Evaporation synergy is a phenomenon that occurs between different classes of soil and allows for a greater amount/quantity of soil water evaporation. 20 of the 66 soil texture class combinations have been shown to exhibit evaporation synergy (Fisher, 2012), however the impact of column width on the functionality of this process is unknown. The 20 synergizing combinations were tested for sensitivity to evaporation with an increasing column width. With a maximum width of 451 cm, 6 of the 20 had ceased evaporation synergy. One combination – loamy sand and silty clay loam – showed the behavior of nodes approached a homogeneous behavior as the distance from the vertical boundary increased. At 75 cm, the bi-texture silty clay loam behaved identical to a homogeneous silty clay loam.

**Key words:** evaporation, capillary, soil physics, soil texture

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Mathematical Investigation of Evaporation Synergy in Bi-Texture Soil Columns as a Function of Column Width

by

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A PROJECT

Submitted to
Oregon State University
University Honors College

In partial fulfillment of the requirement for the degree of

Honors Baccalaureate of Science in Agricultural Sciences (Honors Associate)

Presented May 31, 2013
Commencement June 2013
Honors Baccalaureate of Science in Agricultural Sciences project of Michael J. Sumner presented on May 31, 2013.

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Dean, University Honors College

I understand that my project will become part of the permanent collection of Oregon State University, University Honors College. My signature below authorizes release of my project to any reader upon request.

______________________________
Michael J. Sumner, Author
ACKNOWLEDGEMENT

This project was a special time for me, and there were many people who helped make it possible. Dr. Maria Dragila, my guide and my mentor, pushed me towards completion with kindness and toughness in a way that forced me to challenge my own limitations. The success of this project is a direct reflection on her, and I will be forever grateful. I would like to thank my committee members, Dr. Jay Noller and Dr. Markus Kleber, for taking time out of their schedules to review my work and to help me defend it. It was an enjoyable experience. I would also like to thank the logistical people who assisted me during my data collection processes; Jennifer Cohen in the Biological and Ecological Engineering office who was kind enough to give me a key to the Gilmore Hall Annex each time I needed it, and to the people in the Gilmore Hall Annex Computer Lab for helping me resolve issues.

And last, but certainly not least, I would like to thank my children; Maranda and Jacob. It is difficult to ask others to sacrifice so I can succeed, yet they do it with a smile and a cheer. Without their constant love and support, none of this could be possible. I thank them now, and forever.
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1.0 Introduction

Evaporation synergy is a phenomenon that occurs between different texture classes of soil that share a vertical boundary and allows for a greater amount/quantity of soil water evaporation. Laboratory experiments have demonstrated 20 of the 66 soil texture class combinations have been shown to exhibit evaporation synergy (Fisher, 2012 – Figure 1), however the impact of column width on the functionality of this process is unknown. An investigation of the influence column width has on evaporation synergy could provide valuable insights into soil physics and the processes that control the movement of water in soil.

1.1 Context

The data presented in this paper was collected from a two-dimensional water modeling computer program (HYDRUS, see Appendix C) that uses theoretical mathematical equations to model real soil processes. As with all models, there are inherent limitations – most notably that it does not always reflect reality. Therefore, the purpose of this research is not to prove or disprove the occurrence of evaporation synergy; rather, it is to establish the potential boundaries that would allow a physical experiment to determine the optimal ratio of fine soil to coarse soil in order to maximize the output of the system.

Multiple factors contribute to the function of any ecological service in any natural system. Water movement in soils, and evaporative losses from soils, are no exception. To create
a model that was functional and manageable, some of these factors were controlled. Some key assumptions were:

1. The ratio of soils in the bi-texture columns was always 1:1, and each soil was homogeneous (meaning that any one part of the soil was identical to any other).
2. In each bi-texture column, the soils shared a vertical boundary and there was no mixing of the soils along the boundary.
3. Each column was two-dimensional, with a width and a height.
4. The top of each column was opened to atmospheric flux; the other three sides of the column were allowed no flux.
5. The soil was allowed to evaporate water regardless of day/night dynamics with a potential evaporation rate of 0.4 cm/day.
6. No vegetation or any other biological life was present in any soil.

Due to the variable nature of the HYDRUS computer program, it is important to note that data presented in this paper are only valid at the settings found in Appendix C: HYDRUS Model. Those settings will be referred to as Θ.

1.2 Definition of Terms

Volume of Evaporation (VE) is defined as the volume of water in milliliters that would evaporate from a 1 cm² surface of any particular soil at Θ. The subscript of VE denotes either a hypothetical soil (f = fine soil, c = coarse soil, s = synergizing soil, t = total column) or a soil texture class (NASIS code). The Subscript for bi-texture combinations will

<table>
<thead>
<tr>
<th>Texture Class</th>
<th>NASIS Code</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sand</td>
<td>S</td>
</tr>
<tr>
<td>Loamy Sand</td>
<td>LS</td>
</tr>
<tr>
<td>Sandy Loam</td>
<td>SL</td>
</tr>
<tr>
<td>Loam</td>
<td>L</td>
</tr>
<tr>
<td>Silt</td>
<td>SI</td>
</tr>
<tr>
<td>Silt Loam</td>
<td>SIL</td>
</tr>
<tr>
<td>Sandy Clay Loam</td>
<td>SCL</td>
</tr>
<tr>
<td>Clay Loam</td>
<td>CL</td>
</tr>
<tr>
<td>Silty Clay Loam</td>
<td>SICL</td>
</tr>
<tr>
<td>Sandy Clay</td>
<td>SC</td>
</tr>
<tr>
<td>Silty Clay</td>
<td>SIC</td>
</tr>
<tr>
<td>Clay</td>
<td>C</td>
</tr>
</tbody>
</table>

Table 1: NASIS codes for soil texture classes (NRCS, 2012).
be the two soils’ NASIS code separated with an en dash. Table 1 lists the NASIS codes for all twelve soil texture classes.

All of the evaporation data is presented in volume of evaporation (VE) which is derived from HYDRUS data. The cumulative evaporation at time stamp 120 (day 60), reported in cm$^2$, is the area of a column of water that has evaporated from the surface of the soil column during the 60 day model. If the cumulative evaporation is divided by the width of the column, the result is the average per-cm cumulative evaporation; or, the area of a column of water that has evaporated from 1 cm of the column surface. Adding a third dimension – 1 cm in the z direction – allows the cumulative evaporation to be reported in cm$^3$, and since 1 mL = 1 cm$^3$, the conversion to volume of evaporation is simple. Using a volume as a unit allows for a normalized comparison in order to establish the state of evaporation synergy.

Evaporation synergy is defined as an increase in evaporative losses in a bi-texture soil column. Represented numerically, evaporation synergy occurs when $\text{VE}_s > \text{VE}_c$ and $\text{VE}_s > \text{VE}_f$. Therefore, evaporation synergy ceases when $\text{VE}_s \leq \text{VE}_c$ or $\text{VE}_s \leq \text{VE}_f$. In bi-texture synergizing combinations, the fine soil typically has the higher VE, though in some combinations the coarse soil has the higher VE. It is the highest VE of the two which determines the end of evaporation synergy.

1.3 Scientific Process

A preliminary step in the creation of this project involved evaluation of Fisher’s (2012) research into evaporation synergy. During this step, it was observed that bi-texture combinations had a VE that decreased as the column width increased. This was curious because all 12 homogeneous soils have a constant VE regardless of column width. The question, then, was why does VE decrease in bi-texture soil columns as the width increases?
The justification for the formation of the hypothesis can be seen in Figure 2. It was hypothesized that in a synergizing bi-texture soil column, there is some maximum width \( y \) that the textural boundary influences soil water processes. Therefore, the soil outside the influence of the textural boundary must behave like a homogeneous soil. This width \( y \) is assumed to be constant for each synergizing bi-texture combination, and the width \( x \) variable.

The width \( y \) in Figure 2 implies a fine soil to coarse soil ratio of 1:1. In reality, this is unlikely to be accurate. One of the key factors that drives the horizontal movement of water in synergizing bi-texture columns is hydraulic conductivity, and, in general, the coarser the soil the higher the hydraulic conductivity. The ratio of fine soil to coarse soil would have to be less than 1 for all 20 combinations because water is able to move from farther away in the coarse soil but not able to move equally far into the fine soil. In general, this is important to understand. But since it is assumed \( y \) is a constant, the placement of the vertical boundary within \( y \) is essentially irrelevant, so long as the width \( x \) is equal on either side of \( y \).

\[
\begin{align*}
VE_{\text{average}} &= \frac{VE_c + VE_f}{2} \\
VE_f &= \frac{VE_f \cdot x + VE_s \cdot y + VE_c \cdot x}{2x + y} \\
\text{for } x \neq 0: & f(x) = \frac{x(VE_f + VE_c) + VE_s y}{2x + y} \\
\lim_{x \to \infty} f(x) &= \frac{x(VE_f + VE_c) + VE_s y}{2x + y} \quad \text{for } x \neq 0 \\
\lim_{x \to \infty} f(x) &= \frac{VE_f + VE_c + VE_s y}{2 + \frac{y}{x}} \\
\lim_{x \to \infty} f(x) &= \frac{VE_f + VE_c}{2} = VE_{\text{average}}
\end{align*}
\]

**Figure 2**: Top: conceptual diagram of hypothetical bi-texture soil column showing width of synergizing effect (\( y \)) and width of non-synergizing effect (\( x \)). Bottom: proof the long-term VE of the column equals the average of the two homogeneous soils VE.
Once the assumption was made that $y$ was constant for each bi-texture combination, an equation (EQ 1) was derived from the conceptual diagram in Figure 2, and it was proved (bottom part of Figure 2) the long term behavior of the function approached the average of the two homogeneous soils’ VE.

For all 20 synergizing combinations, Fisher (2012) showed that evaporation synergy occurs ($VE_s > VE_c$ and $VE_s > VE_f$) with a column width of 4 cm wide, and Figure 2 shows that evaporation synergy ceases ($VE_s < VE_c$ or $VE_s < VE_f$) at some width before $\infty$. Therefore, there must be a width between 4 cm and $\infty$ when $VE_s = VE_c$ or $VE_s = VE_f$, whichever homogeneous soil has the higher VE. This is true for all 20 of the synergizing bi-texture combinations.

It was predicted that if each synergizing bi-texture combination was subjected to a series of evaporation experiments with an increasing column width, then at some width, $VE_s = VE_c$ or $VE_s = VE_f$, whichever homogeneous soil had the higher VE. Finding that width for each of the 20 synergizing bi-texture combinations was the focus of this research.

### 1.4 The Stages of Evaporation

The process that controls the evaporation of water from soil can be described in three stages, and the length of time each stage is active is a function of the soil texture. Coarse soils, for example, have larger pores which equates to a lower water holding capacity. Therefore, in a coarser soil more water is able to leave via evaporation than in a finer soil. The moisture content of the surface of the soil determines the stage of evaporation.

During stage 1, the surface of the soil has a moisture content above field capacity. This allows water to leave via evaporation at the highest rate possible (in the models, this was established as 0.4 cm/day). When the surface of the soil reaches field capacity, water must then move vertically in the profile via capillary forces before it can be leave via evaporation. This
creates a gradient of moisture content from the surface down. This zone is called the capillary fringe, and water will move up the fringe from lower levels where moisture content is above field capacity. The size of the fringe is dependent on the texture of the soil. As water leaves via evaporation, the lower levels of the fringe begin to dry out and the depth of the fringe gets deeper. The soil enters stage 3 when the fringe is no longer in contact with the soil surface. Water must then diffuse as a gas through the pores to reach the surface.

2.0 Methods

All of the data was collected using HYDRUS computer software in the Gilmore Annex computer lab on the campus of Oregon State University. There were three dependent experiments which were processed over a two week period in April, 2013.

2.1 Hydrus Model

The settings for all of the HYDRUS models can be found in Appendix C: Hydrus Model. Because the HYDRUS settings can alter the results, it is important to note the volumes of evaporation (VE) presented in this paper are only valid at those settings. All of the pertinent settings were maintained between each model with the exception of column width and column height for the first experiment, and column width for the second and third experiments.

In HYDRUS, a node is a defined point at which data is collected. Every node was centimeter wide in every model, and since HYDRUS counts the zero node as the first node, the number of nodes was always one larger than the column width (in cm). In the bi-texture models, it was important the distribution of nodes be 1:1 between the fine and coarse soils; therefore, the column width was always an odd number so the number of nodes could be an even number.
2.2 Experiment 1: Homogeneous Evaporation

The first experiment was designed to test the assumption that all 12 homogeneous soils maintained a constant VE. The first part was to test the sensitivity of evaporation to column width and the second part was to test the sensitivity of evaporation to column depth.

1. Four models at Θ: column depth = 10 cm, column width = 10, 20, 50, and 100 cm
2. Seven models at Θ: width = 10 cm, depth = 10, 40, 60, 80, 100, 125, and 150 cm

The only HYDRUS data collected was cumulative evaporation at time stamp 120 (day 60). Cumulative evaporation is a measure of the height of water that evaporated from the entire soil surface (not area adjusted). The data was converted to volume of evaporation and graphed using Excel. The results of the first experiment were used to design the second experiment.

2.3 Experiment 2: Bi-Texture Evaporation Synergy

The second experiment was designed to determine the approximate width that each bi-texture combination ceased evaporation synergy. There were 6 models at Θ per synergizing bi-texture combination (total of 120 models): column depth = 100 cm, column width = 1, 11, 51, 101, 301, and 451 cm. Cumulative evaporation was recorded for each data point, converted to volume of evaporation, and graphed in Excel. The data points were interpolated to determine the width when evaporation synergy ceased. The results of the second experiment were used during the third experiment to investigate a single bi-texture combination.

2.4 Experiment 3: Single Bi-Texture Evaluation

The third experiment evaluated a single bi-texture combination in detail to determine the mechanics which caused evaporation synergy to cease. Based on the evaluation during the second experiment, silty clay loam and loamy sand was chosen. Comparing evaporation data on a per-node basis between homogeneous and bi-texture columns was impossible due to limitations
of the HYDRUS computer data output. Therefore, in lieu of evaporation, moisture content data was collected and compared to establish a proxy for evaporation by which the homogeneous and bi-texture columns could be compared. A total of five models were run in order to understand the relationship between evaporation rate and moisture content.

Two models were run at Θ: homogeneous silty clay loam, column depth = 100 cm, column width = 10 cm; homogeneous loamy sand, column depth = 100 cm, column width = 10 cm. The moisture content for each node (100 vertical nodes x 10 horizontal nodes = 1000 total nodes) was collected and exported into excel. The evaporation rate was collected and used in conjunction with surface node moisture content to determine the critical moisture content which prevented the soil from evaporating at the potential rate of 0.4 cm/day. This data was exported into excel and graphed.

Three models were run at Θ: bi-texture combination of silty clay loam (fine) – loamy sand (coarse), column depth = 100 cm, column width = 51, 171, and 451 cm. The highest VE between silty clay loam and loamy sand (determined in experiment 1) was loamy sand. Therefore, the column widths were determined such that one width had $VE_{SCL-LS} > VE_{LS}$ (51 cm), one width had $VE_{SCL-LS} = VE_{LS}$ (171 cm), and one width had $VE_{SCL-LS} < VE_{LS}$. These column widths were estimated from the interpolated graph of silty clay loam and loamy sand established during experiment 2. The moisture content for each node, the evaporation rate for the column, and the cumulative evaporation for the column were exported. These numbers were converted (cumulative evaporation to volume of evaporation), categorized, and graphed in Excel.
3.0 Results

A total of 257 HYDRUS models were run – 132 models for experiment 1, 120 models for experiment 2, and 5 models for experiment 3. For experiments 1 and 2: only volume of evaporation data was recorded. For experiment 3: volume of evaporation, evaporation rate, per-node moisture content, and per-node pressure head were recorded. Experiment 2 used the results of experiment 1, and experiment 3 used the results from experiment 2. This was the dependent relationship between the three experiments.

3.1 Experiment 1: Homogeneous Evaporation

Experiment 1 was performed two parts: one tested the sensitivity of evaporation to column width, and the other tested the sensitivity of evaporation to column depth.

Part 1: Table 2 shows the tabular data collected during part 1 for all texture classes. Figure 3 expresses the data in Table 2 in graphical form. The data points were plotted and interpolated to indicate the linearity of volume of evaporation for homogeneous texture classes.

<table>
<thead>
<tr>
<th>Volume of Evaporation (mL)</th>
<th>Column Width (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>10</td>
</tr>
<tr>
<td>S</td>
<td>7.5</td>
</tr>
<tr>
<td>LS</td>
<td>8.4</td>
</tr>
<tr>
<td>SL</td>
<td>10.5</td>
</tr>
<tr>
<td>L</td>
<td>11.6</td>
</tr>
<tr>
<td>SI</td>
<td>11.2</td>
</tr>
<tr>
<td>SIL</td>
<td>12.0</td>
</tr>
<tr>
<td>SCL</td>
<td>7.9</td>
</tr>
<tr>
<td>CL</td>
<td>7.8</td>
</tr>
<tr>
<td>SICL</td>
<td>5.5</td>
</tr>
<tr>
<td>SC</td>
<td>3.5</td>
</tr>
<tr>
<td>C</td>
<td>3.5</td>
</tr>
</tbody>
</table>
Figure 3: Testing the sensitivity of evaporation in homogeneous soil columns to an increasing column width. Data points were plotted and interpolated to express linearity of VE as a function of column width.

Figure 4: Testing the sensitivity of evaporation in homogeneous soil columns to an increasing column depth. Data points were plotted and interpolated to determine the optimal soil column depth for experiment 2.
Part 2: Table 3 shows the tabular data collected during part 2 for all texture classes. Figure 4 expresses the data in Table 2 in graphical form. The data points were interpolated to determine the optimal depth for experiment 2. The depth was set at 100cm.

### 3.2 Experiment 2: Bi-Texture Evaporation Synergy

Table 4 shows the tabular data collected during experiment 2. The graphs of the data from Table 4 can be found in Appendix A: Bi-Texture Synergizing Graphs. The data points were plotted and interpolated to estimate the width when evaporation synergy ceased.

#### Table 3: Homogeneous soils’ VE (per depth)

<table>
<thead>
<tr>
<th>Column Depth (cm)</th>
<th>10</th>
<th>40</th>
<th>60</th>
<th>80</th>
<th>100</th>
<th>125</th>
<th>150</th>
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</thead>
<tbody>
<tr>
<td>S</td>
<td>3.8</td>
<td>7.8</td>
<td>7.8</td>
<td>7.7</td>
<td>7.5</td>
<td>7.4</td>
<td>7.2</td>
</tr>
<tr>
<td>LS</td>
<td>3.4</td>
<td>8.6</td>
<td>8.5</td>
<td>8.5</td>
<td>8.4</td>
<td>8.4</td>
<td>8.4</td>
</tr>
<tr>
<td>SL</td>
<td>3.2</td>
<td>10.0</td>
<td>10.6</td>
<td>10.5</td>
<td>10.5</td>
<td>10.5</td>
<td>10.5</td>
</tr>
<tr>
<td>L</td>
<td>3.0</td>
<td>9.2</td>
<td>11.1</td>
<td>11.6</td>
<td>11.6</td>
<td>11.6</td>
<td>11.6</td>
</tr>
<tr>
<td>SI</td>
<td>3.1</td>
<td>8.5</td>
<td>10.2</td>
<td>10.9</td>
<td>11.2</td>
<td>11.2</td>
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</tr>
<tr>
<td>SIL</td>
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<td>8.7</td>
<td>10.7</td>
<td>11.7</td>
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<td>12.0</td>
<td>12.0</td>
</tr>
<tr>
<td>SCL</td>
<td>2.4</td>
<td>7.0</td>
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<td>7.9</td>
<td>7.9</td>
<td>7.8</td>
<td>7.8</td>
</tr>
<tr>
<td>SICL</td>
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<td>5.2</td>
<td>5.5</td>
<td>5.5</td>
<td>5.5</td>
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<tr>
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<td>C</td>
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<td>3.1</td>
<td>3.4</td>
<td>3.5</td>
<td>3.6</td>
<td>3.6</td>
</tr>
</tbody>
</table>

#### Table 4: Bi-texture soil’s VE (per width)

<table>
<thead>
<tr>
<th>Column Width (cm)</th>
<th>1</th>
<th>11</th>
<th>51</th>
<th>101</th>
<th>301</th>
<th>451</th>
</tr>
</thead>
<tbody>
<tr>
<td>S - LS</td>
<td>8.2</td>
<td>8.2</td>
<td>8.5</td>
<td>8.4</td>
<td>8.4</td>
<td>8.4</td>
</tr>
<tr>
<td>S - SL</td>
<td>11.0</td>
<td>10.9</td>
<td>10.8</td>
<td>10.8</td>
<td>10.8</td>
<td>10.8</td>
</tr>
<tr>
<td>S - LS</td>
<td>13.9</td>
<td>13.3</td>
<td>12.9</td>
<td>12.8</td>
<td>12.7</td>
<td>12.6</td>
</tr>
<tr>
<td>S - L</td>
<td>14.5</td>
<td>13.8</td>
<td>13.1</td>
<td>12.9</td>
<td>12.5</td>
<td>12.1</td>
</tr>
<tr>
<td>S - SIL</td>
<td>15.5</td>
<td>14.2</td>
<td>13.7</td>
<td>13.4</td>
<td>13.2</td>
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</tr>
<tr>
<td>S - SCL</td>
<td>10.0</td>
<td>9.9</td>
<td>9.8</td>
<td>9.7</td>
<td>9.7</td>
<td>9.6</td>
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<tr>
<td>S - CL</td>
<td>12.0</td>
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<td>11.3</td>
<td>11.1</td>
<td>10.7</td>
<td>10.2</td>
</tr>
<tr>
<td>S - SICL</td>
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<td>9.8</td>
<td>9.2</td>
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<td>9.3</td>
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<td>10.3</td>
<td>10.3</td>
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<td>10.3</td>
</tr>
<tr>
<td>LS - L</td>
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<td>12.4</td>
<td>12.2</td>
<td>12.2</td>
<td>12.0</td>
</tr>
<tr>
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<td>12.5</td>
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<td>LS - SCL</td>
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<td>9.3</td>
<td>9.3</td>
<td>9.2</td>
<td>9.1</td>
<td>9.1</td>
</tr>
<tr>
<td>LS - CL</td>
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<td>11.1</td>
<td>10.7</td>
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<td>9.8</td>
</tr>
<tr>
<td>LS - SICL</td>
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<td>9.0</td>
<td>8.9</td>
<td>8.6</td>
<td>7.9</td>
<td>7.6</td>
</tr>
<tr>
<td>SL - L</td>
<td>11.9</td>
<td>11.9</td>
<td>11.8</td>
<td>11.8</td>
<td>11.7</td>
<td>11.7</td>
</tr>
<tr>
<td>SL - SI</td>
<td>12.6</td>
<td>12.6</td>
<td>12.3</td>
<td>12.1</td>
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<td>11.5</td>
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<tr>
<td>SL - SIL</td>
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<td>13.3</td>
<td>12.9</td>
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<tr>
<td>SC - C</td>
<td>4.5</td>
<td>4.4</td>
<td>4.2</td>
<td>4.1</td>
<td>3.8</td>
<td>3.8</td>
</tr>
</tbody>
</table>
Figure 5: Comparison of volume of evaporation in a bi-texture loamy sand – silty clay loam column and homogeneous columns of loamy sand and silty clay loam, as well as the average homogeneous volume of evaporation. Evaporation synergy ceases at approximately 170 cm.

3.3 Experiment 3: Single Bi-Texture Evaluation

The results from the first step of experiment one can be seen in Figure 5. The graphs of both bi-texture loamy sand – silty clay loam (blue line) as well as the homogenous graphs of loamy sand and silty clay loam (brown lines) are shown. The average of homogeneous is \( \frac{\text{VELS} + \text{VESICL}}{2} \) and equals the long-term behavior of the bi-texture combination. The estimated width when evaporation synergy ceases in this combination was ~170 cm.

Data was unavailable to determine the exact evaporative losses in the bi-texture soil columns on a per-node basis, though the surface node moisture content was used as a proxy to
estimate the length of time each node maintained the potential evaporation rate of 0.3 cm/day. Figure 6 and Figure 7 (page 12) show the relationship between moisture content and evaporation rate for homogeneous loamy sand and homogeneous silty clay loam, respectively. The critical moisture content for silty clay loam was determined to be 0.207 and the critical moisture content for loamy sand was determined to be 0.057. The potential rate of 0.4 cm/day was maintained so long as the moisture content of a surface node was greater than the critical value.

The results from the comparison of moisture contents to evaporation can be seen in Appendix B:LS – SCL Node Comparison. The three graphs show the behavior of the bi-texture columns as the column width increases. It is important to note that these graphs do not represent evaporation data, rather they represent the moisture content levels at the surface of the columns. The comparison comes from the homogeneous behavior (red lines) which is used as a proxy for evaporative losses.

Figure 6: Loamy Sand. Evaporation rate and moisture content as a function of time. Figure 7: Silty Clay Loam. Evaporation rate and moisture content as a function of time.
4.0 Discussion

An important part of the early stages of this project was to determine the behavior of the homogeneous soils. The width of the column did not change the cumulative evaporation per unit area over the 60 day model, but the depth did. Water moves vertically in soil, against the force of gravity, driven by capillary forces. The distance water can rise in a soil is dependent on the soil’s texture; in general, the finer the soil the higher the capillary rise. If the depth of the column is less than the capillary rise of the soil, the bottom nodes dry out and reduce the amount of evaporative losses. Using a depth of 100 cm for the second step allowed all the soils to use the capillary rise aspect of the individual soil to its maximum potential. This ensured the results were not inadvertently influenced by the bottom boundary of the model.

The HYDRUS computer program has some limitations on Mesh size, thus the maximum column width was 451 cm. But since 6 of the 20 bi-texture combinations ceased synergizing, it is safe to assume the other 14 will as well. The soils that perform the best over large widths are also soils that provide many of the best soils for agricultural use – silt, silt loam, and loam. It is not difficult to understand why these soils do such a good job of distributing water throughout their matrix. The reason silty clay loam and loamy sand was chosen for step three was due to the point it ceased synergizing. At 170 cm, this gave a good opportunity to explore the moisture content at smaller (51 cm) and larger (451 cm) widths. The investigation into silty clay loam and loamy sand justified the stated hypothesis. The silty clay loam begins to behave as if it were a homogeneous soil 75 cm from the bi-texture vertical boundary. This is based on the critical moisture content.

In the world of evaporation synergy, loamy sand and silty clay loam is a poor performer. This is due almost exclusively to the poor performance of the silty clay loam. As seen in Table 2,
the volume of evaporation for silty clay loam is 5.5 mL while the volume of evaporation for loamy sand is 8.4 mL. In the bi-texture combinations that include a fine soil with a higher volume of evaporation (unlike loamy sand – silty clay loam), the overall performance is much higher. The width of the synergizing component of a bi-texture system – dubbed ‘y’ in the hypothesis – is likely much larger in other combinations. Yet, the principles that cause the loamy sand – silty clay loam to cease synergizing will occur in other combinations as well.

5.0 Conclusion

There is still much to be discovered about the dynamics of evaporation synergy. A reevaluation of the data led to the formulation of a new hypothesis that tries to explain the reason the loamy sand did not exhibit homogeneous behavior in the 451 cm model. Since the silty clay loam did exhibit homogeneous behavior 75 cm from the vertical boundary, it is expected the loamy sand would as well, only at a much greater distance from the vertical boundary. The next step in this investigation would be to stretch the limits of the model by shortening the width of the fine soil and increasing the width of the coarse soil. This should increase the quantity of water evaporated from the fine soil, though the overall volume of evaporation would decrease.

Discovering the optimal widths for each soil texture class could provide valuable information that could be useful in engineering and agricultural systems to better manage evaporative losses. This knowledge could be used in remediation of contaminated ground water, or to provide an increase in horizontal water movement for agricultural practices in marginal or rain-fed soils. If the manipulation of a natural system can provide a force without the input of non-renewable energy, then the path to true sustainability is within society’s grasp.
References


Graph 1: Sand – Loamy Sand

Graph 2: Sand – Sandy Loam
Graph 3: Sand – Loam

Graph 4: Sand – Silt
Graph 5: Sand – Silt Loam

Graph 6: Sand – Sandy Clay Loam
Graph 7: Sand – Clay Loam

Graph 8: Sand – Silty Clay Loam
Graph 9: Sand – Clay

Graph 10: Loamy Sand – Sandy Loam
Graph 11: Loamy Sand – Loam

Graph 12: Loamy Sand – Silt
Graph 13: Loamy Sand – Silt Loam

Graph 14: Loamy Sand – Sandy Clay Loam
Graph 15: Loamy Sand – Clay Loam

Graph 16: Loamy Sand – Silty Clay Loam
Graph 17: Sandy Loam – Loam

Graph 18: Sandy Loam – Silt
Graph 19: Sandy Loam – Silt Loam

Graph 20: Sandy Clay – Clay
Graph 1: 51 cm bi-texture column of loamy sand (right) and silty clay loam (left). Vertical boundary at 26.5 cm

Graph 1: 171 cm bi-texture column of loamy sand (right) and silty clay loam (left). Vertical boundary at 86.5 cm

Graph 1: 451 cm bi-texture column of loamy sand (right) and silty clay loam (left). Vertical boundary at 225.5 cm
Dimensions changed with each model.

Time duration is set to 60 days. Initial time stamp and minimum time stamp set to 0.00001.

Key change which changes results dramatically.

11 texture classes used.
Appendix C: HYDRUS Model

Potential evaporation rate of 0.4 cm/day

Nodes changed with column size. Number of nodes always 1 larger than size

Initial pressure head set to -1 cm (saturation)