Agricultural Engineering Update

Short Course

Trickle Irrigation Installation for Horticulture Crops

by

Dr. Richard C. Warner
Mr. Jim Baier

Agricultural Engineering Department
Cooperative Extension Service
University of Kentucky

Lexington - March 24, 1987
9 a.m. to 3 p.m. - EST

Princeton - March 28, 1987
9 a.m. to 3 p.m. - CST
Course Outline

1. Trickle Irrigation Overview
   a. Mean monthly precipitation
   b. Mean monthly pan evaporation
   c. Monthly irrigation requirement

2. Design Planning
   a. What is needed to design a system
   b. Design planning map information
   c. Example planning map

3. Water Supply
   a. City water
   b. Other water supplies: pumps, motors, and engines

4. Basic Trickle Irrigation System
   a. Control station
      (1) pump or city water connection
      (2) backflow preventor
      (3) fertilizer tank
      (4) fertilizer injector
      (5) water meter
      (6) filter(s)
      (7) pressure gauges
      (8) pressure regulators
      (9) main shutoff valve
      (10) controllers
      (11) pressure relief valves
   b. Main, submains/manifolds
   c. Laterals
      (1) strip tubing
      (2) hose with emitters
         (a) laminar flow emitter
         (b) turbulent flow emitter
         (c) vortex
         (d) pressure compensating emitter
   d. Fittings
      (1) an example for city water connection
      (2) schematic of various fittings

5. Design Drawing

6. Installation
   a. Tools required
   b. Procedure

7. Emitter Clogging Problems
   a. Needed water quality
   b. Physical, chemical, and biological clogging problems

8. Irrigation Scheduling
   a. Tensiometers
   b. Resistance blocks
1. Trickle Irrigation Overview

Climatic Conditions

Bluegrass Region

<table>
<thead>
<tr>
<th></th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precip.</td>
<td>4.11</td>
<td>4.19</td>
<td>4.66</td>
<td>3.43</td>
<td>2.95</td>
</tr>
<tr>
<td>Evapo.¹</td>
<td>5.96</td>
<td>6.46</td>
<td>6.72</td>
<td>6.25</td>
<td>4.57</td>
</tr>
</tbody>
</table>

Western Region

<table>
<thead>
<tr>
<th></th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precip.</td>
<td>4.43</td>
<td>3.95</td>
<td>3.79</td>
<td>3.33</td>
<td>3.19</td>
</tr>
<tr>
<td>Evap.</td>
<td>6.40</td>
<td>7.15</td>
<td>7.47</td>
<td>6.31</td>
<td>4.66</td>
</tr>
</tbody>
</table>

Irrigation Needs² (Hort. crops)

<table>
<thead>
<tr>
<th>Soil type</th>
<th>Precip. condition</th>
<th>May</th>
<th>Jun</th>
<th>Jul</th>
<th>Aug</th>
<th>Sep</th>
</tr>
</thead>
<tbody>
<tr>
<td>loamy</td>
<td>normal³</td>
<td>0.00</td>
<td>0.36</td>
<td>3.23</td>
<td>1.81</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>dry⁴</td>
<td>0.00</td>
<td>0.50</td>
<td>3.57</td>
<td>2.14</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>very dry⁵</td>
<td>0.14</td>
<td>1.07</td>
<td>4.56</td>
<td>3.55</td>
<td>0.00</td>
</tr>
<tr>
<td>sandy</td>
<td>normal</td>
<td>0.00</td>
<td>0.44</td>
<td>3.44</td>
<td>2.32</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>dry</td>
<td>0.00</td>
<td>0.57</td>
<td>3.74</td>
<td>2.61</td>
<td>0.00</td>
</tr>
<tr>
<td></td>
<td>very dry</td>
<td>0.00</td>
<td>0.62</td>
<td>3.85</td>
<td>2.73</td>
<td>0.00</td>
</tr>
</tbody>
</table>

¹Pan evaporation
²Irrigation required to increase the water holding capacity (WHC) to field capacity whenever WHC decreases to 50%
³Normal 1 year out of 2
⁴Dry 1 year out of 5
⁵Very dry 1 year out of 10

Ponds and Wells

Pond Volume

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>ft³</td>
<td>40% x Width x Length x Depth</td>
</tr>
<tr>
<td>gal</td>
<td>7.48 x ft³</td>
</tr>
<tr>
<td>ac-ft</td>
<td>ft³/43,560</td>
</tr>
</tbody>
</table>
Advantages and Disadvantages of Trickle Irrigation

**Advantages:**
- reduces water volume needed
- reduces water waste (minimizes water runoff)
- water placement to roots
- reduces weed growth
- prevents soil crusting
- improves crop quality and yield, may hasten maturity
- reduces disease problems
- promotes even soil moisture (reduces tomato cracking)
- reduces root zone temperature
- No wind interference with distribution pattern
- Runs on low pressure, uses smaller equipment and less energy
- Easily automated, zoned
- Can be permanent system for perennial crops
- Can inject chemicals
- Can work while watering
- Between rows remains hard and dry for equipment
- Seeds and transplants not washed, damaged or dislodged
- Low labor requirement once installed
- Variable spacing, design

Disadvantages:
- Clean water needed to prevent clogging
- Roots may seek emitters/holes
- Initial assembly labor
- Above ground line damage by equipment
- Rodent damage
- Dislodging supply tubes
- Frequent irrigation required
2. Design Planning

a. What is needed to design a system

Area
  1) area to be irrigated
  2) Topography of area

Crop
  1) Crops to be raised
  2) Field location of crops
  3) Row spacing

Water Supply
  1) Location of water supply
  2) Type of water supply
  3) Pressure
  4) Flowrate

Soil
  1) Soil Series or Soil Type

b. Design Planning Map Information

1. Map scale 1'' = __________ ft

2. Sketch boundary of farm.

3. Locate the water source

4. Locate field(s)

5. Provide elevations on the map or at least
   a. locate highest point in the field
   and elevation difference between
   the water supply and highest point
   b. provide estimate of field slope(s)

6. Location of rows and preferred direction

7. Spacing between rows

8. Plant spacing along rows

Refer to enclosed example
2. Design Planning

a. What is needed to design a system

Area
1) area to be irrigated
2) Topography of area

Crop
1) Crops to be raised
2) Field location of crops
3) Row spacing

Water Supply
1) Location of water supply
2) Type of water supply
3) Pressure
4) Flowrate

Soil
1) Soil Series or Soil Type

b. Design Planning Map Information

1. Map scale 1" = _______ ft

2. Sketch boundary of farm.

3. Locate the water source

4. Locate field(s)

5. Provide elevations on the map or at least
   a. Locate highest point in the field
      and elevation difference between
      the water supply and highest point
   b. Provide estimate of field slope(s)

6. Location of rows and preferred direction

7. Spacing between rows

8. Plant spacing along rows

Refer to enclosed example
3. Water Supply

a. City Water

1. Size of service line ________ in
2. Water meter size ________ in
   - normally 5/8, 3/4, or 1 in
3. Static water pressure ________ psi
   -connect a pressure gauge to a hose bib
   and turn water on
4. Flow rate in gallons per minute ________ GPM
   obtain from the table below:

<table>
<thead>
<tr>
<th>Service Line (in)</th>
<th>Water Meter (in)</th>
<th>Gallons Per Minute for Static Pressure of (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1/2</td>
<td>5/8</td>
<td>30, 40, 50, 60</td>
</tr>
<tr>
<td>3/4</td>
<td>5/8</td>
<td>2.0, 5.0, 6.5</td>
</tr>
<tr>
<td>3/4</td>
<td>3/4</td>
<td>3.5, 7.0, 9.5</td>
</tr>
<tr>
<td>1</td>
<td>3/4</td>
<td>6.0, 9.0, 12.0</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>7.5, 11.5, 15.0</td>
</tr>
<tr>
<td>1 1/4</td>
<td>1</td>
<td>10.0, 13.5, 19.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>12.0, 17.0, 23.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>17.5, 23.5, 28.5</td>
</tr>
</tbody>
</table>


b. Other Water Supplies

-Pump
   Pressure and flow rate depend on irrigation system requirements. A pump should be selected that achieves:
   a. ________ ft of head (H)
   b. ________ gpm

-Drive system
   To determine horse power needs:
   -determine water horse power from

   \[ WHP = \frac{H \times 8.3 \times GPM}{33,000} \]

   -determine break horse power which accounts for pump efficiency being less than 100%
   -obtain pump efficiency from a manufacturing pump curve

   \[ BHP = \frac{WHP}{\text{pump efficiency}} \]

   -select drive system to be used and corresponding efficiency from the table below

<table>
<thead>
<tr>
<th>drive system</th>
<th>efficiency (approx.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>electric motor</td>
<td>90%</td>
</tr>
<tr>
<td>gas engine</td>
<td>25%</td>
</tr>
<tr>
<td>diesel engine</td>
<td>25%</td>
</tr>
</tbody>
</table>
- required motor or engine horse power

Required H.P. = HP/efficiency

- this may be further increased depending upon the connection between the drive system and pump, i.e., direct drive, belt drive, etc.
4. Basic Trickle Irrigation System

a. Control station
- contains all the components that link the water supply to the mainline
- the next 5 figures illustrate the various configurations of trickle irrigation systems
- components of a control station

(1) city water connection or engine or motor and pump
(2) backflow preventor (ex. check valve)
(3) fertilizer tank
(4) fertilizer injector
(5) water meter
(6) filter
(7) pressure gauges
(8) pressure regulator
(9) main shut off valve
(10) controller
(11) pressure relief valve

(2) Check VALVES
- prevents reverse flow of water
- prevents backflow from damaging pump
- prevents suction lines from being drained (prime)
- protects municipal water from contamination

(3) Fertilizer tank
- simply to hold the fertilizer

(4) Fertilizer injector
- injector pump
- venturi
- differential pressure tank
- injector pump
  - type - piston or diaphragm
  - constant concentration
  - require power source
  - more costly than venturi or differential pressure tank
  - requires more maintenance
- venturi
  - suction device
  - significant head loss
  - no power requirements
  - low cost
- differential pressure tank
  - non-uniform concentration
  - good for some chemical application
  - no power requirements
Fig. 1.1.4 An example of a basic trickle irrigation system.
Fig. 3.4.1 Trickle Irrigation System components.
FIGURE 51. Surface application by the trickle method. Water is applied very slowly onto the surface of the soil through special outlet emitters in plastic pipe.
FIGURE 10-1: COMPONENTS OF A TYPICAL MICRO-IRRIGATION SYSTEM
FIGURE 5-1: CHEMICAL INJECTION DEVICES
Water Meters
- determines the rate water is being applied
- determines the quantity of water used
- monitors continuing performance of the irrigation system
- assist in irrigation scheduling and cost analysis

Filters
- selection based on:
  - flow rate (GPM)
  - contaminant (types, site, concentration)
  - required quality
- types of filters
  - screen filter
  - centrifugal separators
  - media filters

Screen Filters
- Fine mesh screen enclosed within a cased housing
- primarily for filtering water containing inorganic materials i.e. sand, silt, scale
- remove small amounts of organic contaminants
- cannot trap and hold large amounts of organic material without restricting the flow

Centrifugal Sand Separators
- remove sand, scale, and other particles that are heavier than water
- often installed on suction side of pump
- self cleaning
- require minimum maintenance
- must be sized correctly

Media Filters
- filters water containing either organic or inorganic contaminants
- ability to hold and entrap large quantities of contaminants
- water is filtered through sand
  *Selection of sand type
    - too coarse sand will lead to poor filtration and system clogging
    - too fine sand will cause unnecessary and excessive backwashing of the filter
    - depends on type of emitters or strip tubing used in the system
- must be cleaned by backwashing or reversing the direction of water flow through the bed

Pressure Gauges
- used to measure pressure at critical locations, i.e. entrance of mains and submains
- may indicate pressure loss due to clogging before and after a filter
- may indicate leakage, line breaks, etc.

Pressure Regulators
JRE 4-1: SCREEN MESH SIZES COMPARED TO 0.020-INCH ORIFICE
TABLE 3.2.1

Classification of screens and particle sizes.

<table>
<thead>
<tr>
<th>Screen mesh no.</th>
<th>Equivalent diameter (micrometer)</th>
<th>Particle designation</th>
<th>Equivalent diameter (micrometer)</th>
</tr>
</thead>
<tbody>
<tr>
<td>16</td>
<td>1180</td>
<td>Coarse sand</td>
<td>&gt;1000</td>
</tr>
<tr>
<td>20</td>
<td>850</td>
<td>Medium sand</td>
<td>250-500</td>
</tr>
<tr>
<td>30</td>
<td>600</td>
<td>Very fine sand</td>
<td>50-250</td>
</tr>
<tr>
<td>40</td>
<td>425</td>
<td>Silt</td>
<td>2-50</td>
</tr>
<tr>
<td>100</td>
<td>150</td>
<td>Clay</td>
<td>&lt;2</td>
</tr>
<tr>
<td>140</td>
<td>106</td>
<td>Bacteria</td>
<td>0.4-2</td>
</tr>
<tr>
<td>170</td>
<td>90</td>
<td>Virus</td>
<td>&lt;0.4</td>
</tr>
<tr>
<td>200</td>
<td>75</td>
<td></td>
<td></td>
</tr>
<tr>
<td>270</td>
<td>53</td>
<td></td>
<td></td>
</tr>
<tr>
<td>400</td>
<td>38</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
FIGURE 160. Filter commonly used in trickle irrigation.
The "Thru Flush" System

During the filtering mode, source water enters the filter through the inlet port and then through the screen cartridge where the particulate is trapped on the inside of the screen. Clean, filtered water flows to your irrigation lines through the outlet port.

Filtering

Flushing

Cleaning the filter is accomplished by simply opening the thru flush valve allowing the force of the water flow to flush the particulate out through the flush port. The SS8 requires 300 GPM water available to provide the thru-flushing cleaning action. The SS6 requires 150 GPM water available to provide thru-flush cleaning action.
FIGURE 4-2: COMMON TYPES OF FILTRATION EQUIPMENT
Lakos Filtering Process

From Water Source (via manifold)

Flow Dispersion Assembly

Filter Tank

Media Sand

Lakos Lateral/Underdrain Assembly

To System
Lakos Backwash Process
(9) Shutoff Valves
- used to shut water flow off completely
- placed in control station unit and at the head of submains

(10) Controllers
- time clock that will operate over a two week period
  and will turn on and off automatic valves for a given period of time each day or every other day
- subunits can automatically be irrigated in sequence thus saving time and labor

(11) Pressure Relief Valves
- installed to prevent high pressures
  1) Sudden opening or closing of a valve
  2) Starting or stopping of a pump
  3) Pressure regulating valve failure
  4) Slamming shut of a check valve
  5) Failure to evaluate static as well as dynamic pressure conditions for a pipeline
    - hydraulic or electric valves
    - automatic unlimited number of cycles
    - order of operation can be changed
    - operating time and quantity of water can be changed

b. Main, Submains, and/or Manifolds
- transports water from source to submain lines

Submain (Manifolds)
- transports water from mainlines to laterals

Supply or Feeder Tubes
- supply water from the submain to the drip line
- allows for correct pressure into the drip line

c. Lateral Line
- strip tubing
- hose with emitters

(1) Strip tubing
Types
- Twin wall
- essentially a tube within a tube
  - water discharged from the supply tube enters the inside tube moves through the length of the row
  - water moves out through interior holes into the outer tube
  - outer tube has perforations every 'x' inches through which water seeps into the soil
- Bi-wall
  - consists of main chamber which water flows until pressure is same throughout the line
  - water flows into a secondary chamber on top of the main chamber and is distributed through holes along the entire chamber
(2) **Emitters**

- Deliver water from laterals to soil at a specific point
- 4 types of emitters
  
(a) **Laminar flow**
  - Smooth fluid flow at low velocities
  - Simple, reliable, inexpensive
  - Flow varies significantly with pressure
  - Susceptible to clogging
  Ex) Microtubes, capillary tubes, spiral path

(b) **Turbulent flow emitters**
  - Fluid particles move rapidly in irregular, random motions
  - Resistant to clogging
  - Less sensitive to pressure variations

(c) **Vortex emitters**
  - Less pressure sensitive than turbulent emitter
  - Water passages are very small
  - Easily clogged by soil particles
  - Require high quality filtering system
  - Requires attentive management
  Ex) Orific vortex emitter

(d) **Pressure compensating emitters**
  - May be laminar or turbulent
  - Delivers correct flow rate over a range of inlet pressures
  - Flow is relatively constant
  - Flow path is modified by elastomeric disc, diaphragm or changing water passage
  - May be used on steep or undulating terrain
Fig. 1a. TUBE

Fig. 1b. SPIRAL

Fig. 1c. COMPENSATING

Fig. 2.1.1 Laminar (long path) emitters.
la. Tube type laminar emitter.
lb. Spiral long path emitter.
lc. Compensating spiral laminar emitter.
PRESSURE COMPENSATED DRIPPERS
FLOW RATE VS. PRESSURE CHART

FLOW RATE (gph)

PRESSURE (PSI)

2 US gph - P.C. Dripper
1 US gph - P.C. Dripper
0.5 US gph - P.C. Dripper
INSERT TEK

REDUCING MALE ADAPTER
(Flip x Insert)

INSERT MALE ADAPTER

INSERT REDUCING COUPLING
1\(\frac{1}{4}\)" PE MAIN 80 ft.

56'

13'

--- = 10 feet

End Caps

Emitter Line

Emitters 1gph
Shut-off Valve

Water Source

Supply Tubes

1/4" PE MAIN LINE 100 ft.

Dripline

End caps 45'

--- = 5 feet
6. Installation

a. Tools required
   * pipe wrench
   * hand saws
   * PVC pipe cutter
   * hacksaw
   * screwdriver
   * files
   * crowbar
   * rags
   * PVC cleaner
   * PVC glue
   * Teflon tape
   * emitter punch tools
   * submain punch tools
   * drill with bit
Guide used to prevent puncturing both walls

Sleeve can be removed for periodic flushing of lateral line.

Feeder tubing cut on bevel on both ends to assist placement in TAPE and submain and to not allow tube to seat against back I.D. of submain.

Submain could be P.E. PVC or flexible vinyl "layflat" NOTE: Insert supply tube into layflat 12". P.E. and PVC to far wall as shown.

Supply tube 30 to 36" long inserted 12" into TAPE. Standard size is .250 x .350 P.E. Supply tube should "force fit" TAPE and submain to insure leak-free hook-up.
b. Installation procedures
* pipe for mailines and submains is laid out
* assemble mainline and submains
* clean pipe before gluing
* make sure correct glue is being used with PVC pipe
  there are different type glues for different size pipes
* in cool weather allow additional time for glue joints
  to cure
* PVC pipe should be cut square
* lateral lines are installed in the field but not yet
  connected to submains
  care should be taken that lateral lines are not
  plugged with soil, etc. Keep ends closed
* close all submain control valves
* fill mainlines with mainline valves open to flush
  foreign material out of mainlines
* assemble manifold lines, leaving ends open
* punch or drill holes into manifold lines for dripline
  supply tubes and emitter lines
* flush manifold lines of any foreign debris
* connect drip line and emitter line
* check system for leaks
* repair any leaks
<table>
<thead>
<tr>
<th>Type of problem</th>
<th>Minor</th>
<th>Moderate</th>
<th>Severe</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physical</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suspended solids a</td>
<td>50</td>
<td>50-100</td>
<td>&gt;100</td>
</tr>
<tr>
<td>Chemical</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>7.0</td>
<td>7.0-8.0</td>
<td>&gt;8.0</td>
</tr>
<tr>
<td>Dissolved solids a</td>
<td>500</td>
<td>500-2,000</td>
<td>&gt;2,000</td>
</tr>
<tr>
<td>Manganese a</td>
<td>0.1</td>
<td>0.1-1.5</td>
<td>&gt;1.5</td>
</tr>
<tr>
<td>Total iron a</td>
<td>0.2</td>
<td>0.2-1.5</td>
<td>&gt;1.5</td>
</tr>
<tr>
<td>Hydrogen sulfide a</td>
<td>0.2</td>
<td>0.2-2.0</td>
<td>&gt;2.0</td>
</tr>
<tr>
<td>Biological</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bacterial population b</td>
<td>10,000</td>
<td>10,000-50,000</td>
<td>&gt;50,000</td>
</tr>
</tbody>
</table>
TABLE 3.1.2

Principal physical, chemical and biological contributors to clogging of trickle systems (after Bucks et al., 1979).

<table>
<thead>
<tr>
<th>Physical (suspended solids)</th>
<th>Chemical (precipitation)</th>
<th>Biological (bacteria and algae)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inorganic particles:</td>
<td>Calcium or magnesium</td>
<td>Filaments</td>
</tr>
<tr>
<td>Sand</td>
<td>carbonate</td>
<td></td>
</tr>
<tr>
<td>Silt</td>
<td>Calcium sulfate</td>
<td>Slimes</td>
</tr>
<tr>
<td>Clay</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plastic</td>
<td>Heavy metal</td>
<td>Microbial decomposition:</td>
</tr>
<tr>
<td></td>
<td>.hydroxides, carbonates,</td>
<td>Iron</td>
</tr>
<tr>
<td></td>
<td>silicates, and sulfides</td>
<td>Sulfur</td>
</tr>
<tr>
<td>Organic particles:</td>
<td></td>
<td>Manganese</td>
</tr>
<tr>
<td>Aquatic plants</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(phytoplankton/algae)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Aquatic animals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(zooplankton)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bacteria</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Oil or other lubricants</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fertilizers:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Phosphate</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Aqueous ammonia</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Iron, copper, zinc,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>manganese</td>
<td></td>
</tr>
</tbody>
</table>
TABLE 3.1.3

Causes of clogging or flow reduction and relative percent occurrence in trickle irrigation emitters at Yuma, Arizona (after Gilbert et al. 1981)\textsuperscript{a}.

<table>
<thead>
<tr>
<th>Causes of clogging</th>
<th>Percent of occurrence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Individual</td>
</tr>
<tr>
<td>Physical factors</td>
<td></td>
</tr>
<tr>
<td>Sand grain</td>
<td>17</td>
</tr>
<tr>
<td>Plastic particles</td>
<td>26</td>
</tr>
<tr>
<td>Sediment</td>
<td>2</td>
</tr>
<tr>
<td>Body parts of insects and animals</td>
<td>3</td>
</tr>
<tr>
<td>Deformed septa\textsuperscript{b}</td>
<td>7</td>
</tr>
<tr>
<td>Biological factors</td>
<td></td>
</tr>
<tr>
<td>Microbial slime</td>
<td>11</td>
</tr>
<tr>
<td>Plant roots and algal mats</td>
<td>3</td>
</tr>
<tr>
<td>Chemical factors</td>
<td></td>
</tr>
<tr>
<td>Carbonate precipitates</td>
<td>2</td>
</tr>
<tr>
<td>Iron-manganese precipitates</td>
<td>0</td>
</tr>
<tr>
<td>Combined factors\textsuperscript{c}</td>
<td></td>
</tr>
<tr>
<td>Physical/biological</td>
<td>8</td>
</tr>
<tr>
<td>Physical/chemical</td>
<td>2</td>
</tr>
<tr>
<td>Chemical/biological</td>
<td>6</td>
</tr>
<tr>
<td>Physical/biological/chemical</td>
<td>2</td>
</tr>
</tbody>
</table>

\textsuperscript{a} Non-detectable (probably physical).
FIGURE 13-2: Tensiometer Components

- Service Cap
- Reservoir
- Rubber Seal
- Vacuum Gauge
- Plastic Tube
- Ceramic Tip
Figure 6. Tensiometers used to measure soil moisture.
Figure 7. --Electrical-resistance soil-moisture meters.