The Hidden Half of the Plant
The Hidden Half of the Plant

- What are root functions?
- How do you study roots?
- Where are the roots?
- How do roots absorb water and nutrients?
- Why is this important?
- Sensor Based Irrigation
- Available Water Capacity (AWC) Irrigation
Root Functions

1. Anchor and support plant

2. Absorb and conduct water and nutrients

Out of sight, out of mind. Eighty percent of all plant problems start with soil/root environment.

There is more plant surface area below ground than above ground.
Root Study Methods

- Trench Profile
- Ingrowth Cores
- Rhizotron
- Minirhizotron
- Pinboard
Root core sampling

4, 8, 12 WAP 2008 - 2016

- Giddings coring machine
- Depth 75 cm (30”)
- Plastic tube liners
- Two sample sites at each plant
- At 12 WAP – Core 3 – Bare ground
Root Morphology

- Cores frozen – cut into 15 cm (6”) segments (5 per core)
  - 6,000 + samples
- Roots separated from soil by hand washing

- Roots placed in container with 50% ethanol

Frozen 15 cm segments

Two wash stations

Label & Boxed

Stored @ 8º C

No. 18, 1 mm sieve

50% EtOH
Root Morphology

• WinRHIZO Pro 2009
• 400 dpi with pixel size at 0.063 mm
• Morphological information acquired:
  • Root length (cm)
  • Root length density (RLD)(cm/cm³)
  • Surface area (SA) (cm²)
  • Average diameter (mm)
  • Root length at 0.25 mm diameter increments

20 x 25 cm tray, 2 mm deep water

Analyzed Image
Root Functions

Absorb and conduct water and nutrients

Do all roots absorb water and nutrients?

Fine roots < 1.0 mm and root hairs absorb almost all water and nutrients

• 98% roots we measured < 1.0 mm
Human Hair

0.017 – 0.18 mm

Root Hair

< 0.01 mm

Fine Roots - < 1 mm (1/32")
Root Length Density (RLD) by Depth (2008 – 2014)

RLD (cm·cm³)

Soil depth (inch)

Average for 7 years

Loamy Sand & Wagram Sand – 76% Roots in 0-12”
Root Length Density (RLD) by Depth (2010) – Fine Roots < 1.0 mm

RLD (cm·cm³)

<table>
<thead>
<tr>
<th>Soil depth (inch)</th>
<th>RLD (cm·cm³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-6</td>
<td>1.2</td>
</tr>
<tr>
<td>6-12</td>
<td>1.4</td>
</tr>
<tr>
<td>12-18</td>
<td>0.2</td>
</tr>
<tr>
<td>18-24</td>
<td>0.1</td>
</tr>
<tr>
<td>24-30</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Wagram Sand – 85% Roots in 0-12”
Tomato Roots – 88% top 10” soil (loam soil)
Watermelon roots – 76% top 12” soil
How do roots absorb water and nutrients?

Giant Sequoia – 387’7”

Watermelon vines – 20 to 30’

What drives this uptake of water?
Transpiration Stream

Water evaporates from leaf

Negative water potential (Suction) down to root tips and root hairs into the soil.
Water Molecule Properties Help

Cohesion

Adhesion

Meniscus
What do we know now?

1. Massive amount of plant material below ground!

2. Size does make a difference – fine roots < 1.0 mm absorb water and nutrients

3. Vast majority of effective roots are in the top 12” soil – Management Zone

4. Transpiration drives uptake of water and nutrients

5. Roots aren’t there then water and nutrients are lost
Effective Root Zone

Application of irrigation water should be limited to an amount that will penetrate only the effective root zone.
SENSOR BASED IRRIGATION

Controller & Network

Sensor

Wireless Communication
How Do Sensors Work?

- Sentek TriSCAN EasyAg 50 cm multisensor capacitance probe (MCP)
- Sensors unit extends 20 inches deep in soil
- Sensors located at 4” (10 cm) increments (4, 8, 12, 16, 20)
- Transmits electromagnetic waves > 100 MHz (15 minutes)
- Soil water content alters frequency
- Change in frequency tells us soil volumetric moisture content (VMC)
1. What is my Management Zone Depth?  
   “How deep is my bucket”?

2. How much water can my bucket hold?  
   “What soil type is in my bucket”?

3. How much of a water deficit can my crop withstand?  
   “How much do we allow to leave our bucket”? 

WHEN DO THE SENSORS TELL THE IRRIGATION TO START??????

How big is my bucket – where is the root zone?

Watermelons – 12” depth
How much water can my bucket hold?

- Volumetric Moisture Content (VMC)
  - Sand – 6-10%
  - Loam – 11-21%
  - Clay – 22+%  

Field Capacity (FC)

Soil Matrix at Field Capacity
AVAILABLE WATER DEPENDS ON SOIL TEXTURE

Soil water content is often expressed in percent by dry weight or by volume. The amount of water that is available to plants is the difference between the field capacity and the wilting coefficient. Field capacity is the amount of water that is held in the soil after the excess moisture has drained away. The wilting coefficient is the amount of water that is held in the soil by the plant roots. The available water is the water that is held in the soil by the plant roots and that is available to the plant. The available water is the water that is held in the soil by the plant roots and that is available to the plant.
1. NRCS Soil Survey
   http://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

2. Soil Texture Analysis
   % Sand, Silt & Clay
   http://www.nrcs.usda.gov/wps/portal/nrcs/detail/soils/survey/?cid=nrcs142p2_054167

<table>
<thead>
<tr>
<th>Soil Texture</th>
<th>Available Water Capacity</th>
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<tbody>
<tr>
<td></td>
<td>Low</td>
</tr>
<tr>
<td>-inch of water / inch of soil-</td>
<td></td>
</tr>
<tr>
<td>Coarse sands</td>
<td>0.05</td>
</tr>
<tr>
<td>Fine sands</td>
<td>0.07</td>
</tr>
<tr>
<td>Loamy sands</td>
<td>0.07</td>
</tr>
<tr>
<td>Sandy loams</td>
<td>0.1</td>
</tr>
<tr>
<td>Fine sandy loams</td>
<td>0.13</td>
</tr>
<tr>
<td>Sandy clay loams</td>
<td>0.13</td>
</tr>
<tr>
<td>Loams</td>
<td>0.18</td>
</tr>
<tr>
<td>Silt loams</td>
<td>0.17</td>
</tr>
<tr>
<td>Silty clay loams</td>
<td>0.13</td>
</tr>
<tr>
<td>Clay loams</td>
<td>0.13</td>
</tr>
<tr>
<td>Silty clay</td>
<td>0.13</td>
</tr>
<tr>
<td>Clay</td>
<td>0.11</td>
</tr>
</tbody>
</table>
Wagram Sand (FuA) – coarse sand
- Picture on right – EC soil map. Lighter the color less water holding capacity
- 12 years of summer and winter cover crops, compost, chicken litter
- Available Water holding capacity greatly improved
How much water do we allow to leave our bucket?

- For Vegetable crops – maximum growth at or near Field Capacity
- Large amount of water in fruit and tissue
- Do not withstand any significant drought stress
- Risk is great

15% Available water - gone
50% Available water - gone

Yield significantly reduced at 50% deficit
Sensor Location in Field???

- 50 A field
- 3 soil types
- 6 irrigation zones
- 2 sensor units
  - 1 at emitter
  - 1 between
- Both go in droughty soil
15% Depletion – Trig @ 9.77%
- Off @ 10.3%

Fertigation

Irrigations

FC @ 10.7%

4” = 10.43%
8” = 6.61%
12” = 10.53%
AVG = 9.19%
Irrigation Trigger @ 9.7%

Fertigation

15%

2nd Irrigation

OFF @ 10.3%
<table>
<thead>
<tr>
<th>YEAR</th>
<th>1 INCH / WK</th>
<th>SENSOR BASED</th>
<th>RAIN</th>
</tr>
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<tbody>
<tr>
<td>2011</td>
<td>83 DAY GROWING SEASON</td>
<td>6.9 &quot;</td>
<td></td>
</tr>
<tr>
<td>WATER APPLIED</td>
<td>11.9 &quot; / A</td>
<td>6.1 &quot; / A</td>
<td></td>
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<td>YIELD</td>
<td>74,210 lbs / A</td>
<td>94,170 lbs / A</td>
<td></td>
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<tr>
<td>2012</td>
<td>98 DAY GROWING SEASON</td>
<td>15.5 &quot;</td>
<td></td>
</tr>
<tr>
<td>WATER APPLIED</td>
<td>14.2 &quot; / A</td>
<td>5.5 &quot; / A</td>
<td></td>
</tr>
<tr>
<td>YIELD</td>
<td>136,462 lbs / A</td>
<td>132,097 lbs / A</td>
<td></td>
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<tr>
<td>2013</td>
<td>99 DAY GROWING SEASON</td>
<td>23.4 &quot;</td>
<td></td>
</tr>
<tr>
<td>WATER APPLIED</td>
<td>14.1 &quot; / A</td>
<td>3.6 &quot; / A</td>
<td></td>
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<tr>
<td>YIELD</td>
<td>74,874 lbs / A</td>
<td>84,743 lbs / A</td>
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<tr>
<td>2014</td>
<td>97 DAY GROWING SEASON</td>
<td>9.6 &quot;</td>
<td></td>
</tr>
<tr>
<td>WATER APPLIED</td>
<td>13.8 &quot; / A</td>
<td>6.6 &quot; / A</td>
<td></td>
</tr>
<tr>
<td>YIELD</td>
<td>143,441 lbs / A</td>
<td>149,413 lbs / A</td>
<td></td>
</tr>
</tbody>
</table>
Nutrient Movement in Soil

- How does water application affect movement of soil nutrients???
- How do we maintain nutrients in Root Zone???

**Soil Solution Sampling**

- Sentek Solusamplers at 8” (Rootzone) and 16” & 24” (below Rootzone) soil depth.

- Solutions collected at pre-plant and designated growth stages: Pre, Transplant, Vining, Flowering, Fruit Set, Fruit Swell and Harvest.

- Solutions analyzed for N, P, K, Ca, Mg and minor elements
NO₃ (gm/m²) at 20 and 40 cm soil depths; Two irrigation treatments

Sensor Based @ 15% AW deficient

Programmed @ 1/7” per day (1”/week)
On Farm Results

1. 12 acre watermelon field

<table>
<thead>
<tr>
<th>Farm</th>
<th>Sensor</th>
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<tbody>
<tr>
<td>67 day season</td>
<td></td>
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<tr>
<td>5.3”</td>
<td>5.1”</td>
</tr>
</tbody>
</table>

Yield

<table>
<thead>
<tr>
<th>Farm</th>
<th>Sensor</th>
</tr>
</thead>
<tbody>
<tr>
<td>69,445 lbs / A</td>
<td>77,541 lbs / A</td>
</tr>
</tbody>
</table>

2. 30 acre watermelon field

- Water use and yields were similar
- Farmer made daily trips to field to monitor soil moisture
- Irrigated according to daily readings
- Sensors automated
- LABOR costs?????????
2012 – “Dry Year”

- Titan Farms cut its water usage 60% per acre
- Standard Operation = 4 irrigations of 20 hrs each (80hrs total)
- Implementation of Sensors went to 8 /4hrs watering 32 hrs

Better Irrigation Management due to technology – Impacted Trees, Fruit, & Financial Bottom Line

- $50,000 investment in equipment saved $500,000 in fuel & electricity
- Saved 72,000 gallons of water per acre or 360,000,000 gallons of water
Sensor Based Irrigation

Positive
• Water Conservation
• Labor Savings
• Fuel Savings
• Fertilizer Savings ??
• Possible Crop Improvement

Negative
• Costs - ~~ $10,000 (Can lease)
  • 2 sensors
  • Controller
  • Network (real time VMC; charts)
• New Technology – @$#%* happens
• Controller capabilities – multi zones
• In field equipment – radio pole
WATER MANAGEMENT

• CROP WATER REQUIREMENTS

• EFFECTIVE ROOT ZONE

• SOIL WATER HOLDING CAPACITY

• IRRIGATION SYSTEMS CAPABILITIES
CROP WATER REQUIREMENTS

• GENERAL RULE OF THUMB:
• VEGETABLES NEED AN AVERAGE OF 1 INCH WATER PER WEEK IN ORDER TO GROW VIGOROUSLY.
  • EARLY GROWTH - .5 INCH WATER / WEEK
  • PEAK GROWTH - 1.0 + INCH WATER / WEEK

• 1 INCH WATER / ACRE = 27,154 GALLONS
• 3,879 GALLONS / DAY = 27,154 GAL. / WEEK
WATER MANAGEMENT

• CROP WATER REQUIREMENTS

• EFFECTIVE ROOT ZONE

• SOIL WATER HOLDING CAPACITY

• IRRIGATION SYSTEMS CAPABILITIES
How big is my bucket – Effective Root Zone?

Watermelons – 12” depth
WATER MANAGEMENT

• CROP WATER REQUIREMENTS

• EFFECTIVE ROOT ZONE

• SOIL WATER HOLDING CAPACITY

• IRRIGATION SYSTEMS CAPABILITIES
SOIL WATER HOLDING CAPACITY

WHAT IS GOING TO DETERMINE HOW LONG AND HOW MUCH WATER STAYS IN THE ROOT ZONE????

1. % SAND
2. % SILT
3. % CLAY
McKoy Farm – Edisto Island
WnB – Wando loamy fine sand; AWC – 0.07; 56.8%
Sk – Seabrook loamy fine sand; AWC – 0.08; 37.5%
### Available Water Capacity

<table>
<thead>
<tr>
<th>Soils</th>
<th>Available Water Capacity (AWC) Inch water / inch soil</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wagram Sand</td>
<td>0.05</td>
</tr>
<tr>
<td>Wando loamy fine sand</td>
<td>0.07</td>
</tr>
<tr>
<td>Seabrook loamy fine sand</td>
<td>0.08</td>
</tr>
<tr>
<td>Barnwell Loamy Sand</td>
<td>0.08</td>
</tr>
<tr>
<td>Orangeburg Sandy Loam</td>
<td>0.10</td>
</tr>
<tr>
<td>Rains Sandy Loam</td>
<td>0.12</td>
</tr>
</tbody>
</table>
WATER MANAGEMENT

• CROP WATER REQUIREMENTS
• EFFECTIVE ROOT ZONE
• SOIL WATER HOLDING CAPACITY
• IRRIGATION SYSTEMS CAPABILITIES
HOW MUCH WATER ARE YOU APPLYING PER ACRE?

• DRIP TAPE FLOW RATE IS 4 gpm / 1,000’

• ROW SPACING IS 6’ = 7,260’ OF DRIP TAPE/ACRE

• 7,260’ ÷ 1,000’ = 7.260 x 4 gpm/1,000’ = 29.04 gpm / A.

FEET OF DRIP TAPE PER ACRE ÷ 1000 x GPM / 1000’ = GPM / ACRE
**Maximum Application Times (minutes)**

<table>
<thead>
<tr>
<th>AWHC (in./in.)</th>
<th>Tubing Flow Rate (gpm/1000')</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>2</td>
</tr>
<tr>
<td>0.05</td>
<td>59</td>
</tr>
<tr>
<td>0.06</td>
<td>70</td>
</tr>
<tr>
<td><strong>0.07</strong></td>
<td><strong>82</strong></td>
</tr>
<tr>
<td>0.08</td>
<td>94</td>
</tr>
<tr>
<td>0.09</td>
<td>106</td>
</tr>
<tr>
<td>0.1</td>
<td>117</td>
</tr>
<tr>
<td>0.12</td>
<td>141</td>
</tr>
<tr>
<td>0.13</td>
<td>153</td>
</tr>
</tbody>
</table>

*12” depth with 20% available water depletion*
DAILY RUN TIME FOR 1 INCH WATER PER WEEK

• 1" water = 27,154 gallons

• How much water is needed each day = 27,154 ÷ 7 = 3,879 gal./day

• Drip tape flow rate = 4 gal / minute / 1,000’

• How many feet of drip tape per acre???
  • 6’ row spacing = 7,260’

• Water application per minute per acre = 29.04 gal / minute

• How many minutes needed to apply 3,879 gallons
  • 3,879 gal. ÷ 29.04 gal. = 134 minutes / day

• 134 MINUTES / DAY = 1 INCH WATER PER WEEK
### Maximum Application Times (minutes) *

<table>
<thead>
<tr>
<th>AWHC (in./in.)</th>
<th>Tubing Flow Rate (gpm/1000')</th>
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<td>70</td>
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<td>0.07</td>
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<tr>
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<td>94</td>
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<tr>
<td>0.09</td>
<td>106</td>
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<tr>
<td>0.1</td>
<td>117</td>
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<tr>
<td>0.12</td>
<td>141</td>
</tr>
<tr>
<td>0.13</td>
<td>153</td>
</tr>
</tbody>
</table>

*12” depth with 20% available water depletion
WnB – Wando loamy fine sand; AWC – 0.07; 56.8%
Sk – Seabrook loamy fine sand; AWC – 0.08; 37.5%
Run Time for Wando loamy fine sand @ 0.07 AWC @ Drip Tape flow rate – 4 gal/min

- After 41 minutes at 12” depth with 20% AW deficit, water and nutrients are moving below the feeder root zone.

- Run time per day for 1” water per week = 134 MINUTES.

- $134 \text{ (TOTAL TIME)} \div 41 \text{ (RUN TIME)} = 3.27 \text{ IRRIGATIONS}$
  
  - 3 IRRIGATIONS @ 45 MINUTES EACH
  - 4 IRRIGATIONS @ 34 MINUTES EACH
<table>
<thead>
<tr>
<th>AWHC (in./in.)</th>
<th>Tubing Flow Rate (gpm/100')</th>
<th>Enter % Depletion</th>
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<tr>
<td></td>
<td>0.16</td>
<td>0.2</td>
</tr>
<tr>
<td>0.02</td>
<td>15.3</td>
<td>23</td>
</tr>
<tr>
<td>0.03</td>
<td>22.9</td>
<td>35</td>
</tr>
<tr>
<td>0.04</td>
<td>30.6</td>
<td>47</td>
</tr>
<tr>
<td>0.05</td>
<td>38.2</td>
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<td>200</td>
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<tr>
<td>0.21</td>
<td>160.5</td>
<td>247</td>
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</table>

Wetted volume per 100 ft @ root zone depth = 157 Enter volume (ft³ of soil)

**Formula**

\[
\text{AWHC} \times \text{Depletion} \times \text{Wetted Volume} \times \text{conversion to gallons} = \text{gallons per 100 ft}^3
\]

\[
\text{Gallons per ft}^3 = 7.48 \quad 1 \text{ ft}^3 = 1728 \quad \text{inch}^3 \quad 1 \text{ gal} = 231 \quad \text{inch}^3
\]

Time of application = \[
\frac{\text{gallons per 100 ft}}{\text{tubing flow rate}}
\]

\[
r = \text{root zone depth}
\]

Volume of a 1/2 cylinder = \[
0.5(\pi r^2 h)
\]

<table>
<thead>
<tr>
<th>(\pi = 3.1416)</th>
<th>(r \text{ (inches)})</th>
<th>(r \text{ (ft)})</th>
<th>(r^2 = )</th>
<th>(h = )</th>
<th>Vol (ft³)</th>
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<tr>
<td>10</td>
<td>0.83</td>
<td>0.69</td>
<td>100</td>
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<td>1.00</td>
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<td>157</td>
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<tr>
<td>14</td>
<td>1.17</td>
<td>1.36</td>
<td></td>
<td></td>
<td>214</td>
</tr>
<tr>
<td>16</td>
<td>1.33</td>
<td>1.78</td>
<td></td>
<td></td>
<td>279</td>
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</tbody>
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QUESTIONS???
Sensor Based Irrigation

• Began research at EREC – 2006

• Commercial fields – 2011
  • Automated Sensor Based
    • Watermelon – 2 fields; 12 acres (1 zone), 30 acres (2 zones)
    • Cantaloupe – 1 field; 28 acres (4 zones)
  • Sensors but manual irrigation
    • Peaches – numerous fields
    • Bell Peppers – numerous fields
    • Blue Berries – 20 acres

• 2013 – Expanded
  • Automated Sensor Based
    • Peaches – 20 acres
    • Bell Peppers – 20 acres (6 zones)
    • Watermelons – 2 fields each 20 acres with multiple zones
    • Cantaloupe – 30 acres (4 zones)
    • Blue Berries – 10 acres
Peaches & Peppers

- Two Farms
- Sensors in fields but irrigation not automated
- Grower based irrigation on sensor readings (Charts)
- Previous irrigation had moved water to 40” soil depth
- Maintained moisture in top 12”
- 70% & 35% reduction in water use on respective farms
- Maintained or improved size and yield of fruit

Significance
1. Above ground source of water with little recharge
2. Pump stations moved from field to field for irrigation
3. Diesel fuel savings
### 1” WATER BANDED OR BROADCAST

- Gallons / Acre = Acre Inch - 27,154 gal
- @ 8’ Row Spacing, linear ft. / Acre - 5,445 linear ft.
- @ 2.5’ Bed Top, sq. ft. / Acre - 13,612.5 sq. ft.
- 13,612 sq. ft. ÷ 43,560 sq ft. = 0.3125 acre

Banded - 0.3125 * 27,154 = 8485.6 gallons / week: **1,212.2 /day**

Broadcast - 27,154 gallons / week: **3,879.1 / day**

<table>
<thead>
<tr>
<th>Season Length (Days)</th>
<th>DATE</th>
<th>Minimum Irrigation</th>
<th>Sensor Based Irrigation</th>
<th>RAIN</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Year</td>
<td>Applied Inches</td>
<td>Inches if Banded</td>
<td>Yield (lbs/A)</td>
</tr>
<tr>
<td>85</td>
<td>2008</td>
<td>4.68</td>
<td>3.79</td>
<td>68,899</td>
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<tr>
<td>90</td>
<td>2009</td>
<td>3.7</td>
<td>4.02</td>
<td>77,222</td>
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<tr>
<td>82</td>
<td>2010</td>
<td>3.62</td>
<td>3.66</td>
<td>41,172</td>
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