	7.9	7.3	41.7	14.5	41.3	21.1	40.1	11.4	37.9	12.0	7.0	38.7	13.7	39.3	12.0	42.0	12.8	15.1	8.3	8.4		
5/28/2010	8:00 AM	9.6	6.1	9.3	6.9	9.1	8.0	6.9	2.5	1.6	11.4	8.3	13.0	9.8	41.0	12.0	11.2	8.3	3.8	13.3	12.7	11.7	15.0	13.7	9.3	12.5	9.3	6.2	14.9	11.8	10.3	10.0	12.8	10.8	11.1	4.7	5.8	35	68
5/28/2010	2:00 PM	9.3	5.8	9.1	6.7	8.8	7.7	6.7	2.9	3.1	10.8	8.1	11.7	9.5	40.9	11.8	10.7	5.2	4.0	12.7	12.5	11.4	14.3	13.3	9.0	12.1	9.1	5.9	14.4	11.6	10.1	9.7	12.3	10.5	10.8	5.4	4.4	33	70
6/1/2010	8:00 AM	8.0	4.9	7.6	5.4	7.3	6.5	5.2	0.0	0.0	9.4	6.7	10.9	7.8	40.9	10.3	9.1	1.0	0.3	11.1	11.0	9.9	11.1	11.6	7.4	9.9	5.9	1.7	11.9	10.0	8.3	7.8	10.2	8.8	9.1	1.3	1.4	32	69
6/2/2010	8:00 AM	7.8	4.8	7.4	5.3	7.1	6.5	5.4	0.0	0.0	8.9	6.6	10.1	7.6	40.9	10.0	8.7	0.6	0.1	11.0	10.8	9.7	10.8	11.6	7.2	9.6	5.6	0.9	11.6	9.9	8.1	7.7	10.0	8.5	8.9	1.2	1.4	41	69
6/3/2010	8:00 AM	7.6	4.8	7.2	5.2	7.1	6.5	5.4	0.0	0.0	8.7	6.4	9.7	7.5	40.8	9.9	8.5	0.2	0.0	10.7	10.6	9.4	10.3	11.3	7.0	9.3	5.2	0.0	11.5	9.8	8.1	7.5	9.9	8.2	8.7	1.0	0.0	38	68.0
6/4/2010	8:00 AM	7.6	4.8	7.1	5.1	7.0	6.3	5.3	0.0	0.0	8.6	6.3	9.5	7.3	39.7	9.7	8.3	0.0	0.0	10.5	10.4	9.3	10.2	11.1	6.7	8.2	4.9	0.0	11.4	9.5	8.0	7.2	9.9	8.1	8.7	0.0	0.0	39	68.0
6/7/2010	8:00 AM	7.4	4.7	6.9	5.0	6.8	6.0	5.0	0.0	0.0	8.2	6.0	8.4	7.0	27.9	9.4	7.9	0.0	0.0	10.3	10.1	9.0	9.7	10.9	6.6	8.8	3.8	0.0	11.1	9.4	7.8	7.0	9.6	7.7	8.5	0.0	0.0	48	71.0
6/9/2010	8:00 AM	7.3	4.4	7.0	4.7	6.7	6.0	5.0	0.0	0.0	7.9	5.7	8.3	6.8	20.2	9.1	7.6	0.0	0.0	10.2	9.8	8.8	9.4	10.7	6.5	7.7	3.8	0.0	11.1	9.2	7.7	6.8	9.7	7.5	8.3	0.0	0.0	47	70.0
6/10/2010	8:00 AM	7.3	4.4	6.8	4.7	6.6	5.8	4.9	0.0	0.0	8.1	5.8	8.1	6.7	18.5	9.0	7.5	0.0	0.0	10.1	9.7	8.8	9.3	10.7	6.3	8.5	3.7	0.0	11.0	9.2	7.7	6.6	9.7	7.3	8.2	0.0	0.0	49	70.0
6/11/2010	8:00 AM	7.2	4.4	6.7	4.6	6.6	5.9	4.9	0.0	0.0	7.8	5.6	7.9	6.6	17.7	8.9	7.4	0.0	0.0	10.1	9.7	8.8	9.2	10.6	6.3	8.4	3.5	0.0	11.0	9.0	7.7	6.5	9.5	7.2	8.1	0.0	0.0	47	70.0
6/14/2010	8:00 AM	6.9	3.9	6.5	4.2	6.3	5.5	4.7	0.0	0.0	7.3	5.1	7.3	6.1	13.7	8.5	7.0	0.0	0.0	9.8	8.9	8.4	8.6	10.2	5.8	8.1	2.9	0.0	10.5	8.5	7.3	6.0	9.3	6.7	7.7	0.0	0.0	52	62.0
6/15/2010	8:00 AM	6.8	3.9	6.4	4.1	6.3	5.2	4.7	0.0	0.0	7.2	5.0	7.1	6.0	13.2	8.3	6.9	0.0	0.0	9.7	9.0	8.4	8.5	10.1	5.7	8.1	2.9	0.0	10.5	8.5	7.3	5.9	9.3	6.6	7.6	0.0	0.0	41	63.0
6/16/2010	8:00 AM	6.9	3.9	6.4	4.2	6.4	5.4	4.7	0.0	0.0	7.2	5.0	7.1	6.0	12.7	8.3	6.9	0.0	0.0	9.8	9.0	8.4	8.4	10.2	5.7	8.0	2.9	0.0	10.5	8.5	7.3	6.0	9.3	6.6	7.6	0.0	0.0	42	66.0
6/17/2010	8:00 AM	6.9	4.0	6.4	4.2	6.4	5.4	4.6	0.0	0.0	7.2	5.0	7.1	6.0	12.8	8.3	6.8	0.0	0.0	9.8	8.9	8.4	8.4	10.2	5.7	8.0	2.7	0.0	10.6	8.6	7.4	5.9	9.3	6.6	7.8	0.0	0.0	34	68.0
6/18/2010	9:00 AM	7.0	3.9	6.5	4.2	6.3	5.3	4.6	0.0	0.0	7.2	5.0	7.1	6.0	12.7	8.3	6.8	0.0	0.0	9.8	9.0	8.4	8.4	10.1	5.7	7.9	2.6	0.0	10.6	8.6	7.4	5.9	9.3	6.6	7.6	0.0	0.0	34	69.0
6/21/2010	8:00 AM	6.9	3.9	6.5	4.1	6.3	5.3	4.5	0.0	0.0	7.1	4.9	7.0	5.8	12.8	8.1	6.6	0.0	0.0	9.8	8.9	8.4	8.2	10.2	5.6	7.9	2.4	0.0	10.5	8.5	7.3	5.8	9.3	6.5	7.6	0.0	0.0	53	70.0
6/24/2010	11:00 AM	6.9	3.8	6.4	3.9	6.3	5.2	4.5	0.0	0.0	7.1	4.8	7.1	5.6	12.9	8.0	6.6	0.0	0.0	9.8	8.9	8.4	8.0	10.1	5.5	7.8	1.8	0.0	10.5	8.3	7.2	5.5	9.3	6.3	7.6	0.0	0.0	41	71.0
6/25/2010	8:00 AM	6.9	3.8	6.5	3.8	6.3	5.2	4.5	0.0	0.0	7.1	4.8	7.1	5.8	12.8	7.9	6.6	0.0	0.0	9.8	8.9	8.4	7.9	10.1	5.5	7.8	1.7	0.0	10.5	8.4	7.3	5.5	9.3	6.3	7.6	0.0	0.0	33	72.0
End of Test																																							

Table 2-2. Task II Data, Replicate B

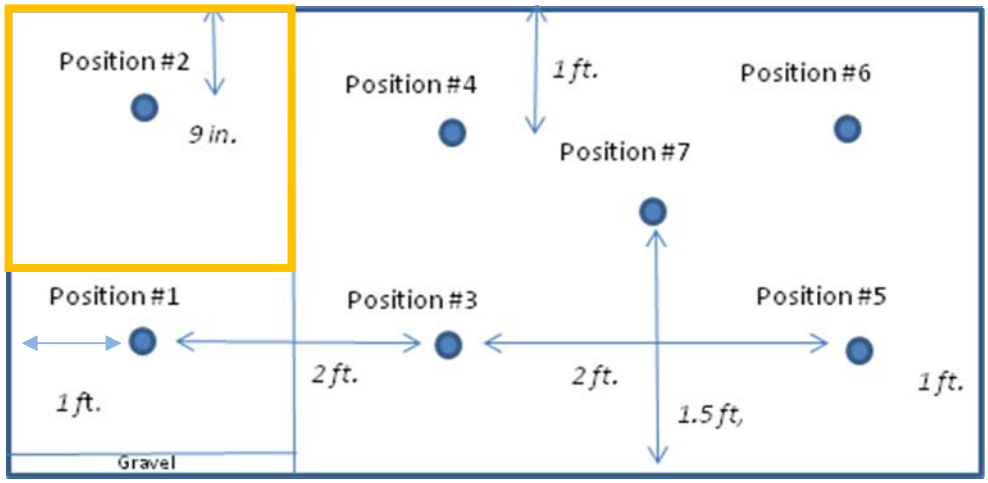
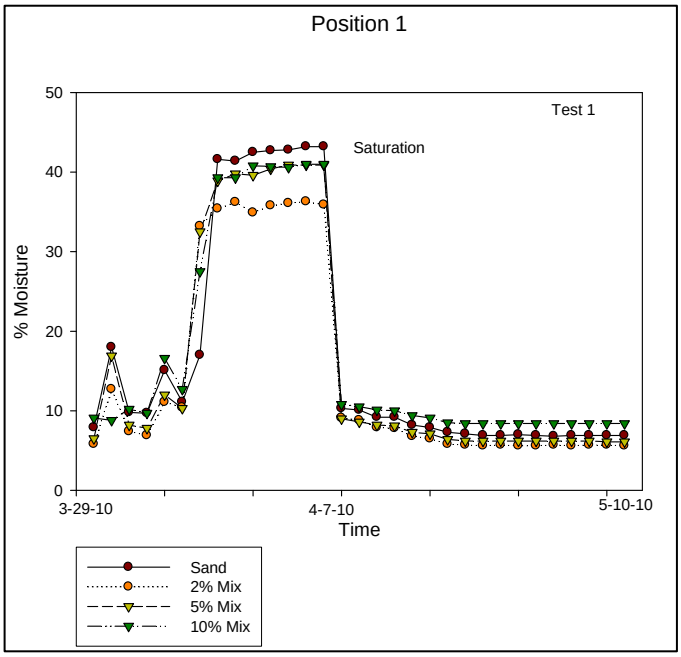


Figure 2-1. Position of the sensors for Task II. The location of the Lassenite treatment area (0%, 2%, 5%, and 10%) in each trough is outlined in orange.

Replicate A



Replicate B

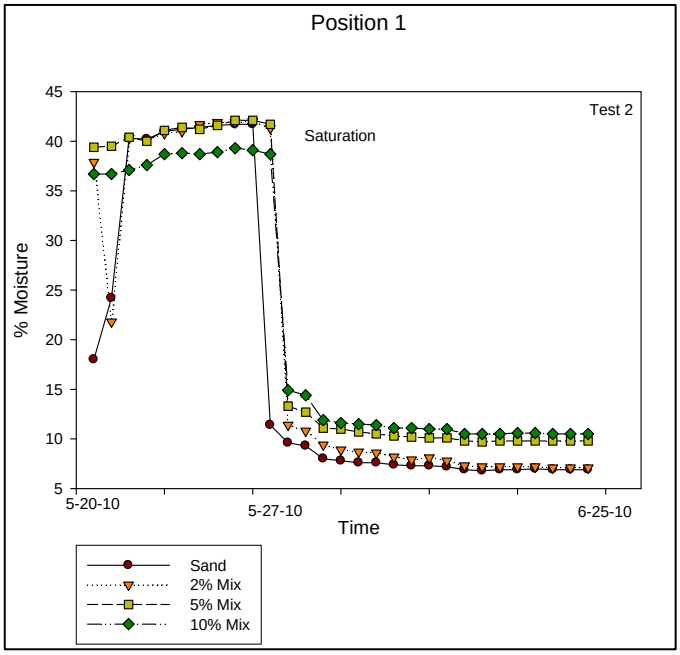


Figure 2-2a&b. Soil moisture changes at Position 1 over time for both replications are shown.

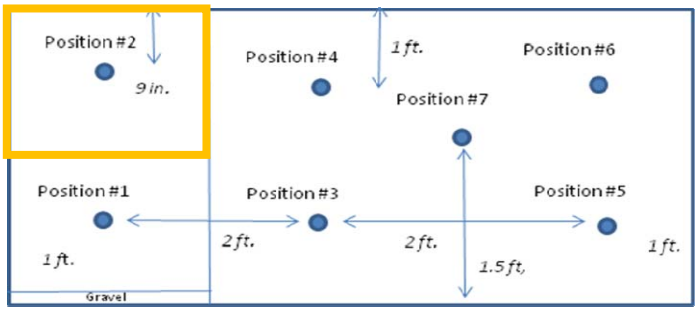
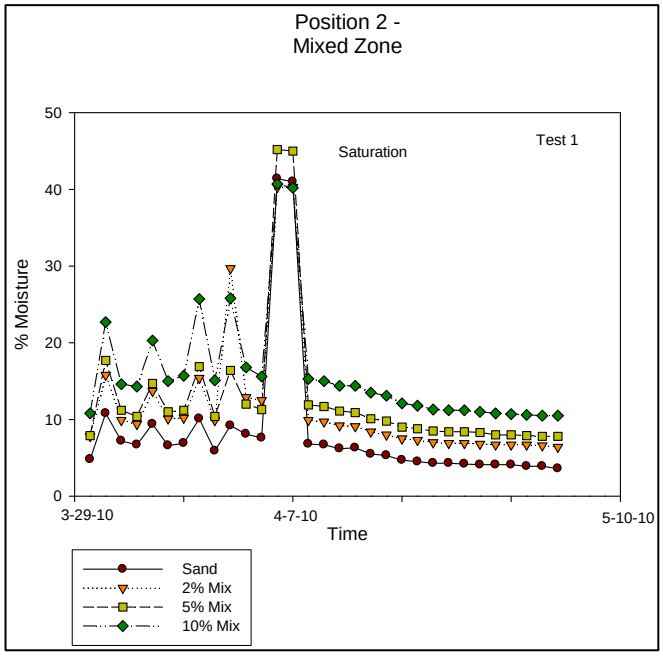


Figure 2-2c. Position of the sensors for Task II. The Lassenite treatment area is outlined in orange. Position 1 is located directly beneath the treatment area, 1' from the end of the trough and 2' from the surface.



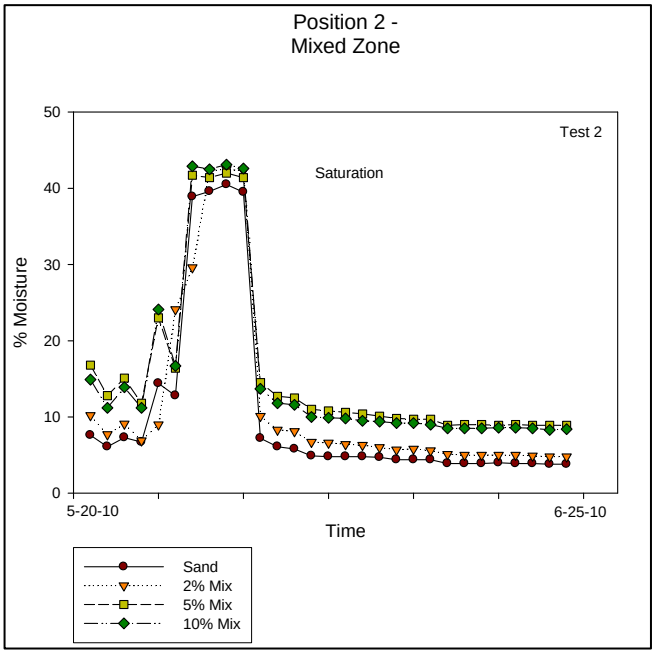


Figure 2-3a&b. Soil moisture changes at Position 2 over time for both replications are shown.

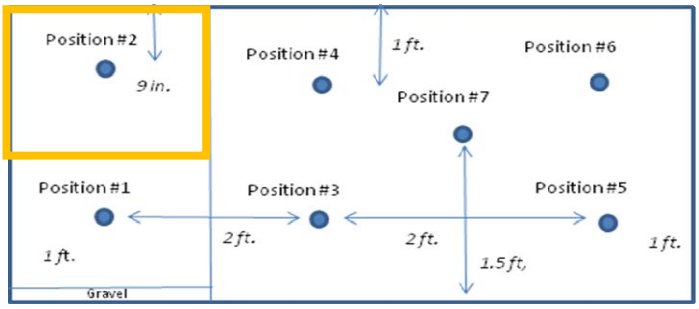
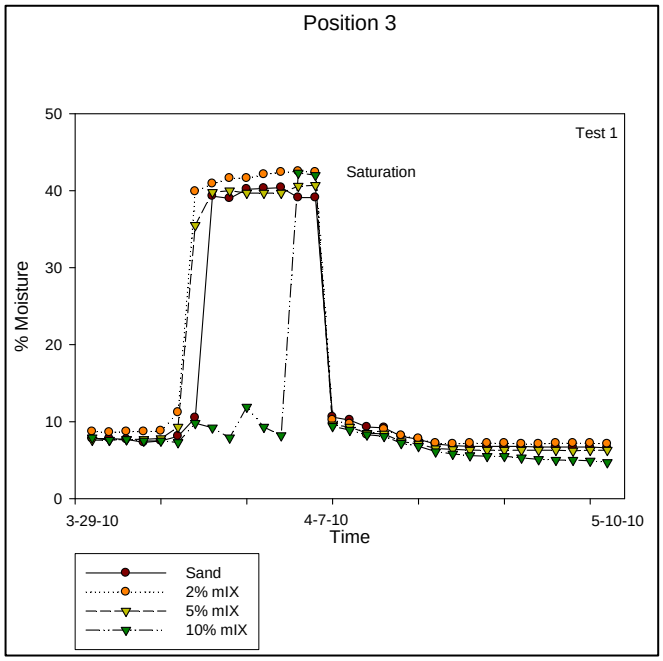


Figure 2-3c. Position of the sensors for Task II. The Lassenite treatment area is outlined in orange. Position 2 is located 1' from the end of the trough and 9" from the surface. It is the only sensor located within the treatment area.



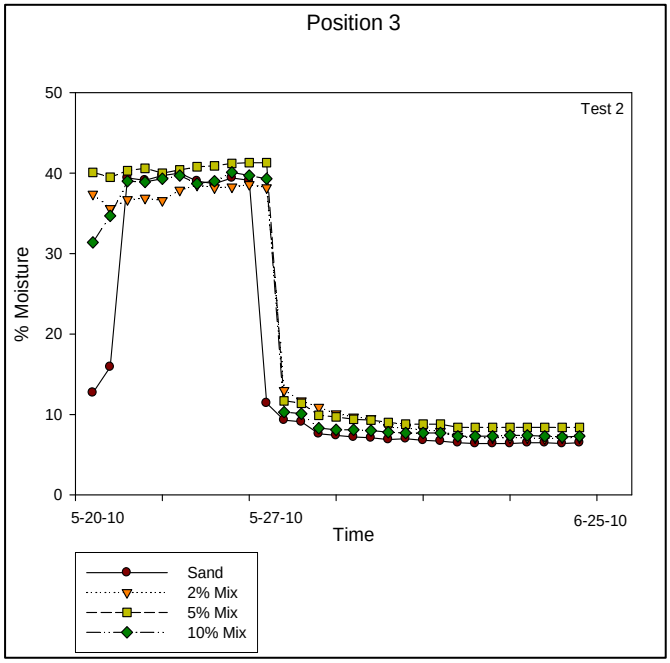


Figure 2-4a&b. Soil moisture changes at Position 3 over time for both replications are shown.

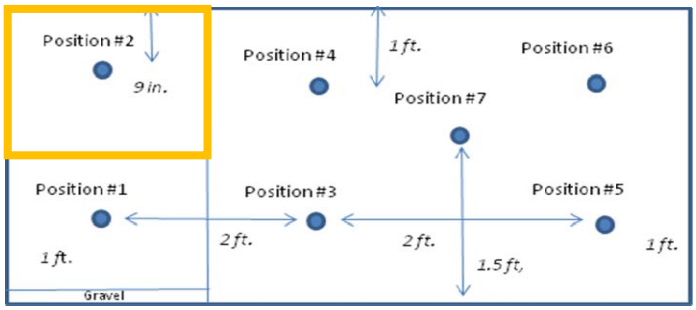


Figure 2-4c. Position of the sensors for Task II. The Lassenite treatment area is outlined in orange. Position 3 is located 3' from the end of the trough and 2' from the surface.

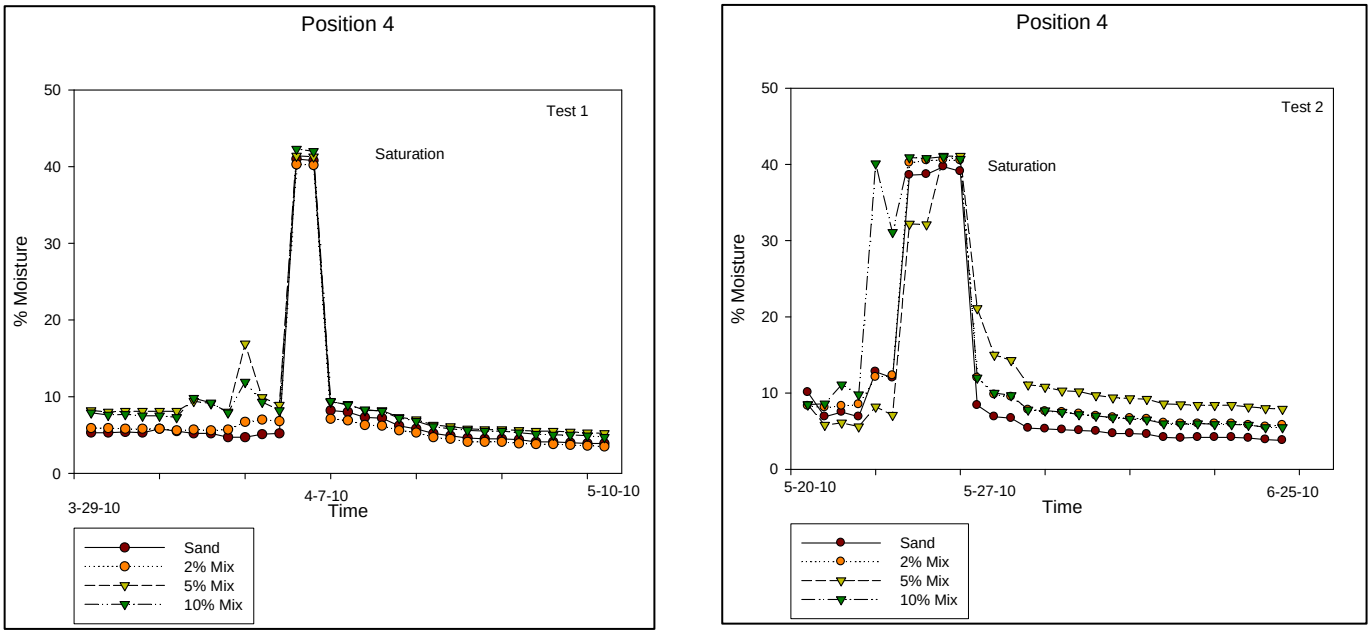


Figure 2-5a&b. Soil moisture changes at Position 4 over time for both replications are shown.

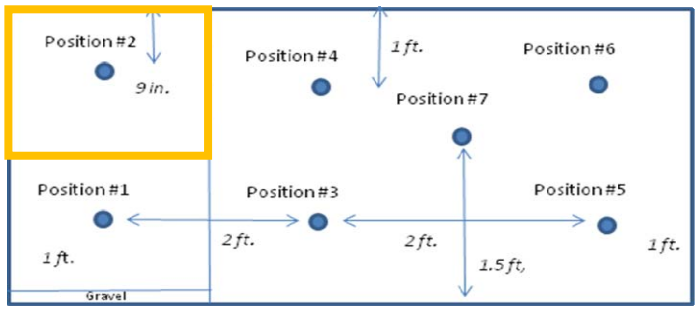


Figure 2-5c. Position of the sensors for Task II. The Lassenite treatment area is outlined in orange. Position 4 is located 3' from the end of the trough and 1' from the surface.

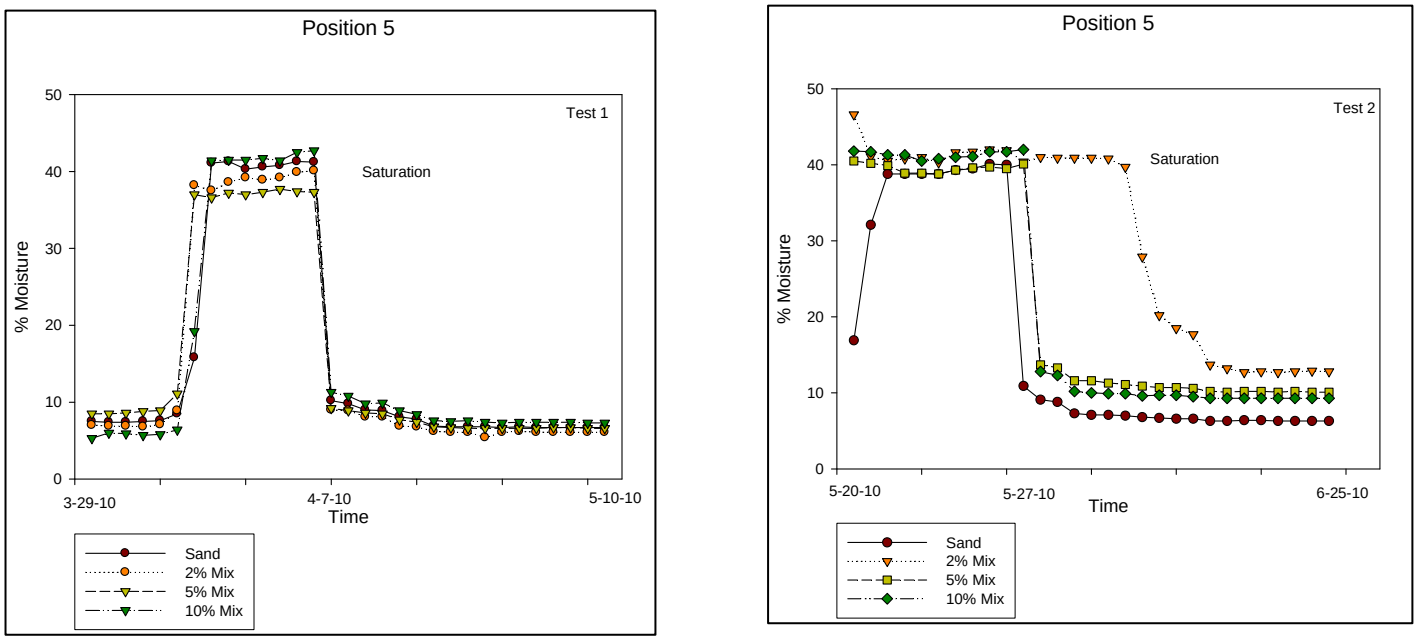


Figure 2-6a&b. Soil moisture changes at Position 5 over time for both replications are shown.

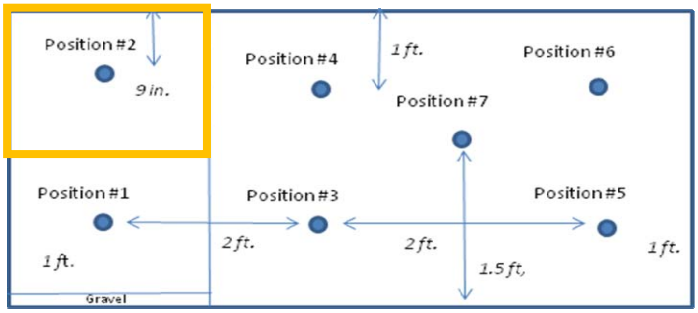
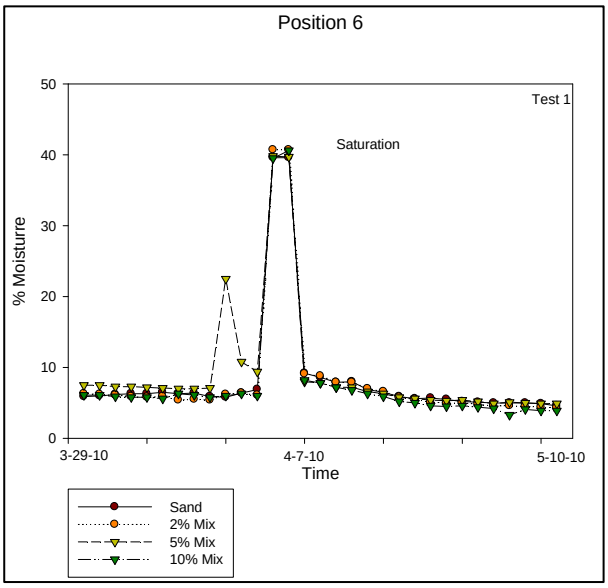


Figure 2-6c. Position of the sensors for Task II. The Lassenite treatment area is outlined in orange. Position 5 is located 5' from the end of the trough and 2' from the surface.



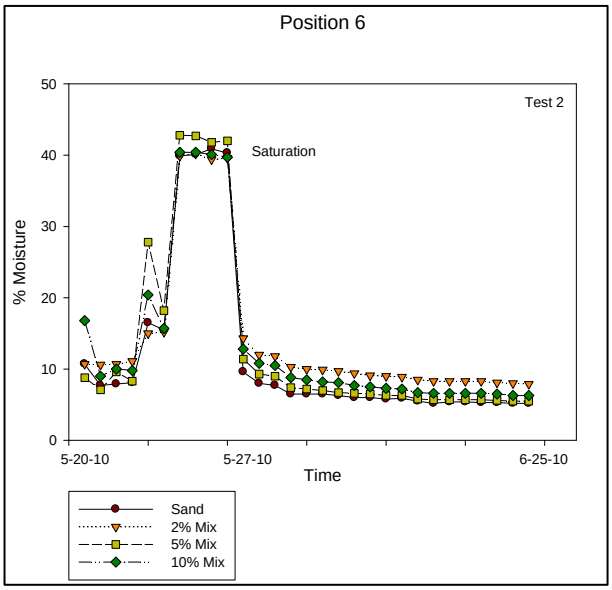


Figure 2-7a&b. Soil moisture changes at Position 6 over time for both replications are shown.

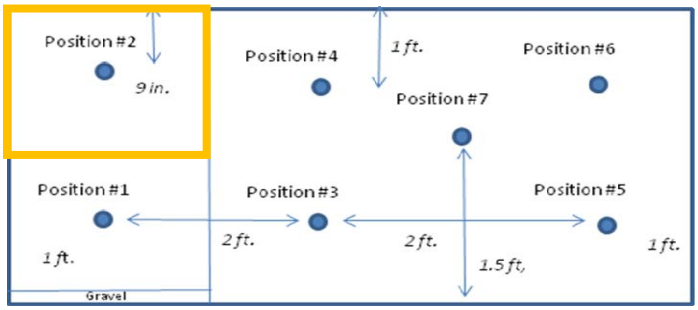
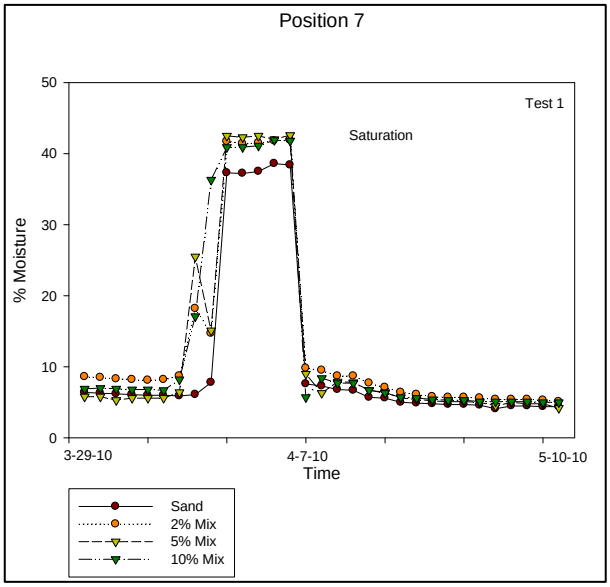


Figure 2-7c. Position of the sensors for Task II. The Lassenite treatment area is outlined in orange. Position 6 is located 5' from the end of the trough and 1' from the surface.



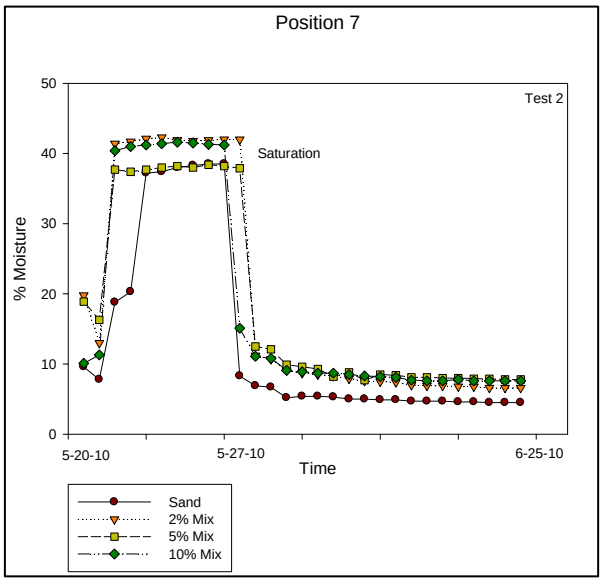


Figure 2-8a&b. Soil moisture changes at Position 7 over time for both replications are shown.

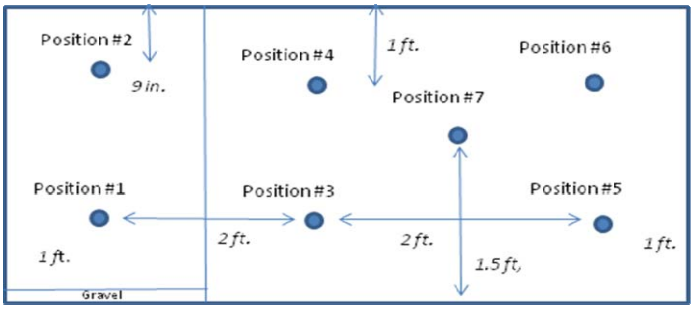


Figure 2-8c. Position of the sensors for Task II. The Lassenite treatment area is outlined in orange. Position 7 is located 4' from the end of the trough and 1.5' from the surface.

Table 2-3. Data Analysis, Task II

Note: Analysis was performed on data collected *after* saturation was achieved. The drains were opened and monitoring continued for approximately 30 days (drying out phase).

AOV table: Dependent variable = percent soil moisture, arcsin transformed to normalize

Sources of variation	Percentage of total experimental variation
Replicates (blocks, r = 2)	7.4
Lassenite mixture (t = 4)	6.2
Hours elapsed since saturation (continuous variable, transformed 1/h to straighten, n = 17 in block 1 and 19 in block 2)	25.8
Sensor (s = 7)	
All F values have 3,3 degrees of freedom	10.9
Block X Lassenite interaction	2.9
Block X Hours	< 0.1
Lassenite X Hours	0.7
Block X Sensor	4.3
Lassenite X Sensor	12.1
Hours X Sensor	0.1
Block X Hours X Sensor	2.0
Block X Lassenite X Hours	1.1
Block X Lassenite X Sensor	7.9
Lassenite X Hours X Sensor	1.1
Block X Lassenite X Sensor X Hours	0.1
Lack of fit to transformed Hours term	16.2

Tests of Lassenite-mixture effects

Factor tested	Tested against	Result
(1) Lassenite	Block X Lassenite	F = 2.14, df = 3,3, P = 0.27
(2) Lassenite X Hours	Block X Lassenite X Hours	F = 0.68, df = 3,3, P = 0.62

(3) Lassenite X Sensor	Block X Lassenite X Sensor	F = 1.53, df = 18,18, P = 0.19
(4) Lassenite X Hours X Sensor	Block X Lassenite X Hours X Sensor	F = 1.75, df = 18,18, P = 0.12

With all sensors **analyzed together**, Lassenite mixtures did not affect (1) overall soil moisture, (2) trends in soil moisture thru time, (3) distribution of soil moisture among sensors, or (4) trends in soil moisture thru time among sensors.

AOV's testing Lassenite mixtures (0, 2, 5, or 10% Lassenite) **split by sensor** (1-7)

Dependent variable = percent soil moisture, arcsin transformed to normalize

Lassenite treatments (t = 4)

Blocks (r = 2)

Hours elapsed (continuous variable transformed 1/hours)

Sensor	F (df 3,3)	P
1	1.80	0.32
2*	15.54	0.025
3	0.62	0.65
4	2.58	0.23
5	0.72	0.60
6	0.68	0.62
7	2.14	0.28

*Tukey's tests comparing means of 4 Lassenite treatments at sensor 2:

Comparison	P (df 3,3)
0% vs 2%	0.26
0% vs 5%	0.042
0% vs 10%	0.026
2% vs 5%	0.19
2% vs 10%	0.094
5% vs 10%	0.76

Appendix 3, Task III Data, Graphs and Analysis

Sensor #	8/9/2010 8:00 AM Pre-Irr.	8/9/2010 8:30 AM Post-Irr.*	8/10/2010 8:00 AM Pre-Irr.	8/10/2010 8:30 AM Post-Irr.*	8/11/2010 8:00 AM Pre-Irr.	8/11/2010 8:30 AM Post-Irr.*	8/12/2010 8:00 AM Pre-Irr.	8/12/2010 8:30 AM Post-Irr.*	8/13/2010 8:00 AM Pre-Irr.	8/13/2010 8:30 AM Post-Irr.*	End of Test	8/16/2010 2:00 PM Post-Test	8/18/2010 8:00 AM Post-Test	8/20/2010 8:00 AM Post-Test	8/23/2010 8:00 AM Post-Test	8/25/2010 8:00 AM Post-Test	8/27/2010 8:00 AM Post-Test
Trough #1 - Sand																	
1	1.5	8.5	3.1	8.7	2.9	8.9	3.7	14.9	3.4	21.8		2.4	2.1	1.7	1.1	0.8	0.3
2	4.6	4.3	3.8	4.3	4.0	3.7	5.0	4.8	4.6	10.1		5.2	4.5	3.9	3.3	2.4	2.4
3	3.2	3.1	3.3	3.2	3.0	3.1	3.0	2.8	2.7	2.7		2.0	1.3	1.5	1.1	0.4	0.2
4	1.5	1.5	1.3	1.3	1.1	1.1	0.7	0.8	0.5	0.7		0.0	0.0	0.0	0.0	0.0	0.0
5	3.7	12.2	5.6	12.1	5.3	11.0	5.6	9.4	5.3	25.9		4.3	3.9	3.5	3.1	2.7	2.2
6	4.2	3.9	3.9	3.5	3.5	8.3	5.0	4.2	5.0	11.9		4.5	4.0	3.6	2.6	2.2	2.3
7	1.5	1.6	1.5	1.3	1.2	1.1	0.9	0.9	0.6	0.7		0.0	0.0	0.0	0.0	0.0	0.0
8	2.8	8.8	4.5	9.8	3.8	9.9	3.7	22.5	3.4	24.2		2.8	2.1	2.3	1.2	0.6	0.2
9	2.5	2.3	2.0	1.7	1.7	1.7	1.5	1.5	1.5	1.6		1.5	1.0	0.9	0.3	0.3	0.0
10	0.9	0.9	1.8	0.7	0.6	0.6	0.6	0.5	0.3	0.3		0.0	0.0	0.0	0.0	0.0	0.0
11	2.0	2.2	2.8	11.4	3.5	9.7	4.5	8.6	4.4	10.0		3.1	2.8	2.3	2.1	1.9	1.7
12	1.5	1.5	1.3	1.6	1.2	1.1	0.9	1.7	1.7	1.7		1.3	1.3	1.1	1.0	0.8	0.6
13	2.4	2.4	2.2	2.1	2.8	2.9	3.2	8.2	4.2	10.3		3.4	2.9	2.7	2.2	2.2	1.9
14	1.4	1.6	1.7	1.6	1.4	1.5	0.8	0.8	1.4	1.5		0.9	0.9	0.2	0.6	0.4	0.3
15	5.0	14.6	7.2	14.6	7.3	13.0	6.6	15.3	6.3	31.2		4.9	4.5	4.3	4.3	3.8	3.4
16	4.2	4.1	4.2	4.5	4.1	4.2	4.3	4.5	3.8	8.1		4.3	4.1	3.9	3.7	3.6	3.6
17	3.6	3.6	3.3	3.3	2.8	2.3	3.3	3.1	3.1	2.9		2.7	2.6	2.0	2.0	1.8	1.9
18	4.1	4.0	3.9	3.9	4.0	3.8	3.7	3.7	3.7	3.9		3.5	3.5	3.2	3.2	3.3	2.1
19	3.8	4.0	4.1	16.1	5.7	12.1	6.2	11.0	6.0	12.9		4.6	4.1	3.8	3.6	3.3	3.2
20	3.3	3.3	3.2	3.2	2.2	3.0	3.0	2.9	2.8	2.9		2.6	2.3	2.2	2.2	2.0	1.9
21	3.7	3.7	3.4	3.4	3.3	3.6	3.6	3.6	3.5	3.5		3.3	3.2	3.2	3.1	3.0	2.8
Trough #2 - Sand																	
22	1.9	8.2	3.3	8.4	3.1	8.5	3.2	7.1	3.3	9.0		2.0	0.9	1.2	0.5	0.2	0.0
23	0.3	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0
24	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0
25	2.2	1.6	1.7	1.7	1.7	1.5	1.2	1.9	1.0	1.2		0.2	0.0	0.0	0.0	0.0	0.0
26	1.1	7.3	2.2	7.2	1.9	7.1	2.0	5.7	2.0	6.3		0.7	0.9	0.7	0.3	0.0	0.0
27	3.9	3.7	3.5	3.4	3.3	3.2	2.9	2.9	2.4	2.7		2.4	2.2	1.7	1.1	0.7	0.4
28	2.0	1.4	1.5	1.5	1.1	1.2	0.9	1.0	0.7	0.8		0.0	0.0	0.0	0.0	0.0	0.0
29	3.2	3.8	4.0	10.1	4.4	10.5	4.2	8.8	4.3	11.3		3.1	2.7	2.4	2.2	1.8	1.6
30	4.0	3.9	3.6	3.7	3.1	3.3	3.2	2.9	2.6	2.7		3.0	2.6	2.1	1.1	0.5	0.0
31	1.5	1.5	1.4	1.7	1.4	1.2	1.0	0.9	0.7	0.7		0.1	0.0	0.0	0.0	0.0	0.0
32	1.5	9.3	3.2	9.3	2.0	9.3	3.9	7.8	1.9	9.6		1.4	1.2	0.9	0.4	0.2	0.1
33	0.8	0.5	0.5	0.3	0.7	0.2	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0
34	3.0	2.3	3.0	9.7	4.1	10.4	4.0	8.8	3.7	10.5		2.4	2.0	1.9	1.5	1.0	0.9
35	2.0	1.6	2.4	6.5	1.4	1.2	1.0	1.0	0.9	0.8		0.6	0.4	0.5	0.1	0.0	0.0
36	4.8	17.1	8.2	15.7	7.1	15.5	7.3	13.5	6.9	16.3		5.3	4.5	4.0	3.7	4.0	3.2
37	4.0	4.2	3.8	3.8	3.6	3.5	3.4	3.4	3.2	3.5		3.7	3.5	3.0	2.8	2.4	2.1
38	2.0	2.0	1.7	2.0	1.7	2.3	2.5	2.3	1.3	2.0		0.8	0.2	0.4	0.6	0.1	0.0
39	2.2	1.8	1.7	1.7	1.4	1.4	1.5	1.3	1.2	2.2		0.8	1.2	0.5	0.3	0.2	0.2
40	4.3	11.8	6.8	13.5	5.8	14.0	6.2	12.4	6.2	15.0		4.7	4.1	3.1	2.8	3.2	3.2
41	2.8	2.6	2.5	2.4	2.6	2.3	2.3	2.2	2.0	2.2		2.0	0.7	1.6	1.4	1.2	1.1
42	4.8	5.0	4.7	4.6	4.5	4.3	4.4	4.0	4.5	4.2		3.7	3.6	3.6	3.1	3.1	2.8

Table 3-1. Data Task 3, Soil Moisture Data from Control (sand) Troughs. Data in blue columns was collected after 25 gallons of water was added to each trough. Data in orange was collected after all water was added to troughs, during the "drying out" phase.

Trough #3 - 5% Mix																	
43	40.5	47.8	43.0	46.3	42.6	45.1	42.0	43.9	41.7	45.0	40.4	38.9	37.2	34.0	30.3	29.0
44	18.4	23.4	20.3	23.2	20.5	23.0	20.7	22.1	20.6	23.6	19.9	18.9	17.0	15.3	13.6	12.5
45	21.1	28.4	24.4	27.9	24.1	28.3	24.0	27.9	23.9	28.7	22.8	21.1	19.3	17.2	15.1	14.3
46	34.7	44.6	41.6	45.6	41.1	45.5	40.9	44.5	40.2	46.9	38.2	34.9	30.9	27.2	24.2	22.9
47	1.7	11.2	3.4	11.5	3.2	10.6	3.5	8.4	3.7	11.8	2.6	2.2	1.7	1.4	0.7	0.3
48	5.4	17.5	7.6	16.3	7.6	14.9	7.7	12.5	7.7	16.4	6.6	6.1	5.7	4.7	4.0	3.5
49	5.1	17.6	9.3	17.0	9.2	17.2	9.2	16.9	9.2	19.2	7.5	6.3	5.3	4.6	3.7	3.4
50	4.2	14.4	6.5	13.5	6.4	14.4	6.3	13.6	6.4	15.2	5.4	5.1	4.3	4.2	3.2	2.6
51	1.6	7.1	1.1	5.9	1.2	6.1	1.1	5.9	1.1	7.3	0.2	0.0	0.0	0.0	0.0	0.0
52	1.1	14.0	4.8	13.0	4.8	12.2	4.7	9.4	4.3	11.9	3.9	3.5	3.1	1.7	2.0	1.6
53	2.6	12.4	3.9	11.8	4.0	10.6	4.0	8.3	4.0	11.5	3.5	3.3	3.1	2.3	2.5	2.5
54	8.2	15.2	7.5	19.1	7.3	15.7	7.3	18.1	7.3	16.4	6.6	6.1	5.9	5.6	5.4	5.1
55	4.5	12.5	5.7	12.4	5.8	11.6	5.8	11.5	5.7	12.8	5.3	4.8	4.8	4.7	4.4	4.4
56	3.4	11.4	4.2	11.5	4.3	11.3	4.6	11.1	4.5	12.9	3.8	3.5	3.2	3.0	2.8	2.6
57	1.4	9.3	2.6	9.2	2.5	9.0	2.6	6.6	2.6	10.5	2.3	1.7	1.5	1.3	1.0	0.9
58	4.6	13.2	6.1	12.9	6.2	12.4	6.2	10.0	6.1	13.9	5.3	5.0	4.6	4.0	3.7	3.6
59	4.4	10.3	5.4	11.4	5.8	12.0	5.6	11.6	5.7	11.6	5.0	4.9	4.6	4.3	4.2	4.0
60	4.3	10.5	5.2	12.4	5.3	12.1	5.6	11.9	5.6	13.5	4.8	4.7	4.0	4.1	3.8	3.7
61	6.1	14.3	7.5	15.2	7.6	15.0	7.5	11.9	7.6	15.8	6.8	6.6	6.5	6.3	6.1	6.3
62	5.4	20.1	5.9	12.3	5.9	12.9	6.1	11.1	12.9	11.4	5.3	4.8	4.8	4.6	4.7	4.3
63	1.0	3.6	1.7	6.6	2.1	10.7	1.8	4.7	16.4	7.3	3.4	1.4	1.1	1.0	0.9	0.9
Trough #4 - 5% Mix																
64	40.1	46.3	42.1	48.1	41.7	44.5	40.8	49.8	37.7	45.1	40.0	39.0	37.4	34.8	31.9	30.2
65	29.5	39.2	37.3	47.7	39.5	44.8	35.0	40.2	33.1	38.2	35.7	29.5	27.2	25.3	22.7	19.6
66	31.0	42.5	38.7	42.6	39.1	42.4	37.9	42.4	37.7	43.6	34.9	31.9	28.6	26.6	21.4	20.1
67	25.7	34.1	31.0	35.4	30.8	32.2	30.6	34.1	30.5	34.1	28.1	26.2	23.2	20.9	18.4	17.5
68	3.6	18.3	6.5	14.8	6.8	15.6	6.7	14.9	6.6	16.6	5.4	4.8	4.1	3.7	2.6	2.1
69	2.7	12.6	6.1	12.0	5.8	11.9	6.0	12.3	6.0	12.6	4.8	3.9	3.2	2.9	1.6	1.0
70	2.6	14.2	6.2	14.3	6.3	14.1	6.5	13.9	6.2	14.7	8.6	3.7	2.5	1.5	0.8	0.3
71	3.6	14.5	13.6	14.7	6.4	15.3	6.3	14.7	6.5	14.9	5.5	4.5	4.3	2.9	2.3	2.0
72	2.5	14.9	6.7	13.7	6.8	13.6	6.3	13.7	6.0	14.2	5.0	3.3	3.0	2.7	0.9	0.5
73	5.4	14.3	7.4	14.7	6.7	14.1	7.3	14.5	9.1	15.3	6.3	5.3	4.0	3.3	2.9	2.4
74	1.4	11.9	4.5	12.5	8.8	12.1	4.8	12.6	5.5	13.4	3.7	5.6	3.5	2.8	2.3	2.3
75	5.0	15.5	6.7	15.8	6.0	15.1	6.8	15.4	7.0	16.6	5.1	5.5	5.2	4.7	4.8	4.2
85	7.9	16.9	10.5	17.0	11.6	16.6	10.7	20.1	10.6	17.5	10.1	8.7	8.2	7.3	6.4	6.3
77	6.9	18.2	8.9	18.2	8.8	17.2	9.1	17.4	9.0	20.2	7.9	7.2	7.1	7.1	6.3	6.1
78	6.0	15.9	9.3	15.9	8.1	15.3	7.9	16.3	7.9	18.0	6.5	7.3	6.4	6.2	6.1	3.8
79	3.0	8.9	4.8	10.2	5.2	9.6	4.4	10.5	4.6	10.6	3.0	3.2	3.2	3.0	2.3	2.5
80	5.2	5.9	7.1	7.4	7.0	8.7	7.1	9.4	7.6	17.7	6.8	5.8	5.5	5.5	4.5	4.4
81	2.5	2.7	3.5	8.5	3.7	8.5	3.9	8.6	3.9	9.4	3.0	2.8	2.5	2.0	1.4	1.5
82	0.4	8.9	4.2	11.3	4.1	9.2	4.5	9.4	4.2	10.0	4.1	3.4	4.0	3.7	2.9	2.8
83	6.0	6.6	7.3	15.0	7.0	14.6	7.9	18.4	7.3	15.4	11.4	6.8	5.9	5.8	5.7	5.4
84	4.3	5.5	5.5	12.0	5.6	11.9	5.6	12.2	5.7	13.2	4.8	4.8	4.5	4.2	4.0	3.8
Humidity/Temp	51/71		46/71		40/72		41/72		42/71	43/71	68/71	41/71	43/71	41/74	53/70	35/71

* Post irrigation readings were taken 15 min. after the water was stopped

Table 3-2. Data, Task III, Soil Moisture Data from Treatment Troughs (5% Lassenite in furrows). Data in blue columns was collected after 25 gallons of water was added to each trough. Data in orange was collected after all water was added to troughs, during the "drying out" phase. Temperature and humidity data were collected during the experiment, but were not controlled.

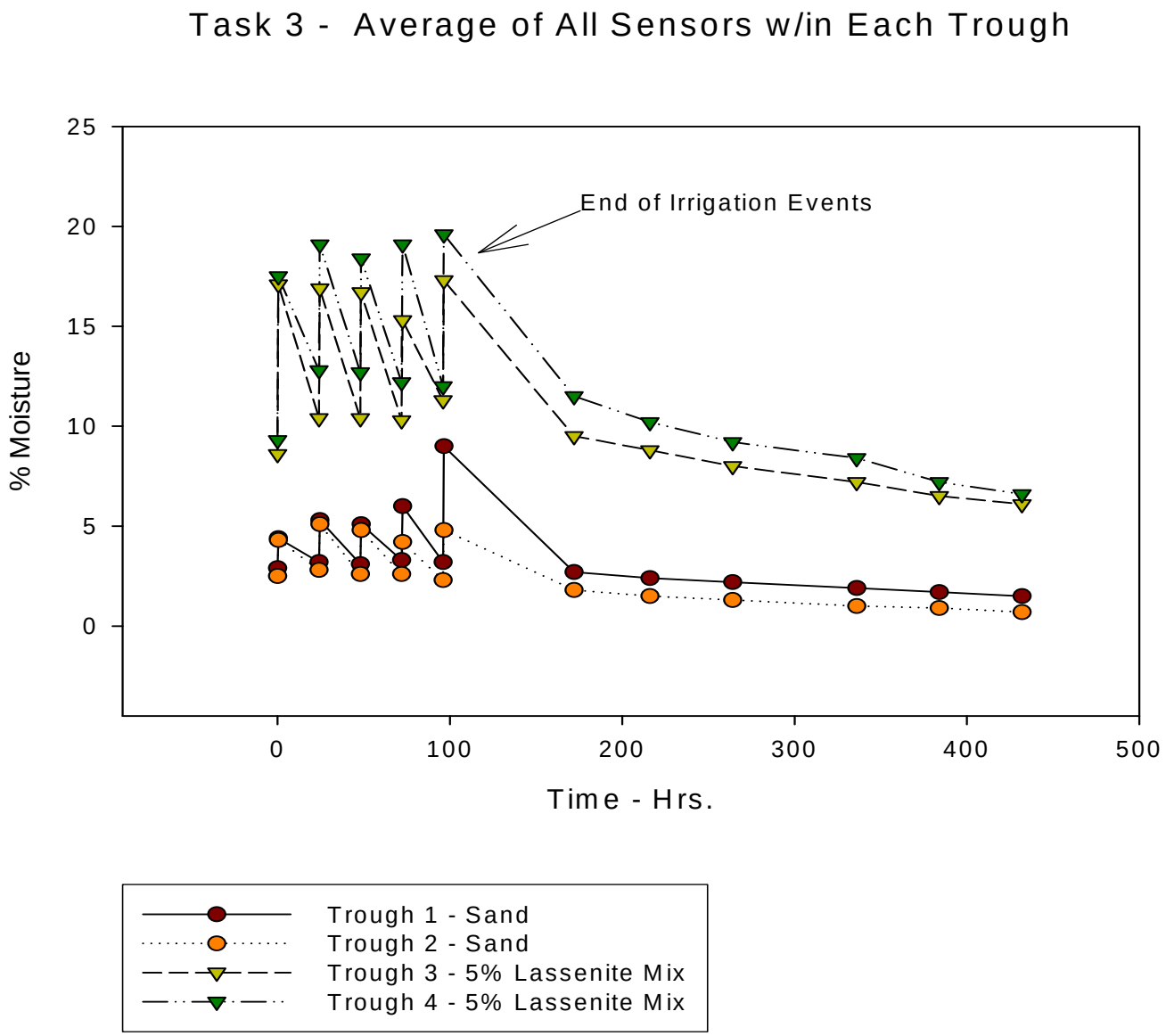


Figure 3-1. Average moisture at all sensors in each trough through time.

		Sensor Numbers				
Trough #	Fill Material	Position # 1*	Position # 2*	Position # 3*	Position #4*	Position #5*
1	Sand	1-4	5-7(left) 8-10 (right)	11-12 (left) 13-14 (right)	15-18	19-21
2	Sand	22-25	26-28 (left) 29-31 (right)	32-33 (left) 34-35 (right)	36-39	40-42
3	5% Mix	43-46	47-49 (left) 50-52 (right)	53-54 (left) 55-56 (right)	57-60	61-63
4	5% Mix	64-67	68-70 (left) 71-73 (right)	74-75 (left) 85,77 (right)	78-81	81-84

*All sensor numbers within a position increase from the water source toward the end of the trough, except for sensor #85 which was a substitute

Position #1 - In furrow, 3” deep, @ 3’,6’,9’, 11.5’ from water source.

Position #2 – Parallel to furrow, midway between side and furrow, 3” deep, @ 3’,6’,9’ from water source.

Position #3 – Parallel to furrow, midway between side and furrow, 9” deep, @ 4’,8’ from water source.

Position #4 – Directly beneath furrow, 9” deep, @ 3’,6’,9’,11.5’ from water source.

Position #5 – Directly beneath furrow, 12 “ deep, @ 4’,8’,11’ from water source.

Table 3-2. Sensors 1-84 were placed in the four troughs at five different positions, based on depth and distance from water source.

Figures 3-2 through 3-22 compare soil moisture results from similar locations in each trough.

Note scale differences on "% Moisture" axis.

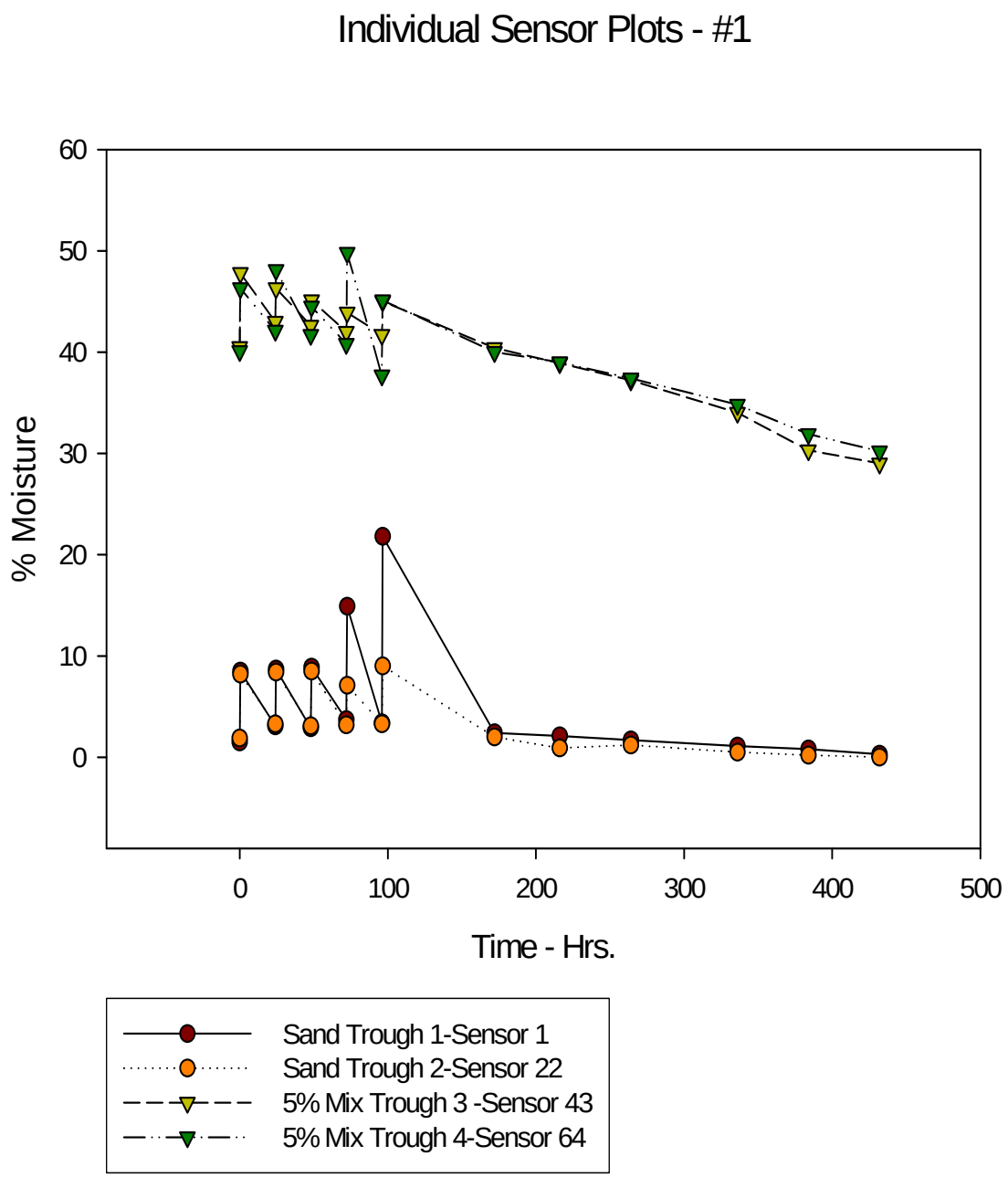


Figure 3-2. Position 1: Sensors 43 and 64 located within the 100% Lassenite furrow, 3" deep and 3' from the water source; Sensors 1 and 22 in similar positions in control trough.

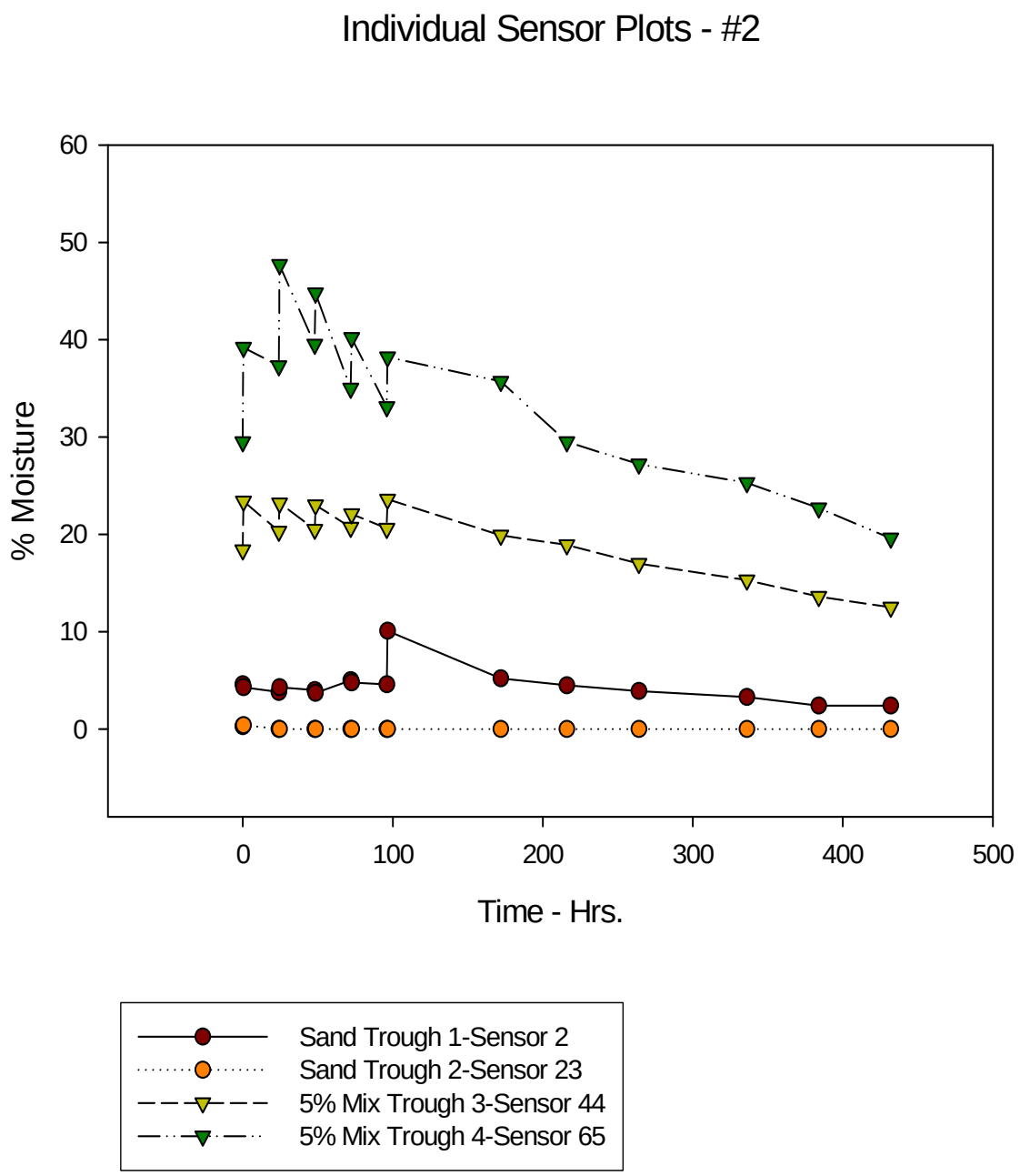


Figure 3-3. Position 1: Sensors 44 and 65 located within the 100% Lassenite furrow, 3" deep and 6' from the water source; Sensors 2 and 23 located in similar position in control trough.

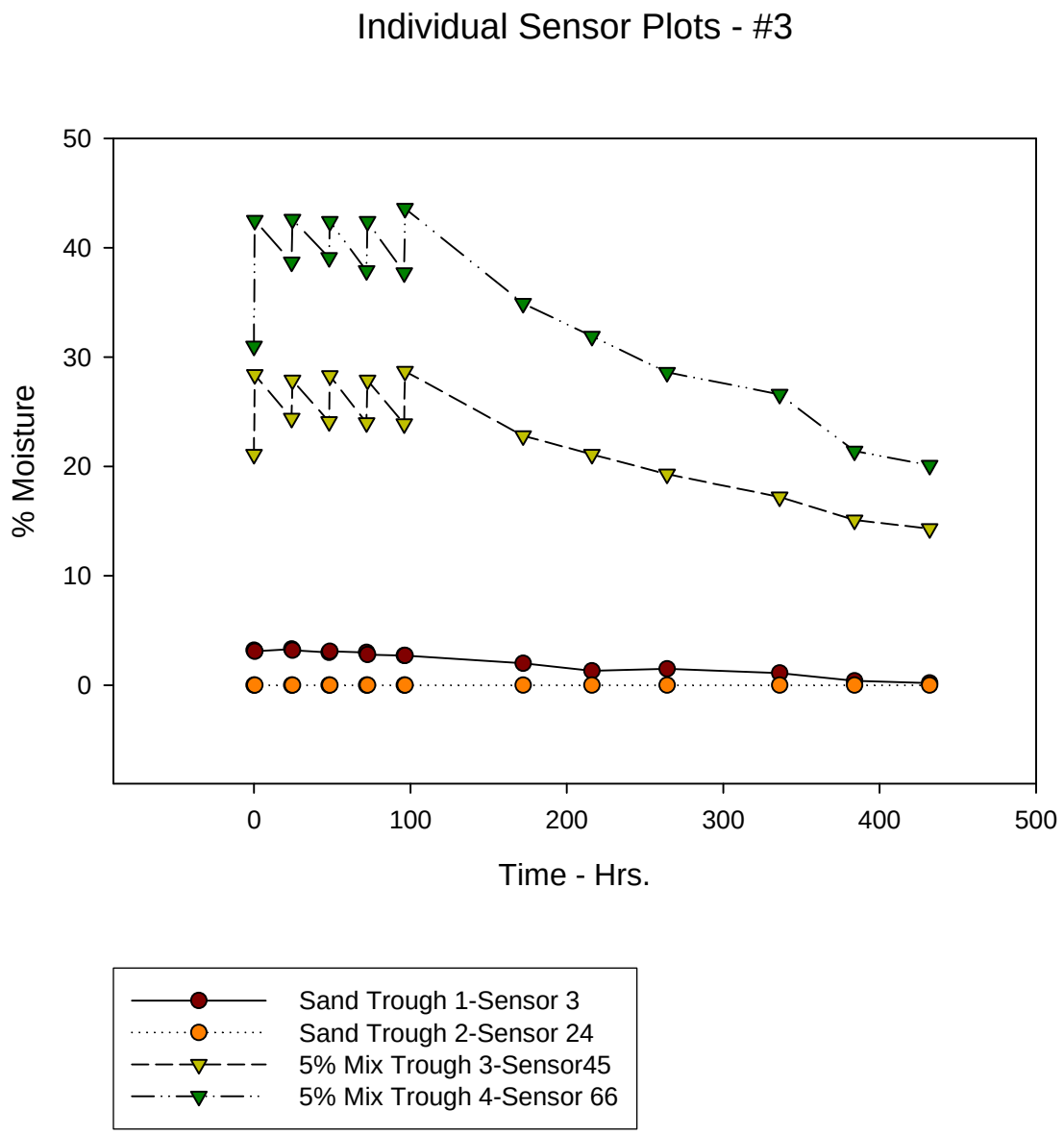


Figure 3-4. Position 1: Sensors 45 and 66 located within the 100% Lassenite furrow, 3" deep and 9' from the water source; Sensors 3 and 24 located in similar positions in control trough.

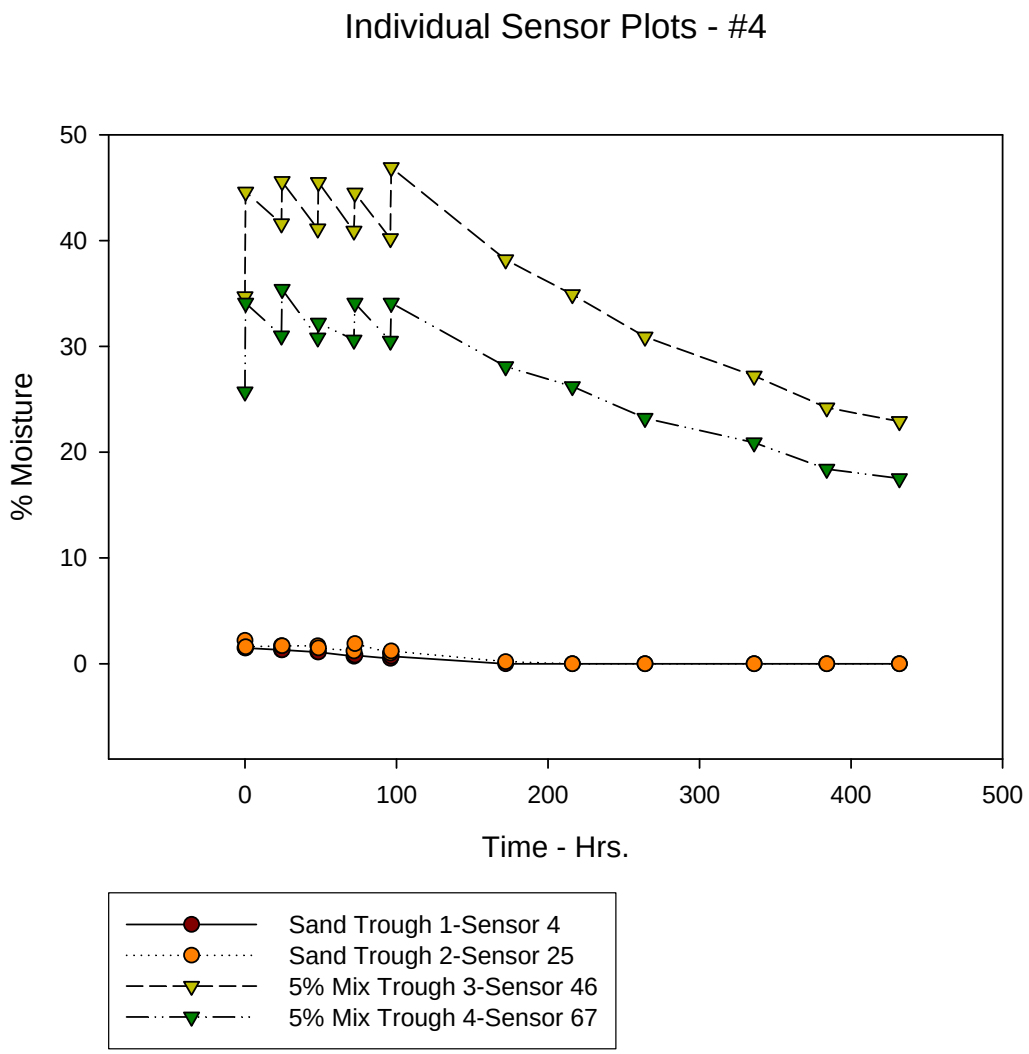


Figure 3-5. Position 1: Sensors 46 and 67 located within the 100% Lassenite furrow, 3" deep and 11.5' from the water source; Sensors 4 and 25 located in similar position in control trough.

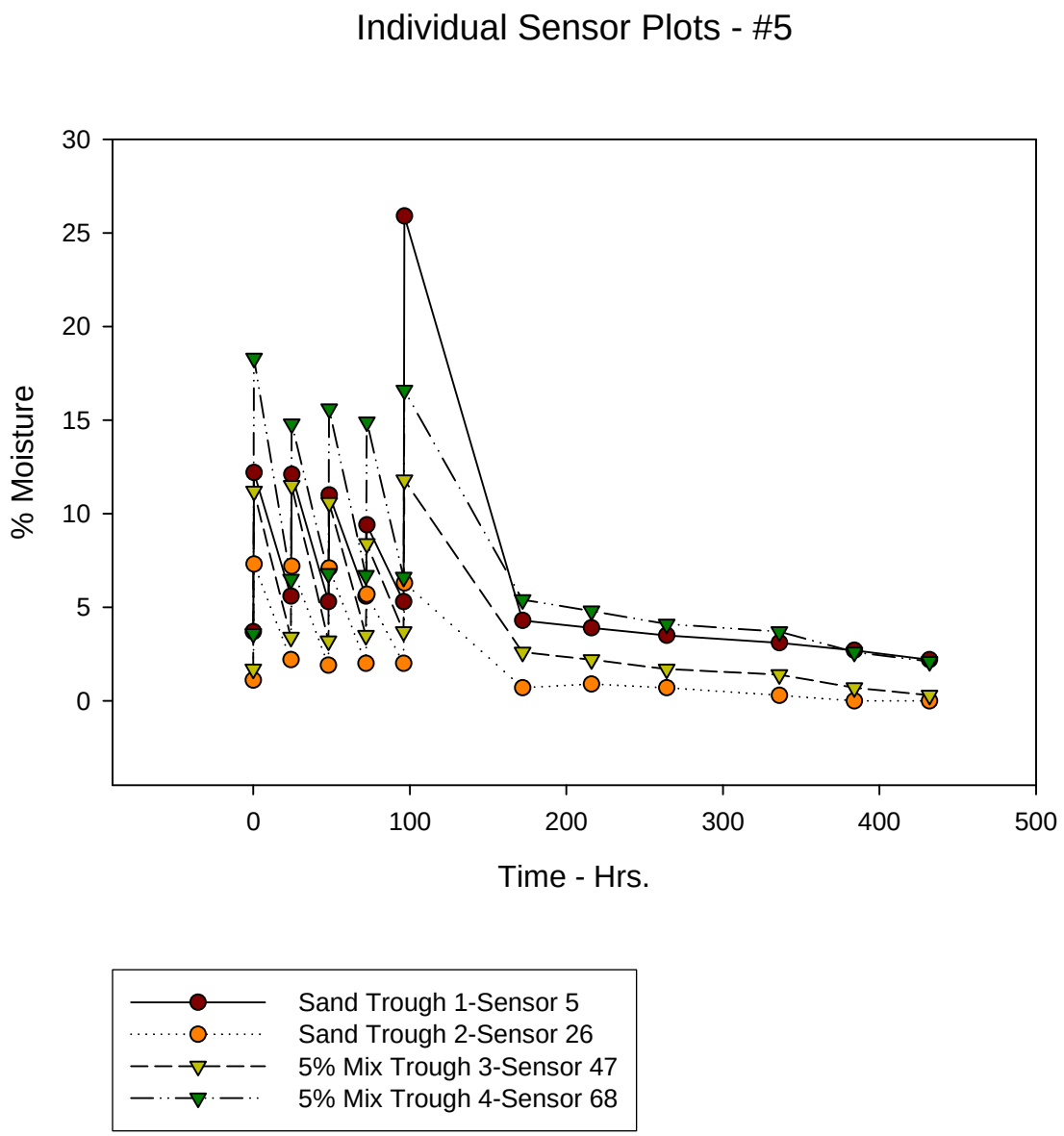


Figure 3-6. Position 2: Sensors 47 and 68 located parallel to the 100% Lassenite furrow, midway between one side of the trough and the furrow, 3" deep and 3' from the water source; Sensors 5 and 26 placed in similar positions in control trough.

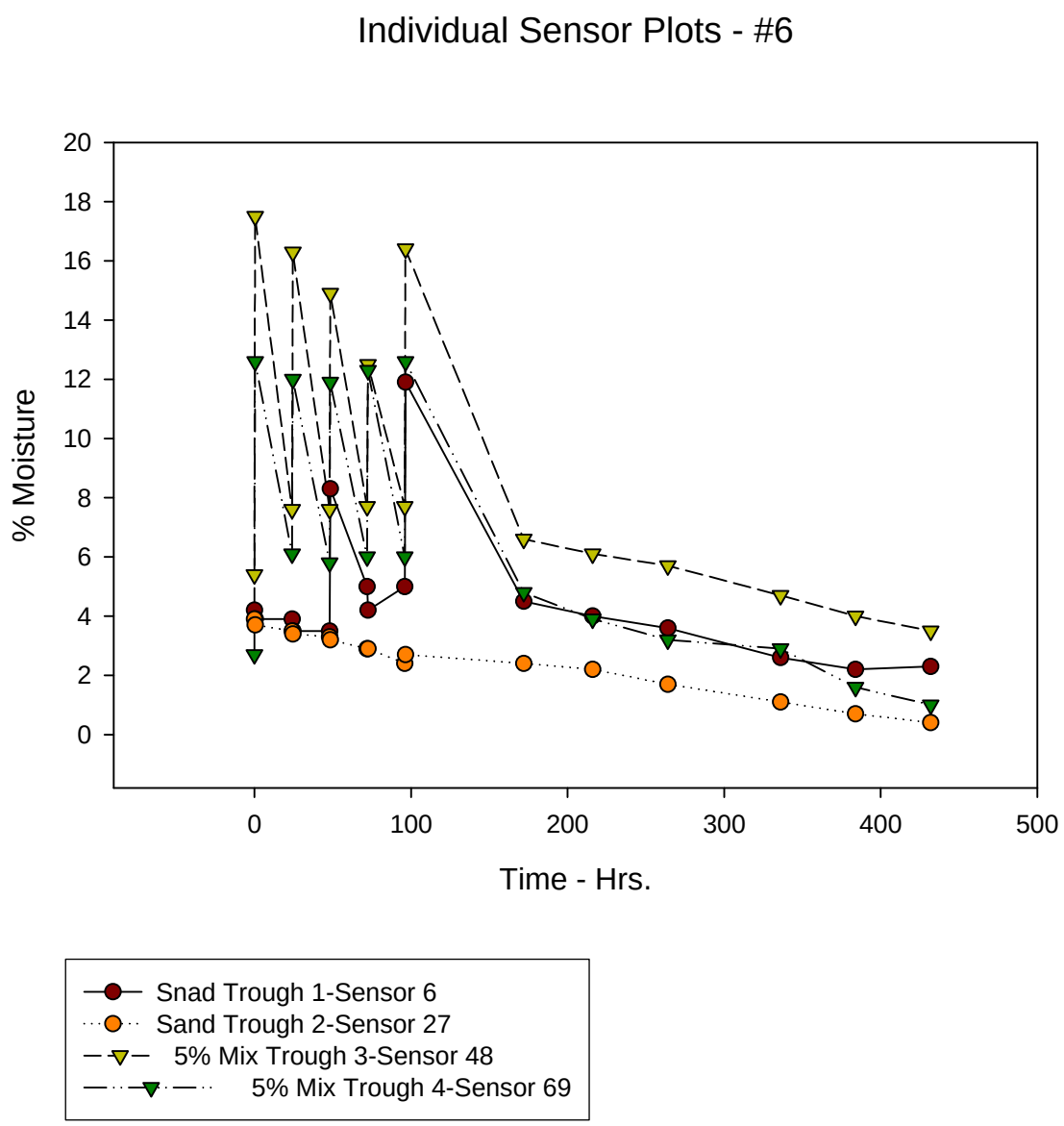


Figure 3-7. Position 2: Sensors 48 and 69 located parallel to the 100% Lassenite furrow, midway between one side of the trough and the furrow, 3" deep and 6' from the water source; Sensors 6 and 27 placed in similar locations within control trough.

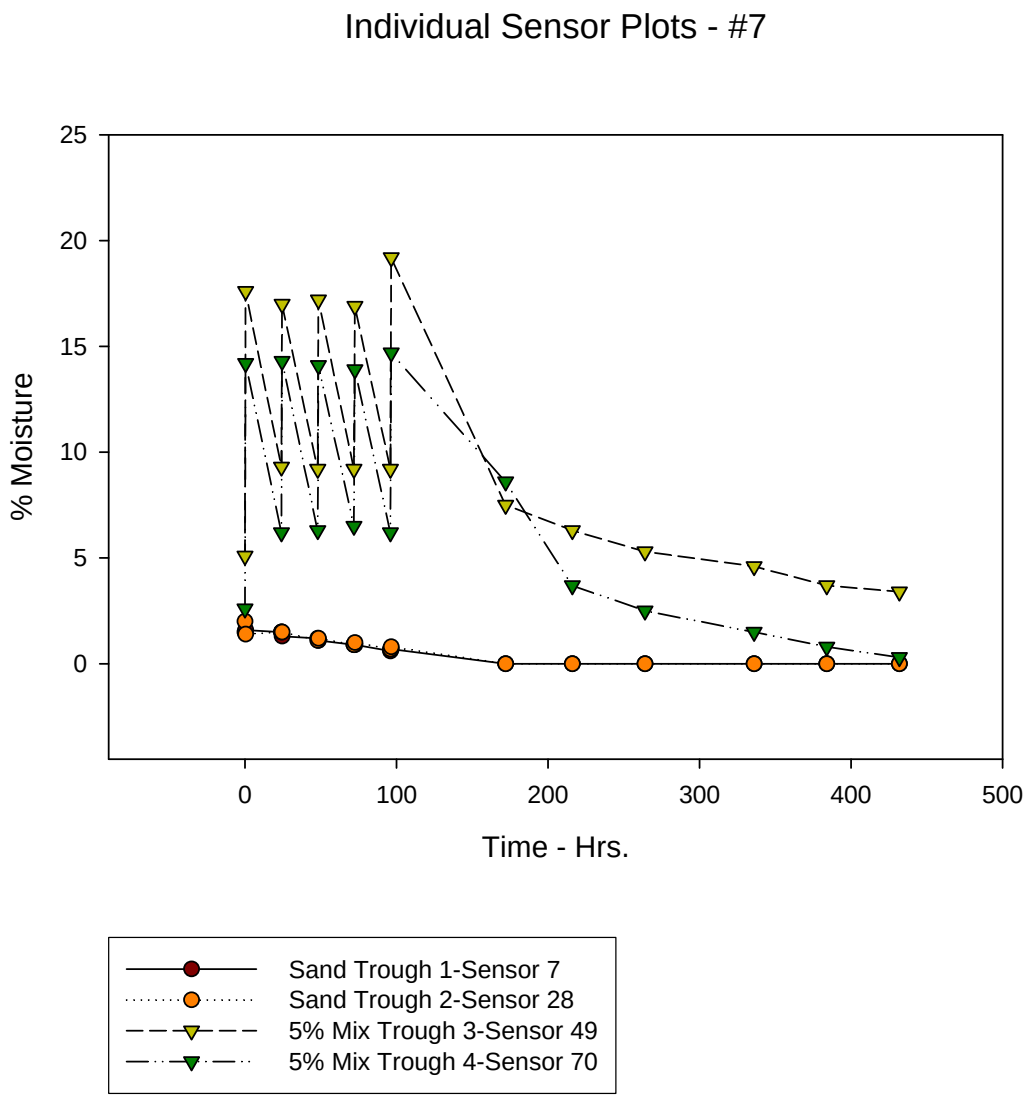


Figure 3-8. Position 2: Sensors 49 and 70 located parallel to the 100% Lassenite furrow, midway between one side of the trough and the furrow, 3" deep and 9' from the water source; Sensors 7 and 28 placed in similar locations within control trough.

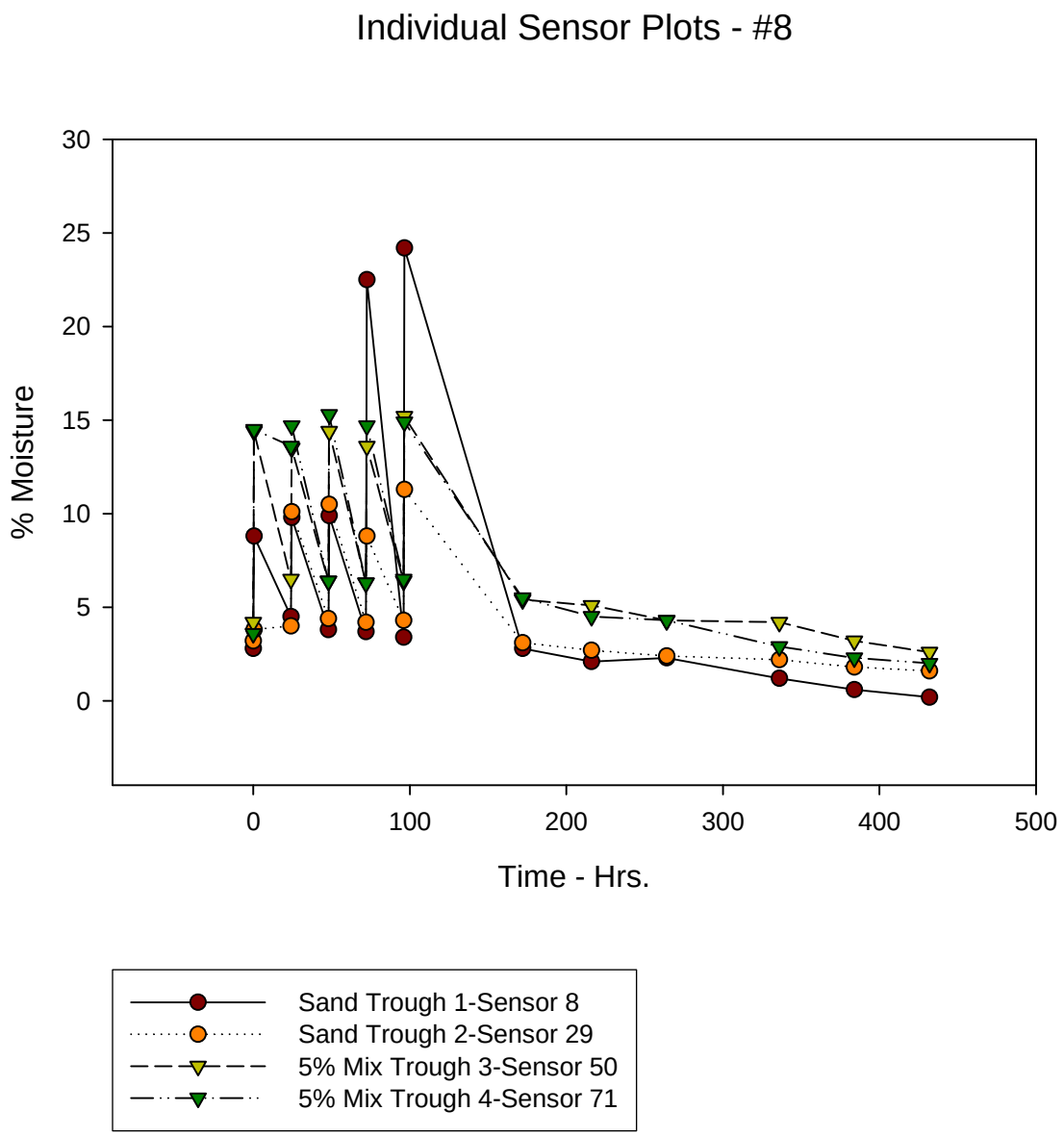


Figure 3-9. Position 2: Sensors 50 and 71 located parallel to the 100% Lassenite furrow, midway between one side of the trough and the furrow, 3" deep and 3' from the water source; Sensors 8 and 29 placed in similar locations within control trough.

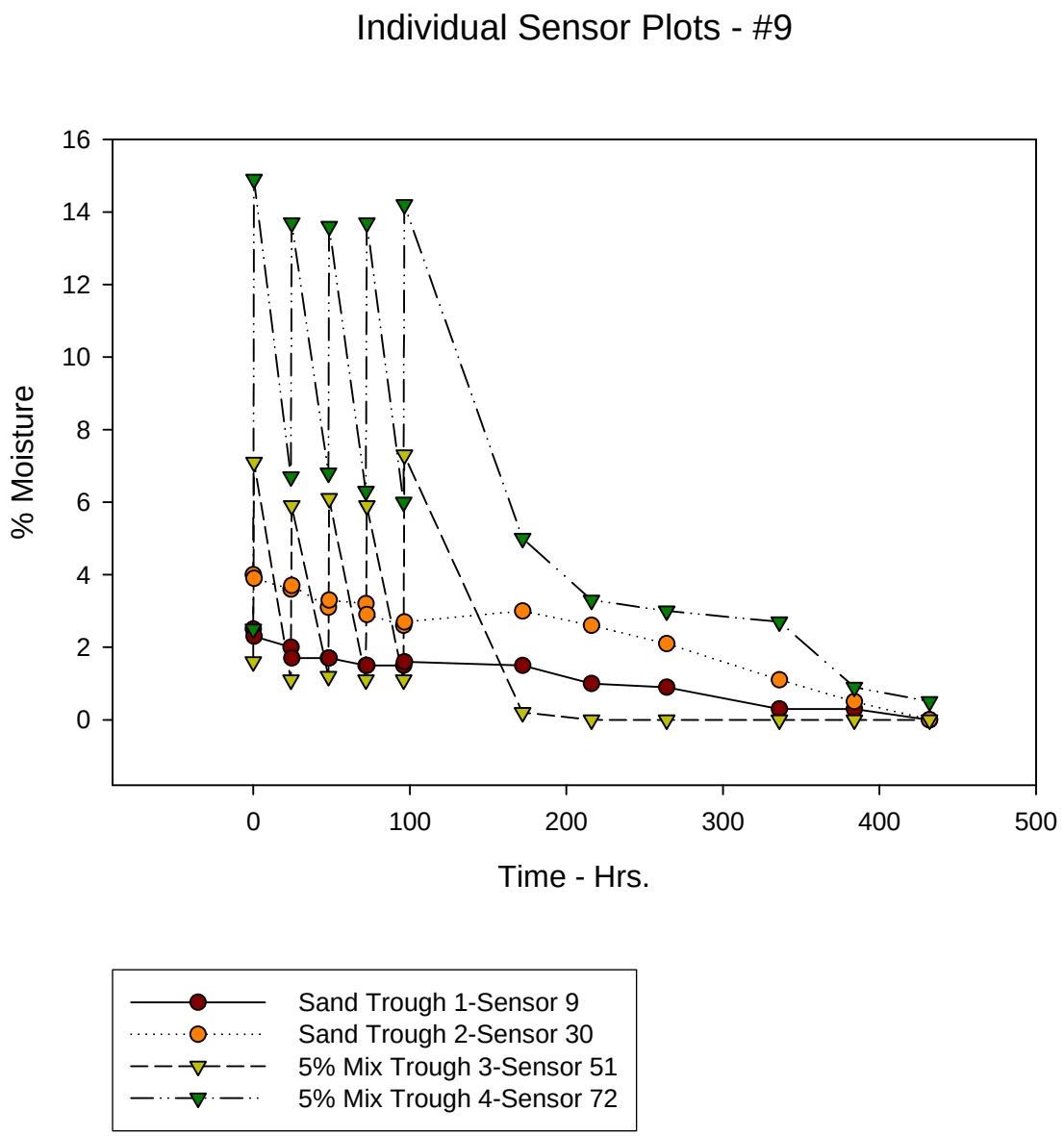


Figure 3-10. Position 2: Sensors 51 and 72 located parallel to the 100% Lassenite furrow, midway between one side of side of the trough and the furrow, 3" deep and 6' from the water source; Sensors 6 and 27 placed in similar locations within control trough.

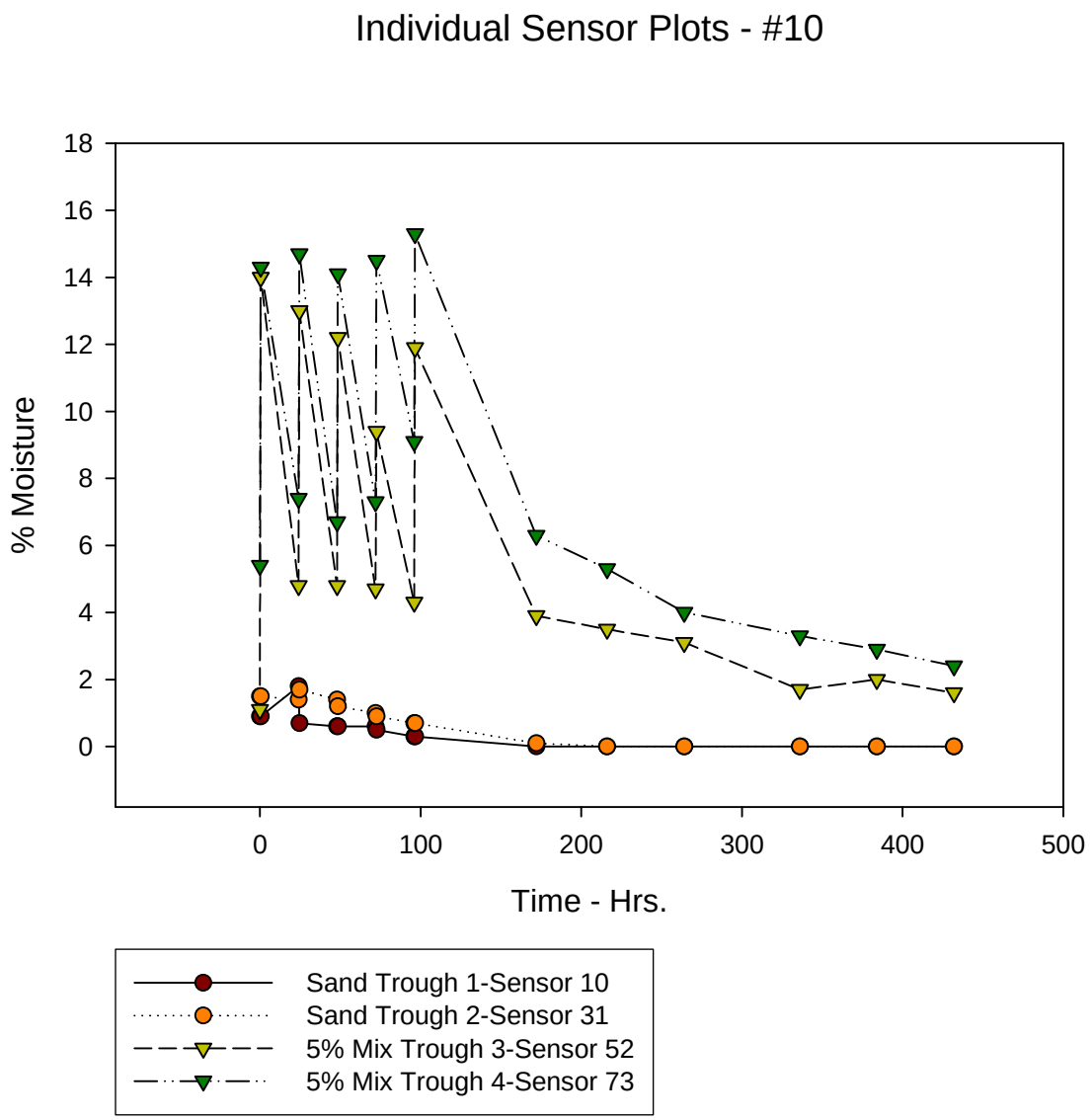


Figure 3-11. Position 2: Sensors 52 and 73 located parallel to the 100% Lassenite furrow, midway between one side of the trough and the furrow, 3" deep and 9' from the water source; Sensors 10 and 31 placed in similar positions in control trough.

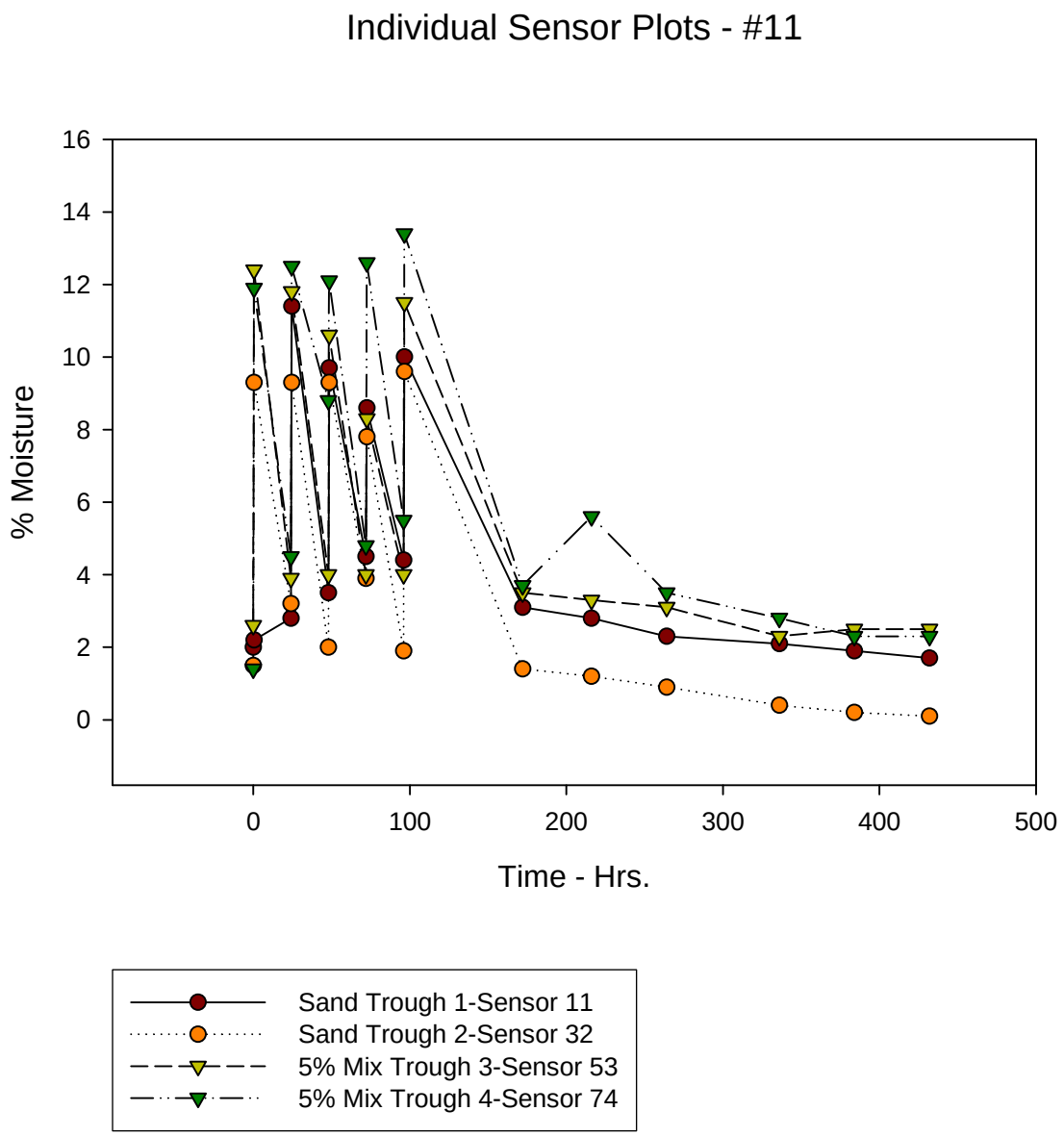


Figure 3-12. Position 3: Sensors 53 and 74 located parallel to the 100% Lassenite furrow, midway between one side of the trough and the furrow, 9" deep and 4' from the water source; Sensors 11 and 32 placed in similar position in control trough.

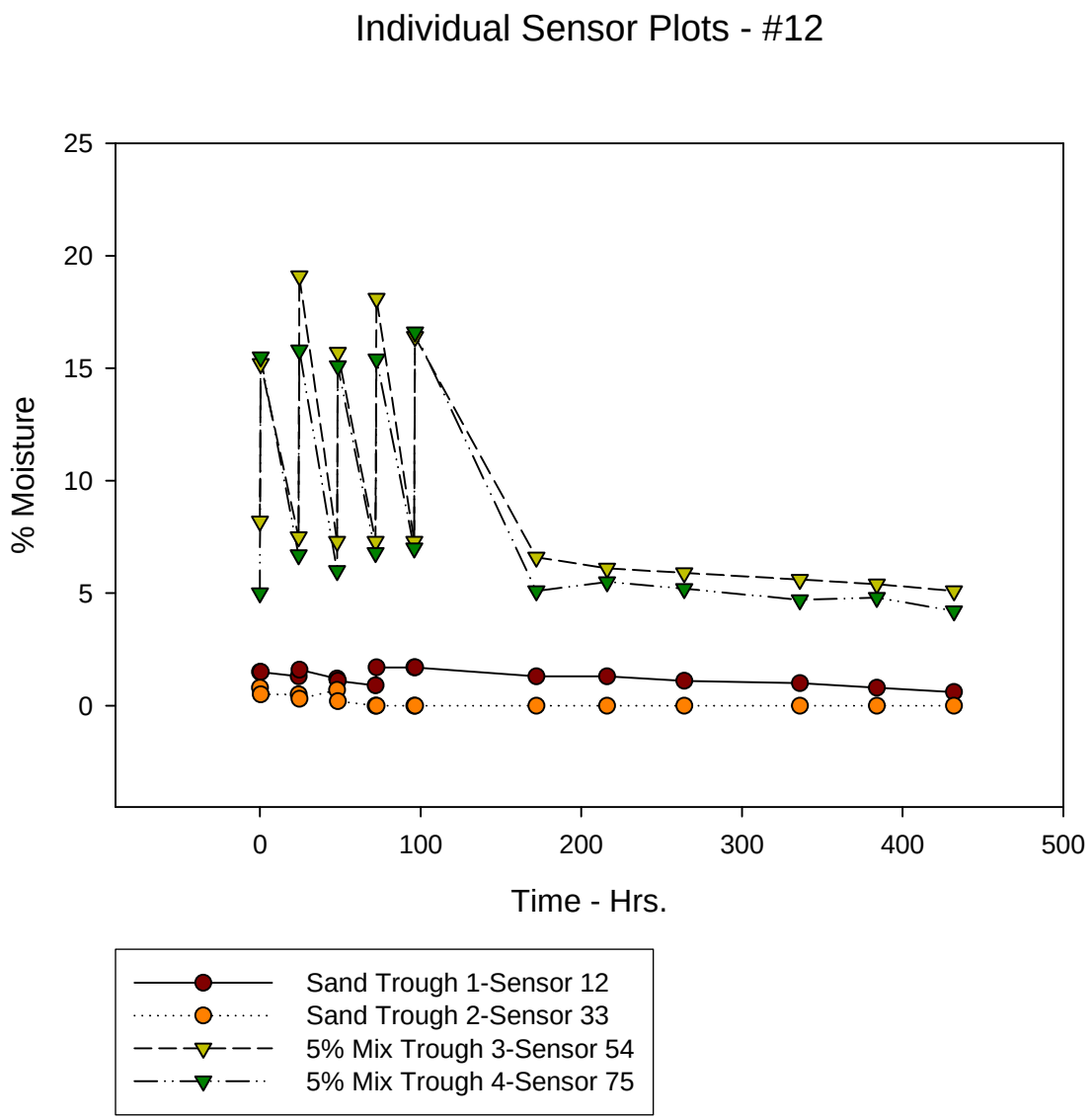


Figure 3-13. Position 3: Sensors 54 and 75 located parallel to the 100% Lassenite furrow, midway between one side of the trough and the furrow, 9" deep and 8' from the water source; Sensors 12 and 33 placed in similar locations in control trough.

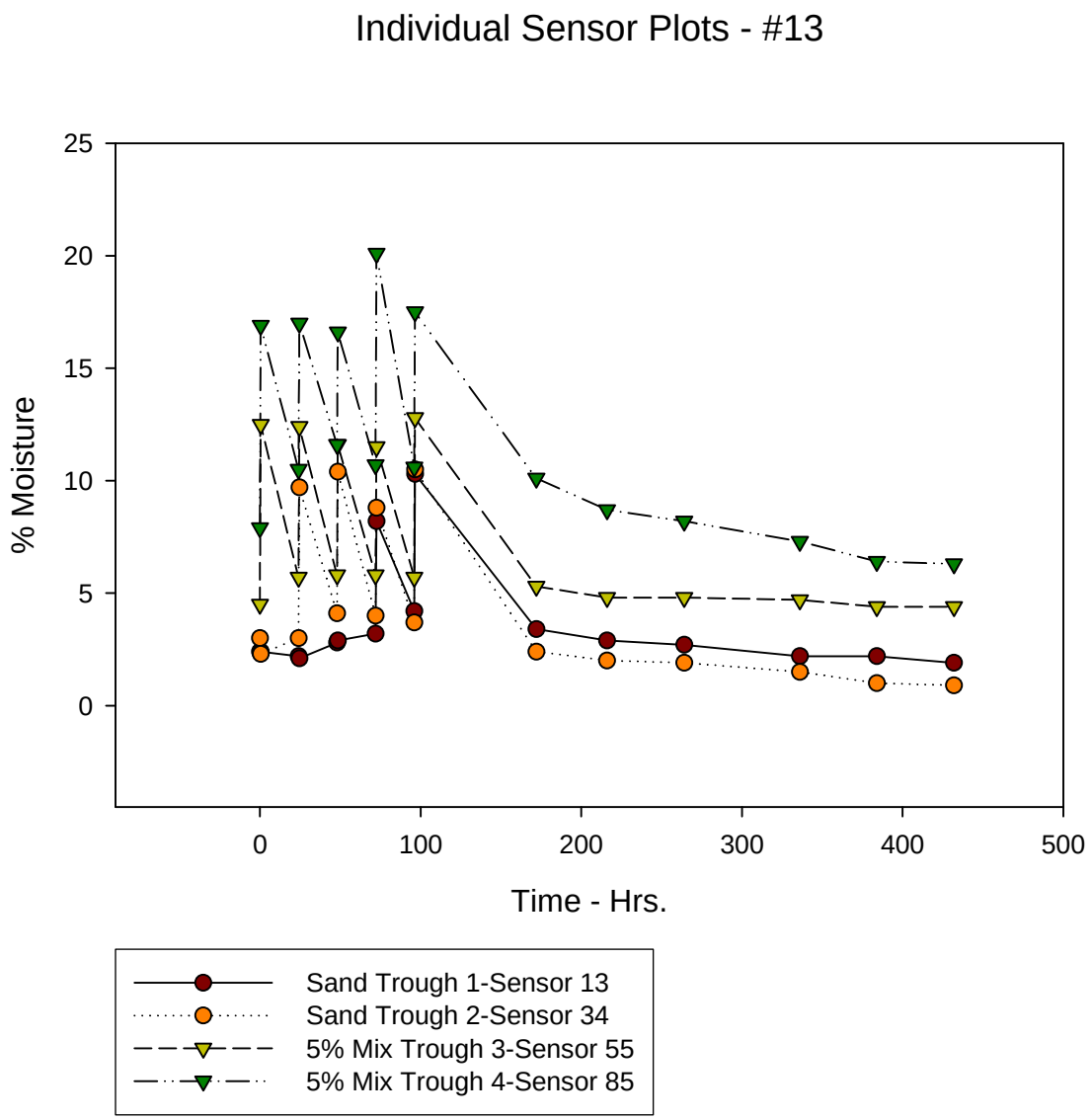


Figure 3-14. Position 3: Sensors 55 and 85 located parallel to the 100% Lassenite furrow, midway between one side of the trough and the furrow, 9" deep and 4' from the water source; Sensors 13 and 34 placed in similar locations within control trough.

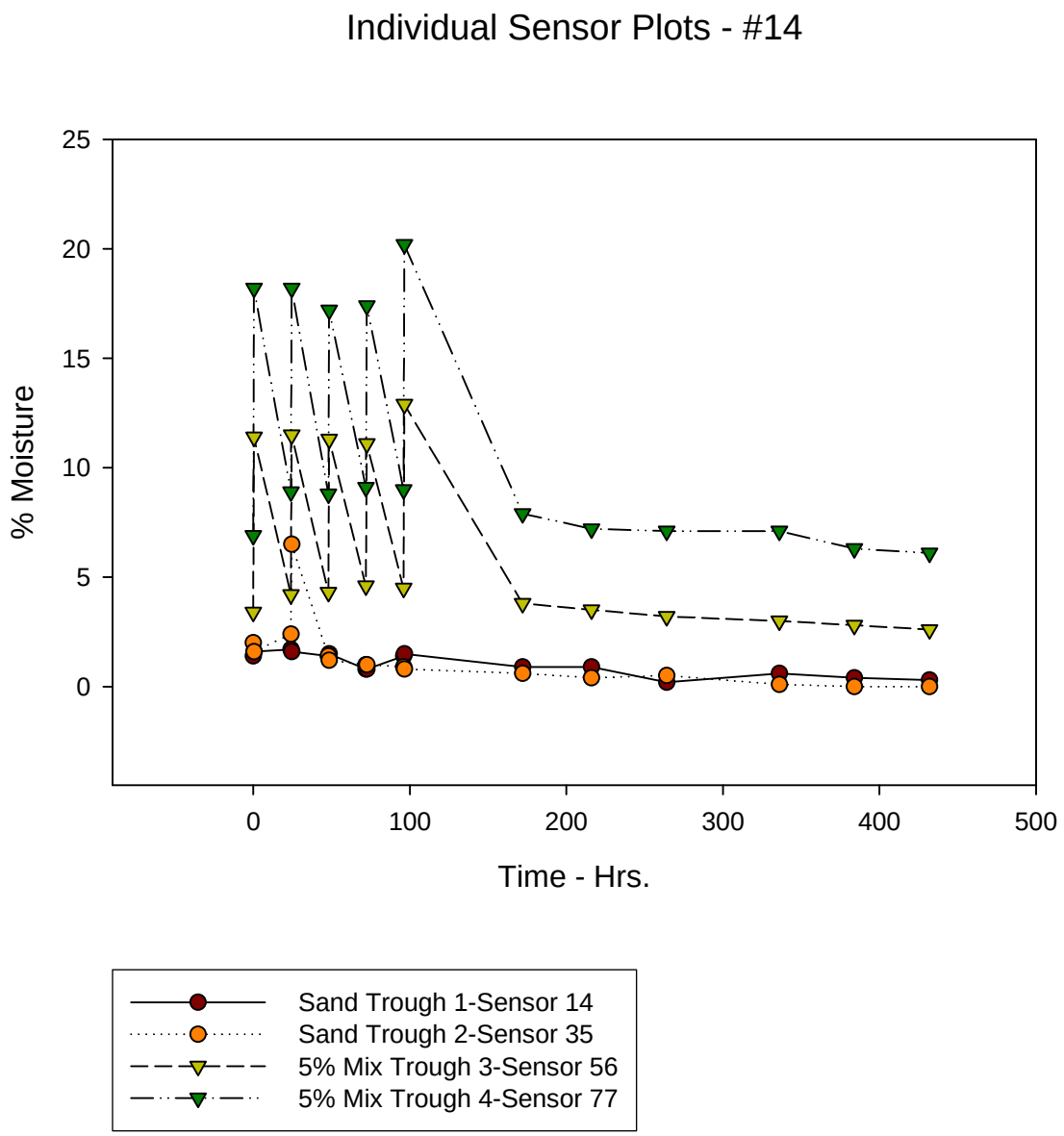


Figure 3-15. Position 3: Sensors 56 and 77 located parallel to the 100% Lassenite furrow, midway between one side of the trough and the furrow, 9" deep and 8' from the water source; Sensors 14 and 35 located in similar positions within control trough.

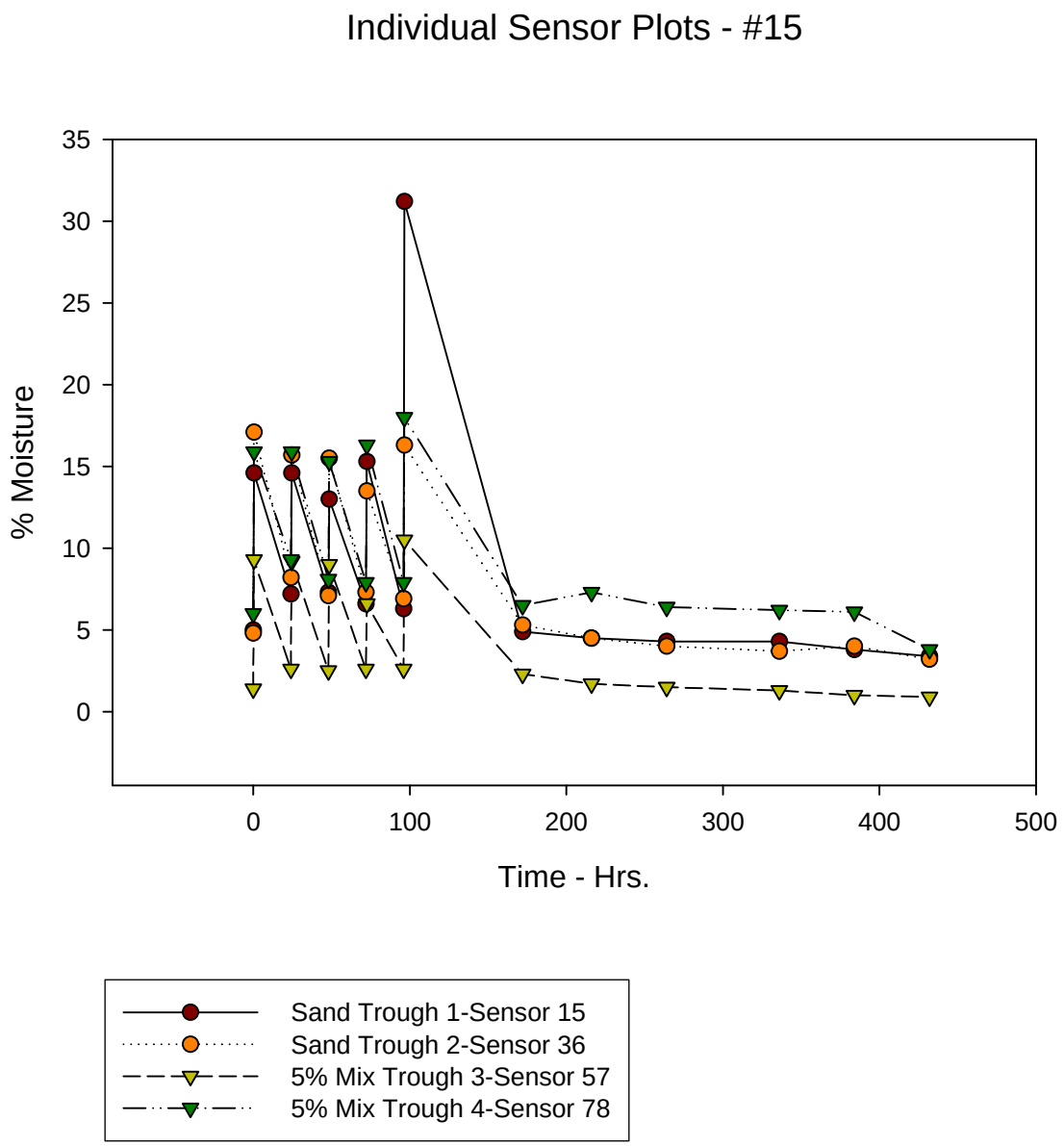


Figure 3-16. Position 4: Sensors 57 and 78 located directly beneath the furrow, 9" deep and 3' from the water source; Sensors 15 and 36 placed in similar positions within control trough.

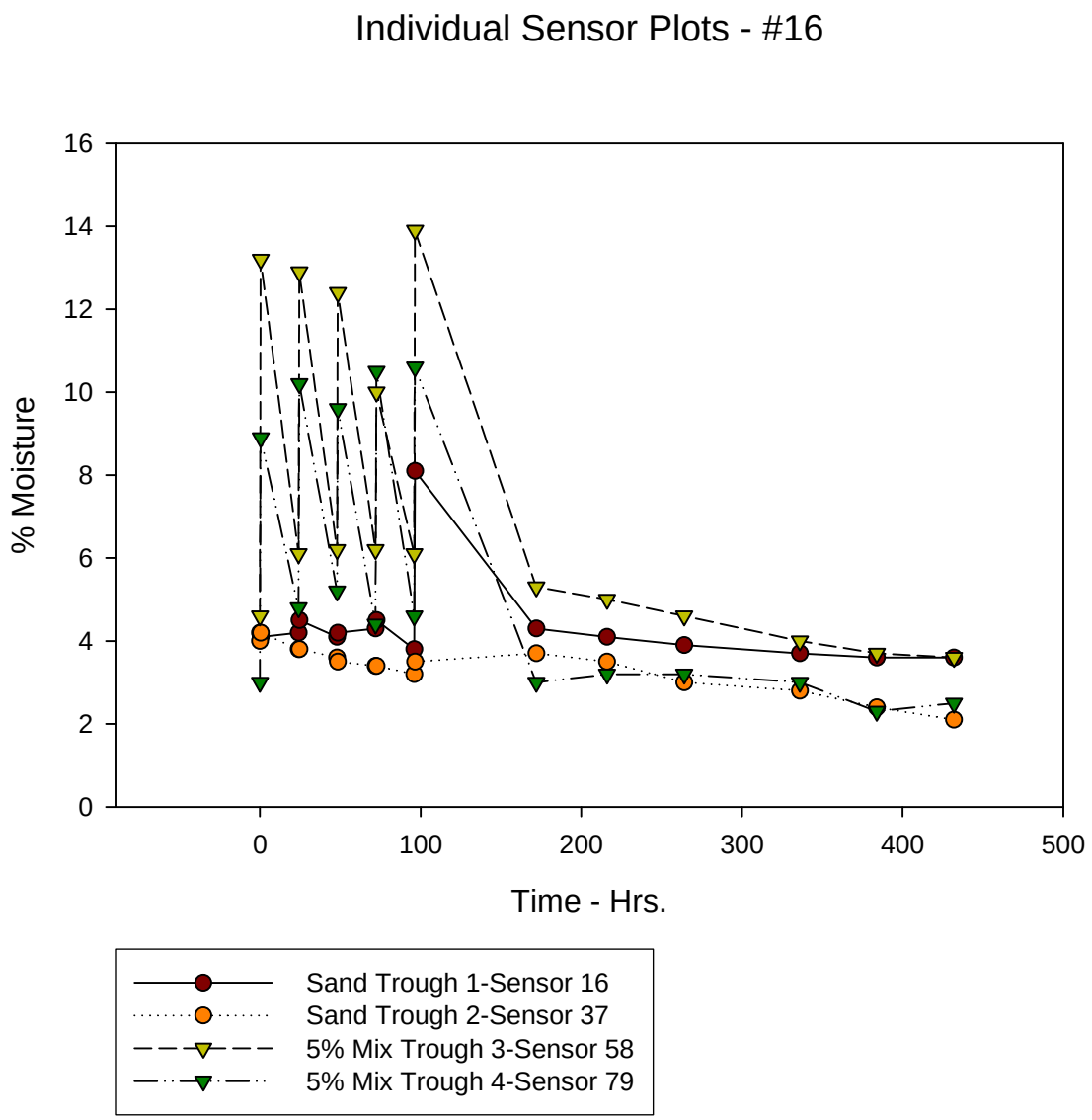


Figure 3-17. Position 4: Sensors 58 and 79 located directly beneath the furrow, 9" deep and 6' from the water source; Sensors 16 and 37 placed in similar positions within control trough.

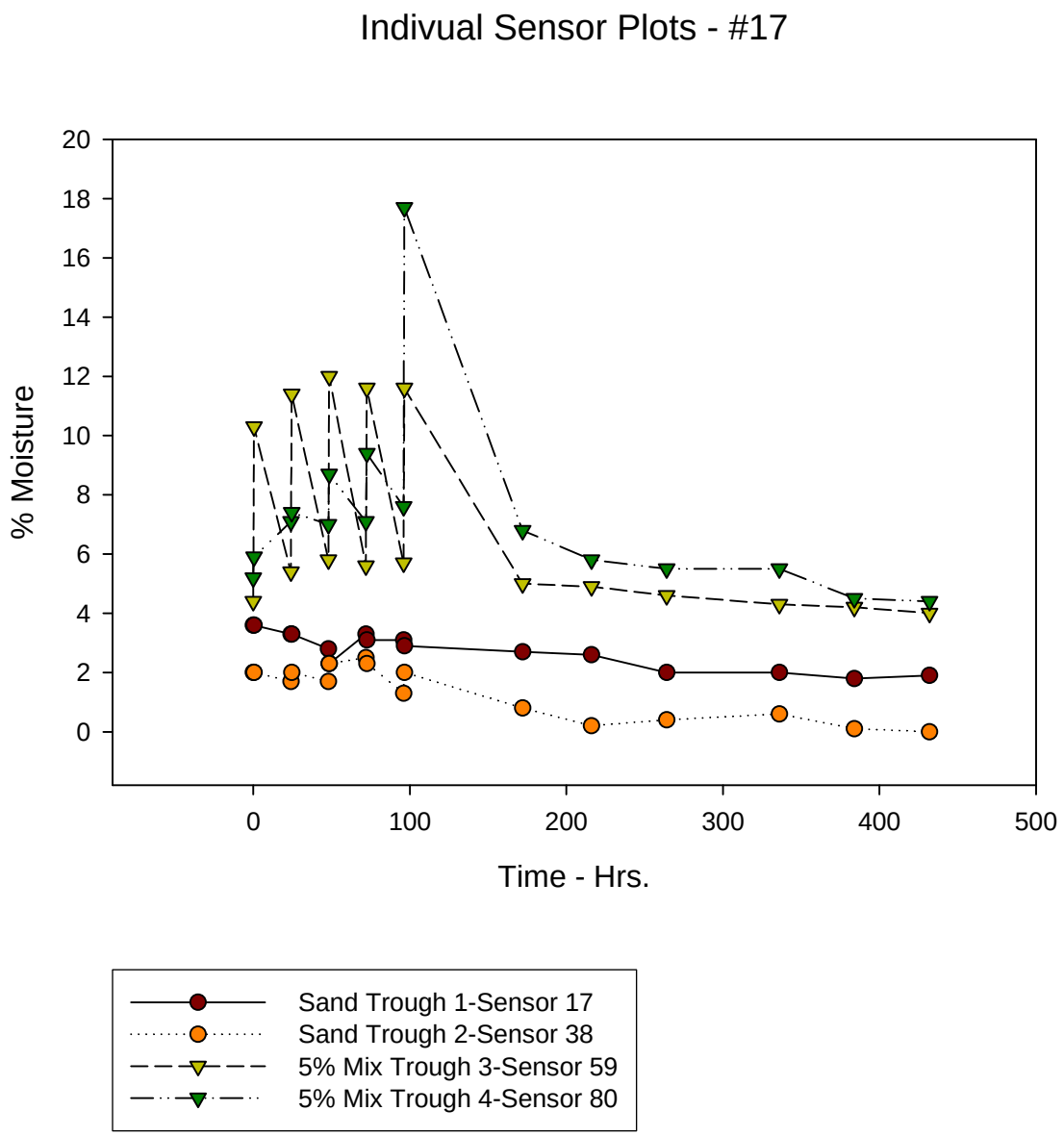


Figure 3-18. Position 4: Sensors located directly beneath the furrow, 9" deep and 9' from the water source; Sensors 17 and 38 placed in similar positions within control trough.

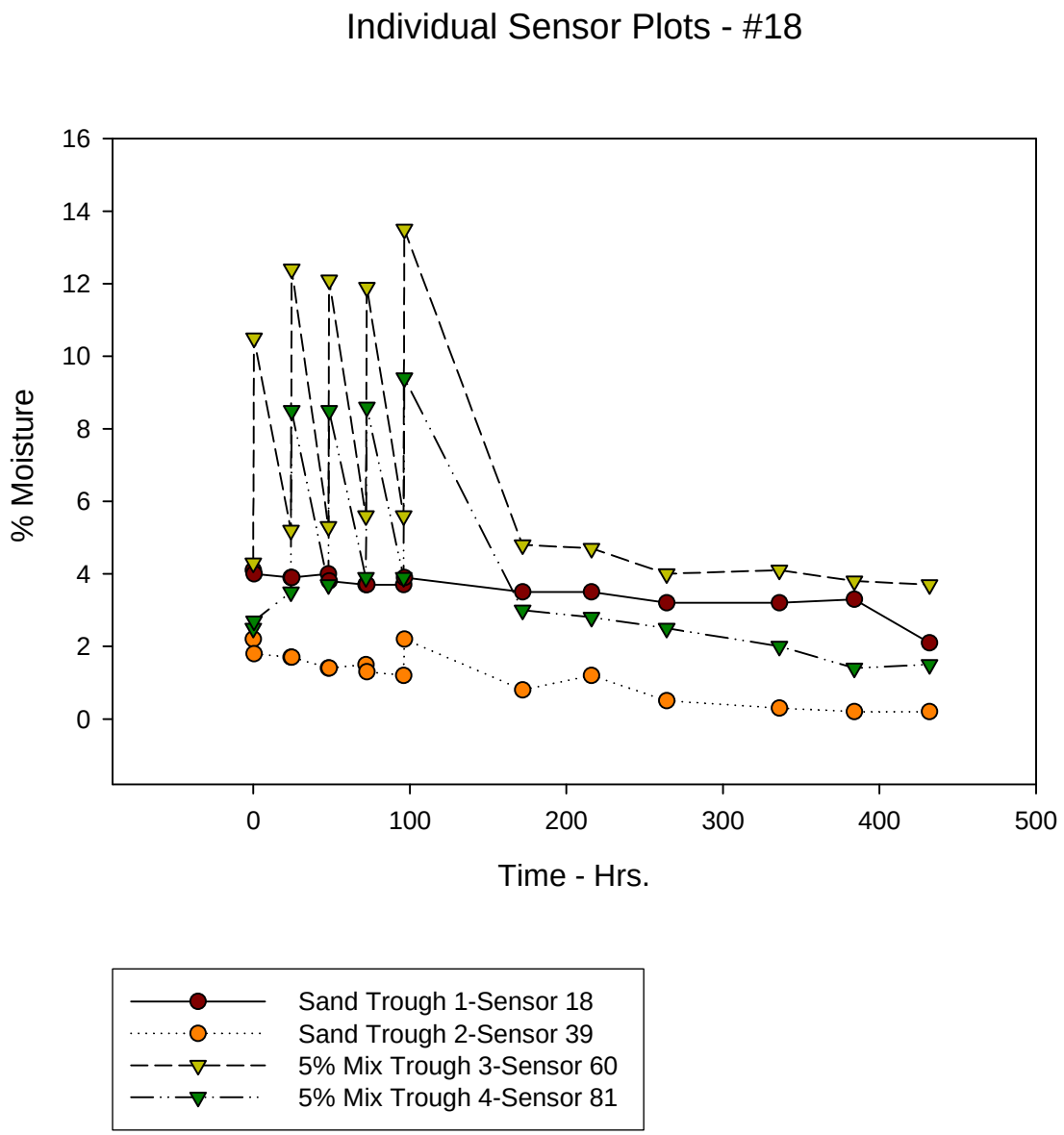


Figure 3-19. Position 4: Sensors 60 and 81 located directly beneath the furrow, 9" deep and 11.5' from the water source; Sensors 18 and 39 placed in similar positions within control trough.

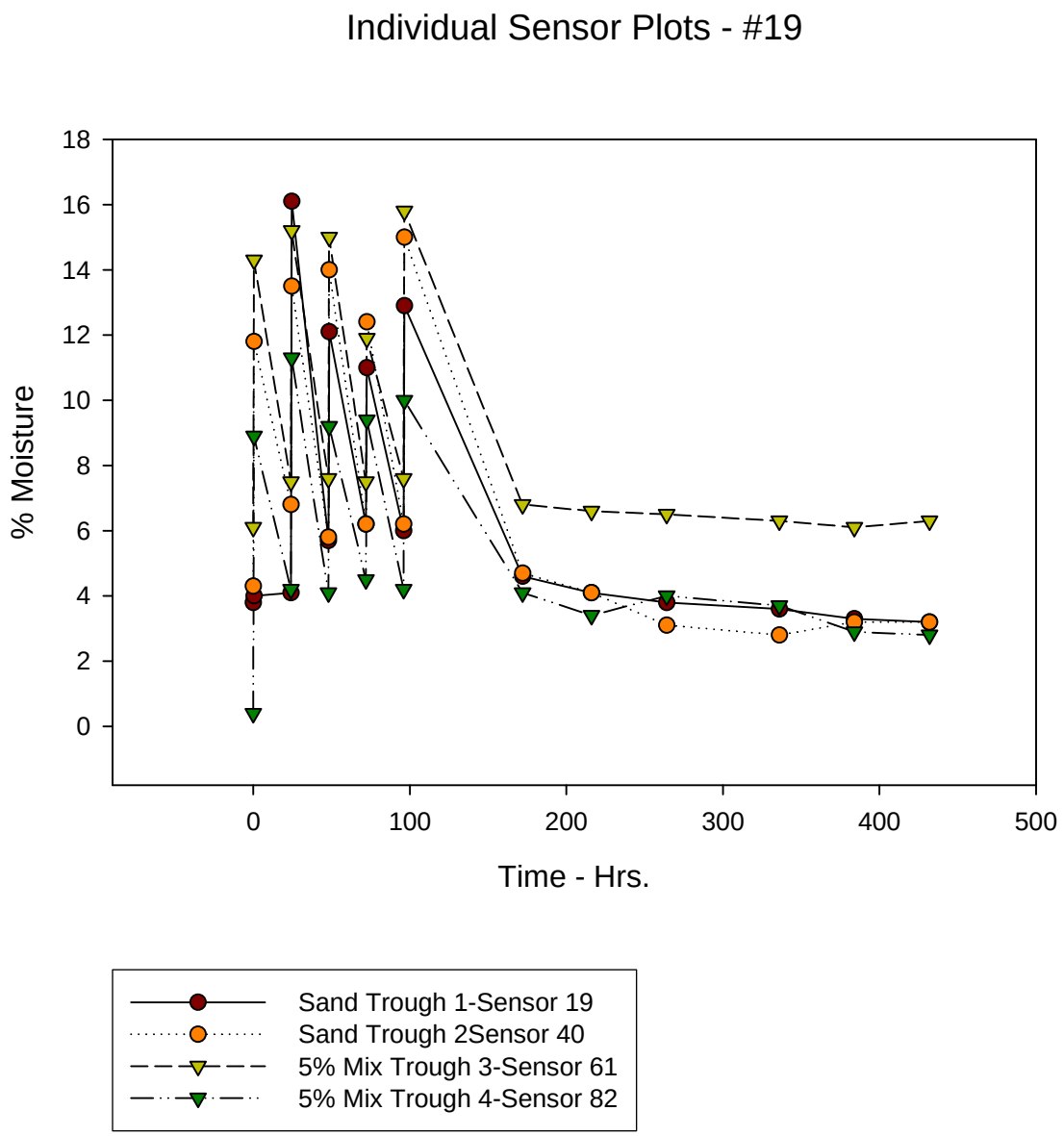


Figure 3-20. Position 5: Sensors 61 and 82 located beneath the furrow, 12" deep and 4' from the water source; Sensors 19 and 40 placed in similar positions within control trough.

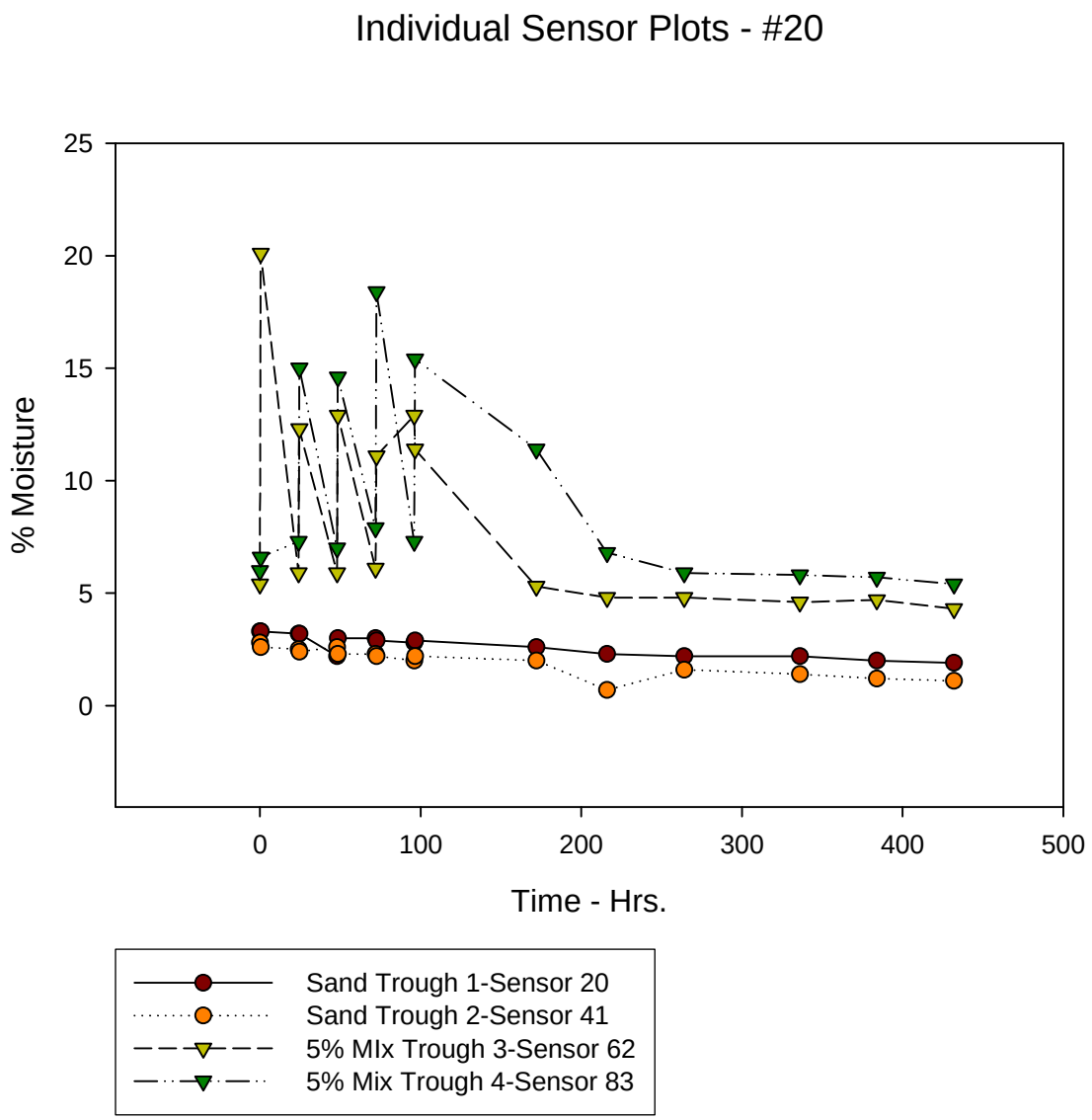


Figure 3-21. Position 5: Sensors 62 and 83 located directly beneath the furrow, 12" deep and 8' from the water source; Sensors 20 and 41 placed in similar positions within control trough.

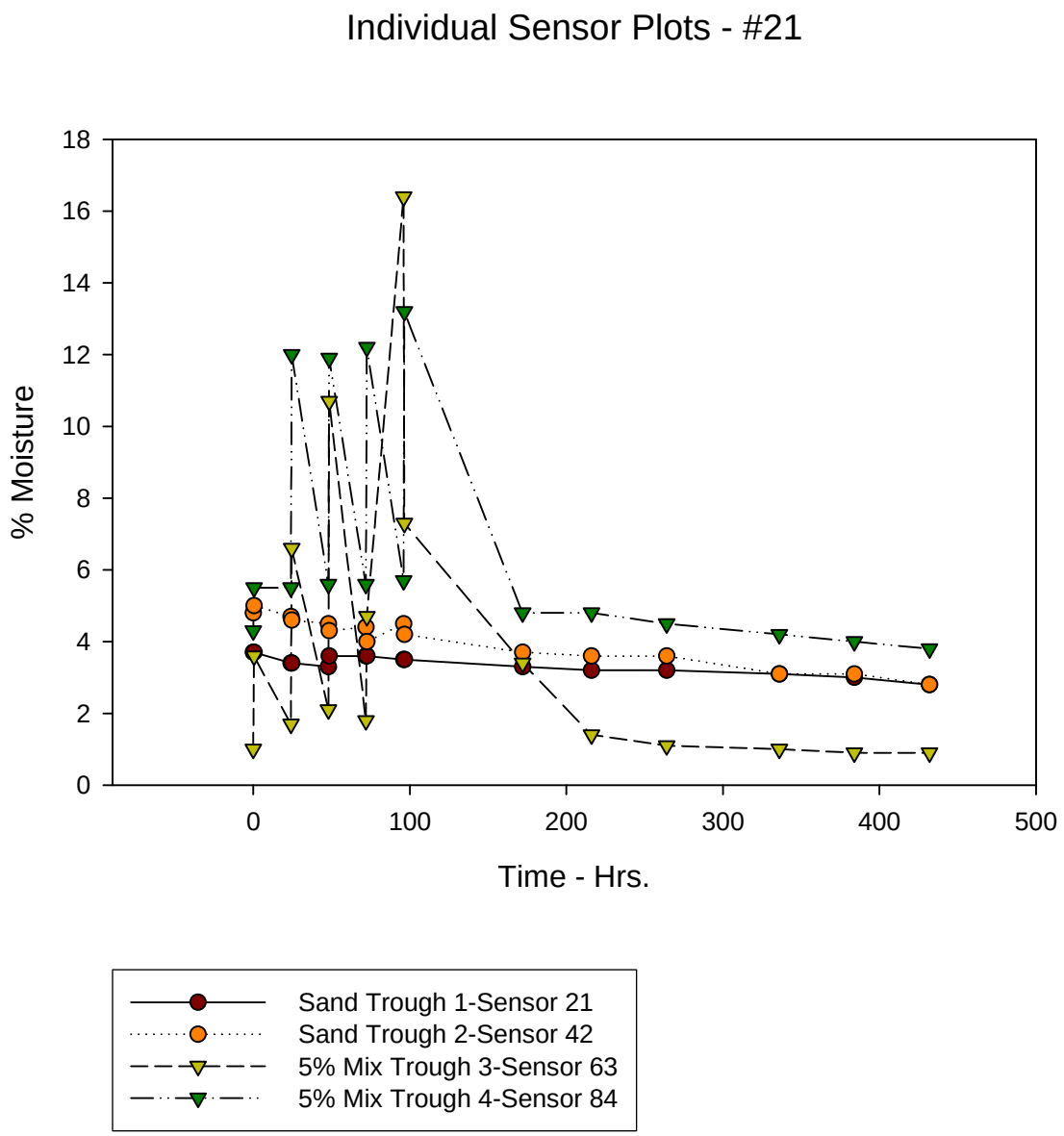


Figure 3-22. Position 5: Sensors 63 and 84 located directly beneath the furrow, 12" deep and 11' from the water source; Sensors 21 and 42 placed in similar positions within control trough.

Data Analysis Task III

3-1. Comparison of Soil Moisture Post-irrigation

a. Sensors Kept Separate:

AOV table: Dependent variable = soil moisture, arcsin transformed to normalize

Sources of variation

Replicates (blocks, r = 2)

Lassenite mixture (t = 2)

Sensor (s = 21)

Factor tested	Tested against	Result
(1) Lassenite	**Block X Lassenite**	**F = 49.7, df = 1,1, P = 0.090**
(2) Lassenite X Sensor	**Block X Lassenite X Sensor**	**F = 7.38, df = 20,20, P < .001**

Lassenite mixtures weakly affected (1) overall soil moisture, and (2) strongly differed among sensors.

b. Sensors Grouped by Position:

AOV table: Dependent variable = soil moisture, arcsin transformed to normalize

Sources of variation

Replicates (blocks, r = 2)

Lassenite mixture (t = 2)

Sensor Position (p = 5)

Factor tested	Tested against	Result
(1) Lassenite	Block X Lassenite	F = 54.9, df = 1,1, P = 0.085
(2) Lassenite X Position	Block X Lassenite X Position	F = 25.8, df = 20,20, P = .004

Lassenite mixtures weakly affected (1) overall soil moisture, and (2) strongly differed among sensor positions.

c. Split by Sensor Position:

Position 1

(1) Lassenite	Block X Lassenite	F = 34.8, df = 1,1, P = 0.11

Position 2

(1) Lassenite	Block X Lassenite	F = 33.2, df = 1,1, P = 0.11

Position 3

(1) Lassenite	Block X Lassenite	F = 96.9, df = 1,1, P = 0.064

Position 4

(1) Lassenite	Block X Lassenite	F = 47.9, df = 1,1, P = 0.091

Position 5

(1) Lassenite	**Block X Lassenite**	**F = 623, df = 1,1, P = 0.025**

Greatest difference in moisture between Lassenite mixtures was at sensor position 5, other positions were weakly or not different.

3-2. Comparison of Soil Drying-out after Last Irrigation

a. Sensors Kept Separate

AOV table: Dependent variable = soil moisture, arcsin transformed to normalize

Sources of variation

Replicates (blocks, r = 2)

Lassenite mixture (t = 2)

Hours elapsed since last post-irrigation reading (continuous variable, h +1 to include last irrigation reading, and transformed 1/(h + 1) to straighten, n = 7 in both blocks)

Sensor (s = 21)

Factor tested	Tested against	Result
(1) Lassenite	Block X Lassenite	F = 19.1, df = 1,1, P = 0.14
(2) Lassenite X Hours	Block X Lassenite X Hours	F = 6.63, df = 1,1, P = 0.236
(3) Lassenite X Sensor	**Block X Lassenite X Sensor**	**F = 12.3, df = 20,20, P < .001**
(4) Lassenite X Hours X Sensor	**Block X Lassenite X Hours X Sensor**	**F = 5.57, df = 20,20, P < .001**

Lassenite mixtures did not affect (1) overall soil moisture or (2) trends in soil moisture thru time, but did affect (3) distribution of soil moisture among sensors, and (4) trends in soil moisture thru time among sensors.

b. Sensors Grouped by Position:

AOV table: Dependent variable = soil moisture, arcsin transformed to normalize

Sources of variation

Replicates (blocks, r = 2)

Lassenite mixture (t = 2)

Hours elapsed since last post-irrigation reading (continuous variable, h +1 to include last irrigation reading, and transformed 1/(h + 1) to straighten, n = 7 in both blocks)

Sensor Position (p = 5)

Factor tested	Tested against	Result
(1) Lassenite	Block X Lassenite	F = 18.6, df = 1,1, P = 0.14
(2) Lassenite X Hours	Block X Lassenite X Hours	F = 8.89, df = 1,1, P = 0.21
(3) Lassenite X Position	Block X Lassenite X Position	F = 95.5, df = 4,4, P < .001
(4) Lassenite X Hours X Position	Block X Lassenite X Hours X Position	F = 1.25, df = 4,4, P = 0.42

Lassenite mixtures did not affect (1) overall soil moisture or (2) trends in soil moisture thru time, but did affect (3) distribution of soil moisture among sensor positions. (4) Trends in soil moisture thru time among sensor positions were not different (this is different from above, with sensors separate).

c. Split by Sensor Position

Position 1

Factor tested	Tested against	Result
(1) Lassenite	**Block X Lassenite**	**F = 64.5, df = 1,1, P = 0.079**
(2) Lassenite X Hours	Block X Lassenite X Hours	F = 0.04, df = 1,1, P = 0.88

Weak Lassenite effect at Position 1. Trends thru time not different between Lassenite treatments.

Position 2

(1) Lassenite	Block X Lassenite	F = 20.8, df = 1,1, P = 0.14
(2) Lassenite X Hours	Block X Lassenite X Hours	F = 3.3, df = 1,1, P = 0.32

No Lassenite effect at Position 2.

Position 3

(1) Lassenite	Block X Lassenite	F = 7.20, df = 1,1, P = 0.23
(2) Lassenite X Hours	**Block X Lassenite X Hours**	**F = 541, df = 1,1, P = 0.027**

No Lassenite effect at Position 3. Trends thru time different between Lassenite treatments.

Position 4

(1) Lassenite	Block X Lassenite	F = 1.29, df = 1,1, P = 0.46
(2) Lassenite X Hours	Block X Lassenite X Hours	F = 10.0, df = 1,1, P = 0.20

No Lassenite effect at Position 4. Trends thru time not different between Lassenite treatments.

Position 5

(1) Lassenite	Block X Lassenite	F = 5.57, df = 1,1, P = 0.26
(2) Lassenite X Hours	Block X Lassenite X Hours	F = 47.1, df = 1,1, P = 0.092

No Lassenite effect at Position 5. Trends thru time weakly different between Lassenite treatments.

Appendix 4. Reference Literature

4-1. LEED: Leadership in Energy and Environmental Design

The Leadership in Energy and Environmental Design Green Building Rating System, established in 2000, is a voluntary, consensus-based national standard for developing high-performance, sustainable buildings developed and administered by the U.S. Green Building Council.

The Green Building Rating System represents the US Green Building Council's effort to provide a national standard for what constitutes a "green building". The rating system document states the basic intent, requirements and submittals that are necessary to achieve each prerequisite and voluntary credit. Projects earn one or more credits toward certification by meeting or exceeding each credit's technical requirements. Points add up to a final score that relates to one of four possible levels of certification.

Western Pozzolan manufactures products that help reduce a building's overall impact on the environment, and thus can contribute to a project's ability to earn points toward LEED certification. Western recognizes that no product by itself is LEED certified and that no product can guarantee a specific number of points for LEED certification.

The application of Lassenite Pozzolan can help achieve LEED credits in a number of areas.

Stormwater Management

Heat Island Effect

Water Efficient Landscapes

Innovative Water Technologies

Additional points may be awarded for using regional materials.

Please refer to the US Build Green Council website at www.usgbc.org for additional information

4-2 Lassenite ATS Application Guidelines

PROCESSED LASSENITE

Processed Lassenite Pozzolan is kiln fired or calcined at very high temperatures to produce a ceramic like textured particle that is resistant to breakdown. Lassenite is a naturally occurring material and contains no additives. Lassenite is extracted from a surface mine located in Lassen County, California. This deposit originated 26 million years ago when nearby volcanoes erupted and the volcanic ash was deposited into freshwater lakes. These freshwater lakes contained large amounts of protozoa called Diatoms. The skeleton of this tiny organism is extremely porous and adsorbent which allows for the efficient movement of water that adds to the permanent availability of water to turf and plants. This material is used primarily for topdressing after aeration or injection into the root zone and blended with sand and/or topsoil for new construction.

Existing Turf/Sports Fields/Topdressing Golf Course
Fairways/Rough/Tee Boxes:
Application of 250 to 500 pounds per 1,000 square feet of turf is recommended. Application can be performed by the use of a drop spreader. Prior to application, the turf should be cut short and thoroughly aerated (or aerated in two different directions). Utilize drag-mats to increase the amount of Lassenite entering the soil profile. Thoroughly water the turf to charge the Lassenite.

Injection/Drill and Fill:
Application of a minimum of 150 to 350 pounds per 1,000 square feet is recommended when utilizing drill and fill or injection equipment.

Trees/Shrubs/Container Plants:
Add a mixture of one part Lassenite to five parts potting soil.

New Construction or Renovation:
Apply at a rate of 5% to 10% by volume in the top 4 to 6 inches of the soil profile. Rototill 1,000 to 2,000 lbs. of Lassenite per 1,000 square feet or pre-mix one pound of Lassenite for every 5 pounds of sand/soil mix in the soil profile.

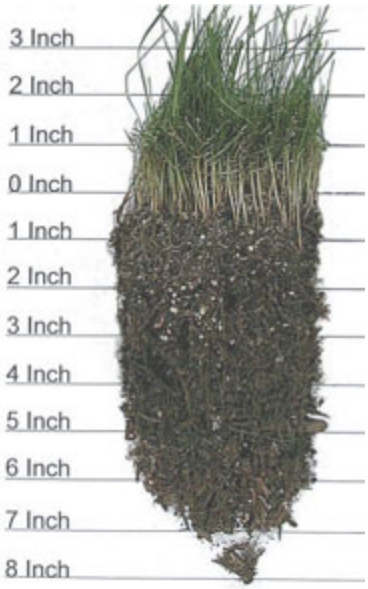
4-3. Lassenite ATS Soil Amendments

Pozzolan is extracted from a surface mine located in Lassen County, California, 30 miles north of Reno, Nevada. This deposit originated 26 million years ago when nearby volcanoes erupted and the volcanic ash was deposited into fresh water lakes. These freshwater lakes contained large amounts of protozoa called Diatoms. This tiny organism is extremely porous and absorbent which allows for the efficient movement of water to turf and plants.

Time is money and **Lassenite ATS** reduces the watering frequency of hard to maintain turf areas. The benefits of adding **Lassenite ATS** to your soil profile and plants include:

- Reduces the frequency of watering.
- Reduce labor costs associated with intensive turf management
- Increased quality and quantity of yields
- Reduction in the use of fertilizers
- Allows the soil to absorb and hold water
- Forces open and maintains air and water passageways
- Accelerates blooming and optimizes maturation
- Promotes deeper roots and increases the number of fine root hairs

Tests show that the addition of **Lassenite ATS** to your turf provides the following results:



- **Increased moisture retention** – In a number of different tests, including absorbency tests, **Lassenite ATS** retained between 92 and 102% of its mass in water. **Lassenite ATS** ensures consistent delivery of moisture to the plants' root system. Stored water in the soil horizon was increased 181% over controls.
- **Decreased compaction** – The ability of a soil additive to aerate a soil is a function of the compaction properties of the material. If the product compacts dramatically, soil porosity will decrease, resulting in a less aerated soil. A 46% improvement in porosity was observed attesting to **Lassenite ATS's** inherent ability to improve the aeration of soils.
- **High capillarity** – **Lassenite ATS** possesses a strong wicking ability or conduit effect. **Lassenite ATS** can actually pull water

uphill. Tests show a dramatic improvement of soil with the addition of **Lassenite ATS** and is strong evidence of the products ability to evenly distribute moisture throughout the soil column.

- **No soil expansion** – Because of the concerns raised by expansive soils, it is important to document a soil additive's expansion characteristics. Test results confirmed that **Lassenite ATS** exhibits no expansion characteristics thereby allowing for the ease of moisture movement in the soil.
- **High CEC** (Cation Exchange Capacity) – Due to its high CEC, adding **Lassenite ATS** to your soil can greatly improve the soil ability to hold onto nutrients.

LASSENITE POZZOLAN & SAND MIX DESIGNS

FOR
TOPDRESSING, DRILL & FILL, DRYJECT® & ROOTZONE CONSTRUCTION

Based upon volumetric calculations

Assumptions:

One cubic yard of sand weighs 2,700 lbs or 1.35 tons

One cubic yard of Lassenite weighs 1,107 lbs or 0.5535 tons

One cubic foot of Lassenite weighs 41 lbs

TOPDRESSING

For One Cubic Yard of One Ton of Greensmix:

90% Sand/10% Lassenite:

0.90 x 2700 lbs/yd³ = 2,430 lbs Sand

0.10 x 1,107 lbs/yd³ = 111 lbs Lassenite

Each cubic yard of 90/10% blended Greensmix will weigh 2,541 lbs

Each ton of 90/10% blended Greensmix will contain 1,913 lbs sand and 87 lbs Lassenite

85% Sand/15% Lassenite:

0.85 x 2700 lbs/yd³ = 2,295 lbs Sand

0.15 x 1,107 lbs/yd³ = 166 lbs Lassenite

Each cubic yard of 85/15% blended Greensmix will weigh 2,461 lbs

Each ton of 85/15% blended Greensmix will contain 1,865 lbs sand and 135 lbs Lassenite

80% Sand/20% Lassenite:

0.80 x 2700 lbs/yd³ = 2,160 lbs Sand

0.20 x 1,107 lbs/yd³ = 221 lbs Lassenite

Each cubic yard of 85/20% blended Greensmix will weigh 2,381 lbs

Each ton of 80/20% blended Greensmix will contain 1,811 lbs sand and 188 lbs Lassenite

70% Sand/30% Lassenite:

0.70 x 2700 lbs/yd³ = 1,890 lbs Sand

0.30 x 1,107 lbs/yd³ = 332 lbs Lassenite

Each cubic yard of 70/30% blended Greensmix will weigh 2,222 lbs

Each ton of 70/30% blended Greensmix will contain 1,701 lbs sand and 299 lbs Lassenite

Example: One sixteenth inch of 70% Sand 30% Lassenite to cover 100,000 ft^2

100,000 ft^2 x .005 ft (.0625”/12”) = 500 ft^3 Topdressing material

500 ft^3/27 ft^3 =18.52 yd^3 x 2,222 lbs/ yd^3 = 41,151 lbs or 20.2 tons of 70/30% blend required

Example: One sixteenth inch of 70% Sand 30% Lassenite to cover One Acre (43,560 sq ft)

43,560 ft^2 x .005 ft (.0625”/12”) = 218 ft^3 Topdressing material

218 ft^3/27 ft^3 =8.1 yd^3 x 2,222 lbs/ yd^3 = 18,000 lbs or 9 tons of 70/30% blend required

DRILL & FILL

Using a one inch drill bit at an application rate of 0.25 yd^3 per 1,000 ft^2.

The area of application consists of 100,000 ft^2 of greens

.25 yd^3 x 100 (100,000/1,000) = 25 yd^3

25 yd^3 x 1,107 lbs/ yd^3 Lassenite = 13.84 tons

13.84 tons x .10% waste = 1.38 tons + 13.84 = 15.2 tons of Lassenite required

DRYJECT®

Using 3” x 2” spacing at an application rate of 5 ft^3 per 1,000 ft^2.

The area of application consists of 100,000 ft^2 of greens

5 ft^3 x 100 (100,000/1,000) = 500 ft^3

500 ft^3 x 41 lbs/ ft^3 Lassenite = 20,500 lbs or 10.25 tons of Lassenite required

Using 3” x 3” spacing at an application rate of 4 ft^3 per 1,000 ft^2.

The area of application consists of 100,000 ft^2 of greens

4 ft^3 x 100 (100,000/1,000) = 400 ft^3

400 ft^3 x 41 lbs/ ft^3 Lassenite = 16,400 lbs or 8.2 tons of Lassenite required

Using 3” x 4” spacing at an application rate of 3 ft^3 per 1,000 ft^2.

The area of application consists of 100,000 ft^2 of greens

3 ft^3 x 100 (100,000/1,000) = 300 ft^3

300 ft^3 x 41 lbs/ ft^3 Lassenite = 12,300 lbs or 6.15 tons of Lassenite required

4-4. Lassenite ATS Specifications

PHYSICAL ANALYSIS

Hydraulic Conductivity Inches/Hour	Bulk Density g/cc	Capillary Pore Space	Non-Capillary Pore Space
10.9	.81	50 %	18%

Capillary or water holding pore space is made up of small pores that hold water against the force of gravity retaining much is it for use by the plant. Non-capillary or air holding pore space is made up of larger pores. When drained of water these pores fill with air providing oxygen to the root zone. The physical measurements show that Lassenite Pozzolan Soil Amendments have a very high amount of total porosity and retain a very high amount of plant available water. Therefore, Lassenite Soil Amendments will be very effective in increasing the capillary or water filled porosity of a root zone. Test results determined that the addition of Lassenite Soil Amendments can beneficially change the water release pattern in the soil profile, eliminating localized dry spots and reducing irrigation requirements. Many inorganic amendments maintain the ability to absorb moisture. Lassenite has the unique ability to make the majority of this moisture available to the plant.

The ability of a soil amendment to aerate soil is a function of the compaction properties of the material. Lassenite Soil Amendments blended into a soil horizon result in a dramatic improvement of porosity, attesting to Lassenite's inherent ability to improve the aeration of the soils and reduce compaction.

Ideally, a growing medium has an equal amount of air and water pore space after free drainage. Lassenite is a tool designed to provide the Turf Manager with the ability to change the physical characteristics of the soil profile, depending upon existing site conditions and environmental influences, in order to produce the most desirable balance between air and water filled pore space.

4-5. Lassenite ATS Scientific Studies

The USGA recommends testing the stability of golf course green building materials. This is accomplished by using the ASTM C-88 Sulfate Soundness Test. Greater than 12% degradation over a 20-year period is unacceptable.

Western Pozzolan's Lassenite ATS Soil Amendments far exceed this recommendation by degrading less than 3%.

DISCUSSION OF LAB RESULTS

The physical measurements test was performed on the pure pozzolan to determine the saturated hydraulic conductivity (infiltration rate), moisture retention at 30 cm tension, bulk density, particle density, total porosity, capillary porosity and air-filled porosity.

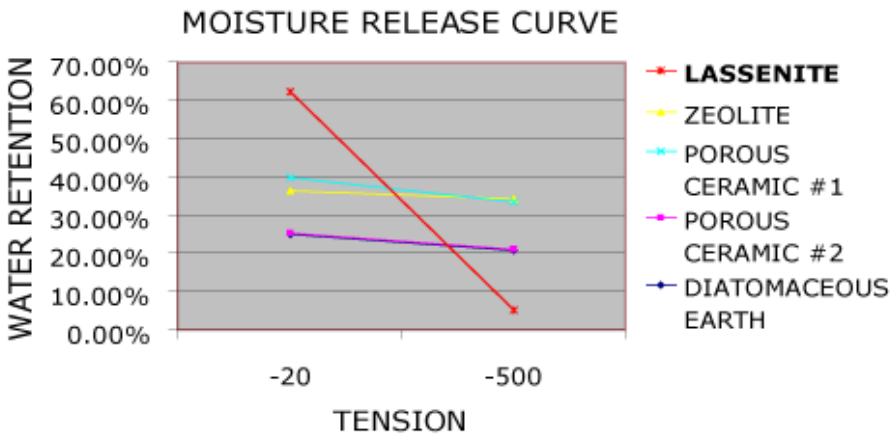
The physical measurements of the pozzolan showed it to have acceptable saturated hydraulic conductivity of 10.9 inches per hour which is in the normal range of 6-12 inches per hour recommended by the USGA. The pozzolan retained 62.1% moisture at 30 cm tension. The pozzolan had a low bulk density of 0.81 g/cc and a low particle density of 2.49 g/cc. The pozzolan had a high 67.7% total porosity, a very high 50% capillary porosity and an acceptable 17.7% air-filled porosity.

The physical measurements show that the pozzolan will have a high amount of total porosity and retain a very high amount of water. Therefore, the pozzolan will be effective in increasing the capillary porosity of a root zone sand.

To determine at what tension the pozzolan releases the majority of water, the water retention was measured at a range of tension including 0.03 bar, 0.3 bar, 2 bars, and 15 bars. The 0.03 bar moisture retention is representative of the maximum moisture retained by a 12” depth of soil (as in a putting green root zone). The 0.3 bar is the maximum moisture retained in a field situation similar to a fairway using native soil. The 2 bar value is representative of the moisture content at which a turf would be irrigated. The 15 bar value is considered to be the maximum amount of water that can be removed by plants. The measured values for the pozzolan are as follows:

Tension	Moisture Content (%)
• 0.03	• 62.1
• 0.3	• 9.3
• 2.0	• 3.6
• 15.0	• 0.8

Graph based upon studies of pozzolan by a USGA approved laboratory and four of the other top selling soil amendments.



As you can see from the graph Lassenite not only has the ability to absorb a great deal more moisture but will also release it to the plants prior to what is called the "theoretical wilt point" or -500 cm. This value was chosen because under most normal irrigation cycles a rootzone would rarely be allowed to exceed this value before resupplying water. This information is the key to the ability of Lassenite to eliminate localized dry spots and reduce irrigation requirements.

MISSISSIPPI UNIVERSITY SALT STUDY

This study is now complete, yielding encouraging results. Dr Barry Stewart requests that we do not post the final report until it is published in a scientific journal but has provided the following quote:

"Preliminary data indicate that sand amended with LSA holds 25% more water at field capacity than unamended sand. The incorporation of LSA into sand based rootzones and irrigated with 1000 ppm salts (as NaCl) produced no negative results."

Upon publication, the report will be available in its entirety

Jumeirah Golf Estates Test Program

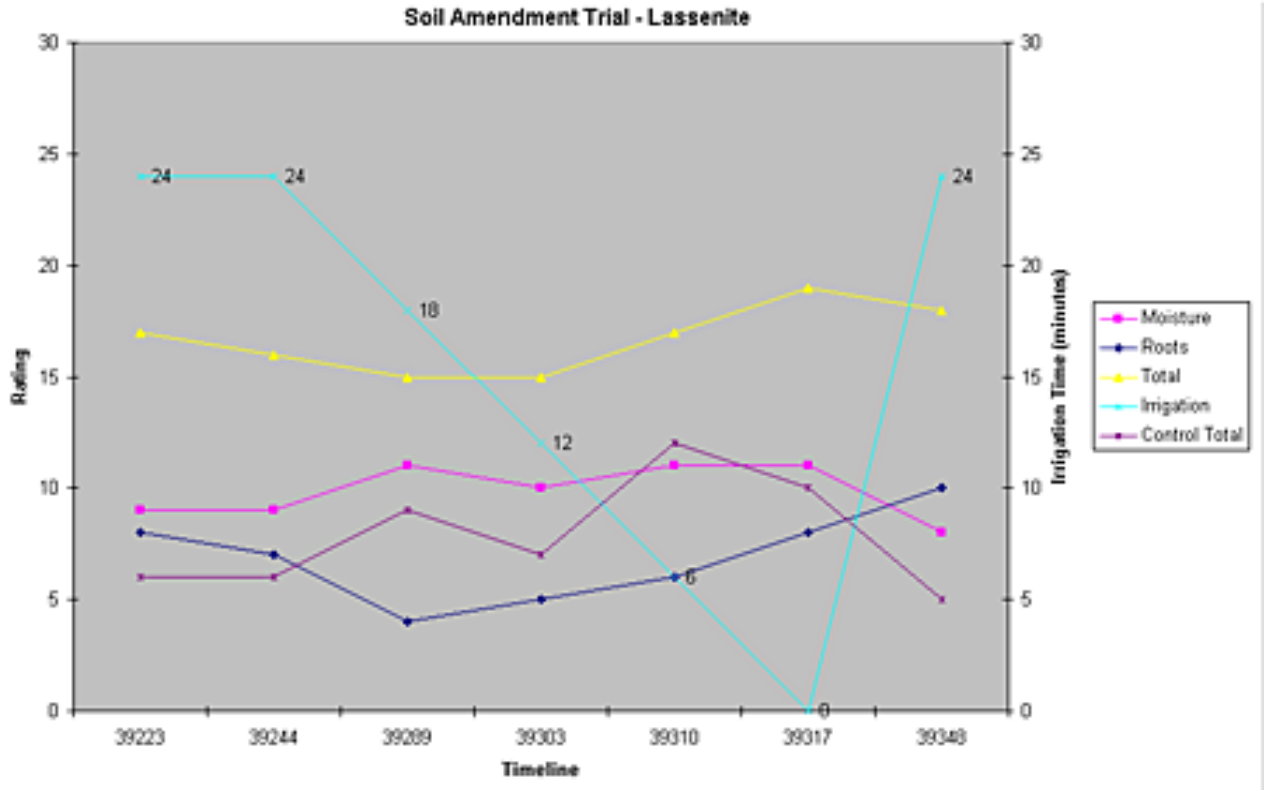
This is a study of the Lassenite Pozzolan for root production and moisture content in 419 Bermuda grass grown from sprig. The graphs below chart the productivity of each amendment against the control (dune sand from site) rating: moisture, root structure, root mass, and a combination of the overall root health and moisture content ("total" line on charts). The figures you see on the charts are values in the trial having 11 as the highest and 1 as the lowest. Example: the moisture rating for the Lassenite increased from 9 to 11 when the irrigation was reduced from 100% to 75%. While there was a decrease in irrigation amount, the Lassenite plot increased its value (moisture rating) compared to other products as well as the control. In general, we at JGE used this study to find the amount of water applied that would peak the products performance relating to root health and plant aesthetics.

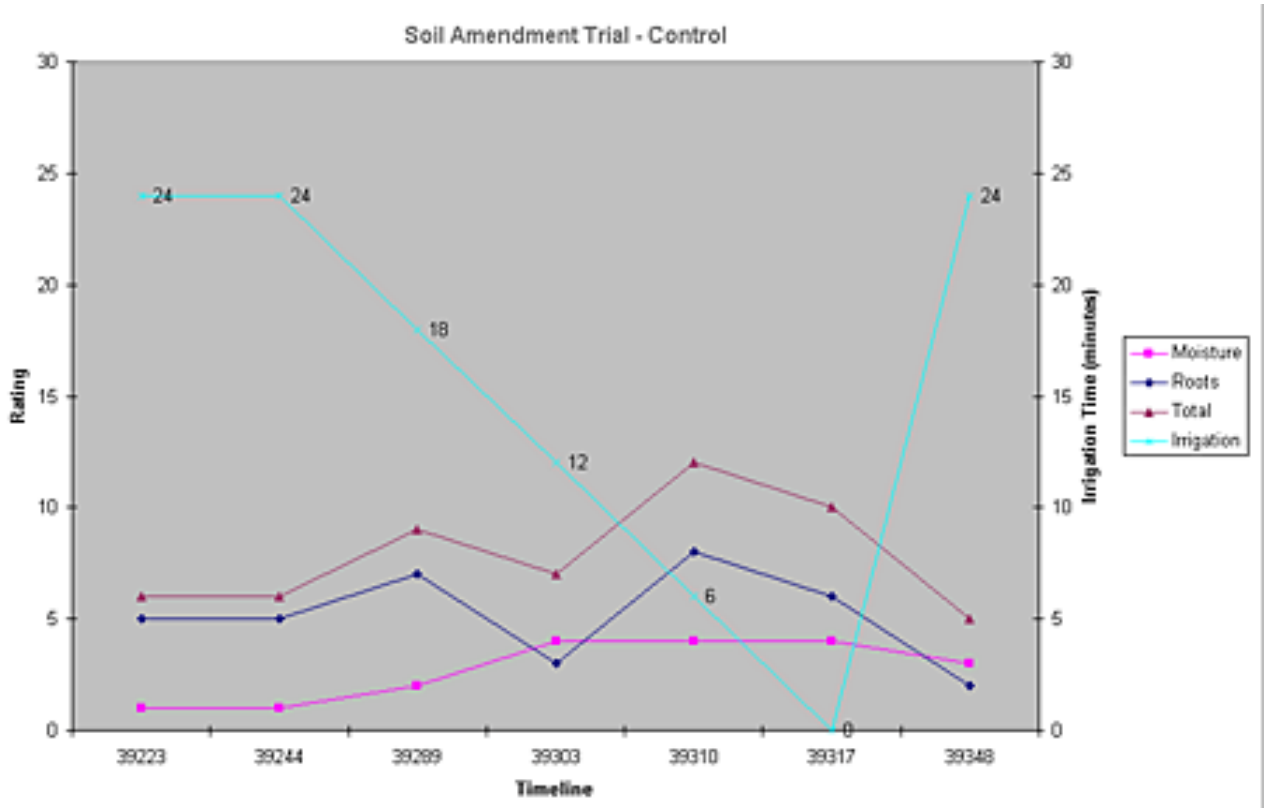
Lassenite @ 75%= 18min
Sample taken: 26-07-07

Lassenite @ 50%= 12min
Sample taken: 16-08-07

Lassenite @ 25%= 6min
Sample taken: 23-08-07

Lassenite @ 0%= 0min
Sample taken: 23-09-07


Soil Amendment Trial - Lassenite
Rating
Irrigation Time (minutes)
Timeline
39223
39244
39289
39303
39310
39317
39348
Moisture
Roots
Total
Irrigation
Control Total


Soil Amendment Trial - Control
Rating
Irrigation Time (minutes)
Timeline
39223
39244
39289
39303
39310
39317
39348
Moisture
Roots
Total
Irrigation

Bentgrass Establishment in Sand-based Rootzones Using Subsurface Drip Irrigation

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Abstract

Greenhouse studies were performed to evaluate the feasibility of establishing seeded bentgrass in sand-based rootzones using subsurface drip irrigation (SDI). Several commercially available products were investigated. Products were mixed at several percentages by volume. Percentages by volume were 10, 20, 30, and 40. Study investigated the use of subsurface drip irrigation with tubing buried at 15 cm. All treatments contained one tube per container. Each study was conducted for six weeks and percentage coverage, moisture content, root length and plant biomass data were collected. Percentage coverage and fresh weight biomass data are presented. Data analysis confirms that seeded bentgrass can be established using subsurface drip irrigation. Many of the treatments retained consistent moisture content for the duration of the study at various soil depths. Some treatments with higher percentages of additives had greater biomass and higher percentage coverage. However, this trend did not follow for all additives. Root length followed a similar trend. Establishment of seeded bentgrass in sand-based rootzones is possible using subsurface drip irrigation.

Objectives

Several experiments were conducted to determine if a suitable rootzone mix could be used when establishing seeded bentgrass using SDI. Various amendments and sand textures were used. Each experiment differed slightly in its materials since these were initial studies. Materials used in each experiment are detailed in Table 1.

Materials and Methods

Study consisted of several commercially available amendments (Table 1) that are common in golf course putting green rootzone mixes. These products were mixed at 10, 20, 30, 40-% by volume with golf sand or finer textured golf sand. Also, one experiment contained native soil mixed at 20, 40, 60-% by volume with golf sand. Treatments consisted of using 19 liter containers for establishment. Drip irrigation tubing was placed 15 cm deep. System was designed as a loop and grid. Drainage holes were drilled in the bottom of containers. A layer of pea gravel was placed in container then rootzone mixture was added. Containers were tamped to settle contents. Containers were seeded with Dominant Plus creeping bentgrass, Agrostis stolonifera. Weekly moisture content and percen age coverage were taken. At the conclusion of the study fresh weight of clippings were taken as well as root length.

Table 1. Experiment and Rootzone Mixture

Experiment	Treatment	Sand	Levels of Treatments (% of Material)
1		golf sand	
	Peat Moss (PM)		10, 20, 30, 40, 60
2		golf sand	
	Western Pozzolan-lassenite (WP)		10, 20, 30, 40
	Profile Greens (GR)		10, 20, 30, 40
	$PermO_2Pore$ (PP)		10, 20, 30, 40
	Peat Moss (PM)		10, 20, 30, 40
3		cyclone sand	
	Western Pozzolan-lassenite (WP)		10, 20, 30, 40
	Profile Greens (GR)		10, 20, 30, 40
	$PermO_2Pore$ (PP)		10, 20, 30, 40
	Peat Moss (PM)		10, 20, 30, 40

Table 2. Experiment Means at Six Weeks

Experiment 1		
Treatment	Cover (%)	Biomass (g)
PM 10	10	0.37
PM 20	20	0.56
PM 30	40	0.7
PM 40	40	2
PM 60	60	5.43
Control-Pure Sand 0 0.23		

Table 2. Experiment Means at Six Weeks (cont.)

Experiment 2		
Treatment	**Cover (%)**	**Biomass (g)**
WP 10	43.3	1.43
WP 20	50	1.63
WP 30	33.3	1.3
WP 40	13.3	0.73
GR 10	35.5	0.56
GR 20	5	0.1
GR 30	5	0.1
GR 40	5	0.1
PM 10	0.3	0.2
PM 20	40	2.7
PM 30	18.3	1.6
PM 40	50	5.6
Control-Pure Sand	19	0.86
Experiment 3		
Treatment	**Cover (%)**	**Biomass (g)**
WP 10	53.3	0.16
WP 20	36.6	0.2
WP 30	40	0.2
WP 40	58.3	0.43
GR 10	12	0.1
GR 20	7	0.1
GR 30	4	0.13
GR 40	1	0.1
PP 10	16	0.1
PP 20	18	0.1
PP 30	11	0.1
PP 40	14	0.03
Native 20	11.6	0.13
Native 40	45	2.13
Native 60	65	0.93
Control-Pure Sand	35	0.1

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Results

During this research a series of attempts were made to establish bentgrass using SDI (Table 2). During the course of the experiment difference texture of golf sand was used. Although many treatments did yield germination by the end of the study, the cover was quite low. Pictures of each study are shown below indicating the lack of uniformity and undesirable coverage at 6 weeks.

Conclusion

The most promising treatment in these and subsequent studies was Western Pozzolan at 30%.

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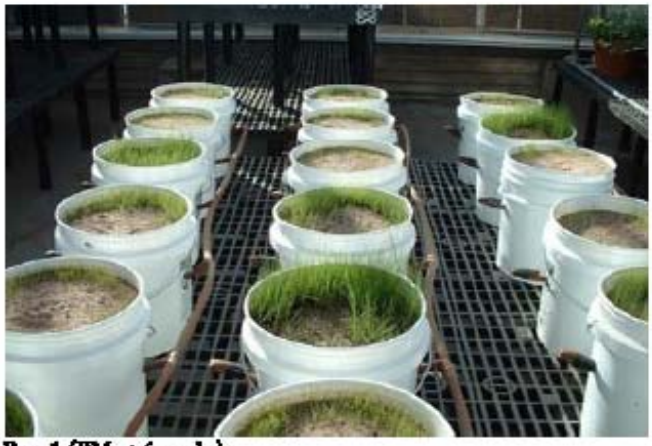
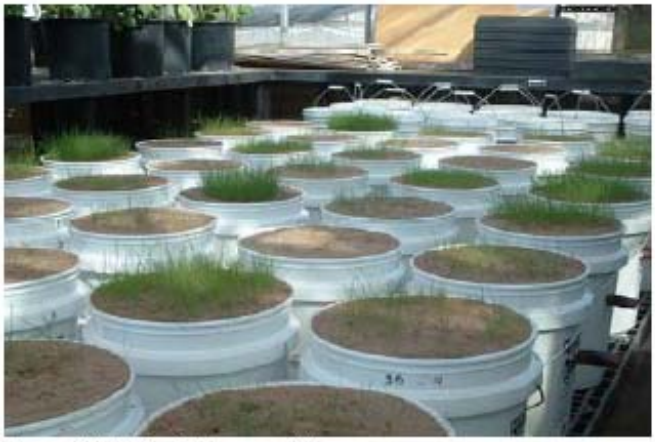


Exp. 1 (PM at 6 weeks)



Exp. 2 (WP, GR, PM at 6 weeks)

Exp. 3 (WP, GR, PP, Native at 6 weeks)