Water Quality for Hydroponics

PLANTS, LLC

Laurie Ruberg, Ph.D.

Plant Lessons And ENgaging Technology Systems

Objectives of this Presentation

1. How can using hydroponics help to address global water security issues?
2. What are the water quality requirements for successful hydroponic plant production?
3. What kind of data is needed from a water monitoring program?
4. How do water quality concerns vary based on the water source?
5. What monitoring media, variables, and sampling procedures are most important?
6. What are the most important water quality tests?
7. Why it is important to maintain quality assurance of analytical results and procedures?

Hydroponic: Advantages / Disadvantages

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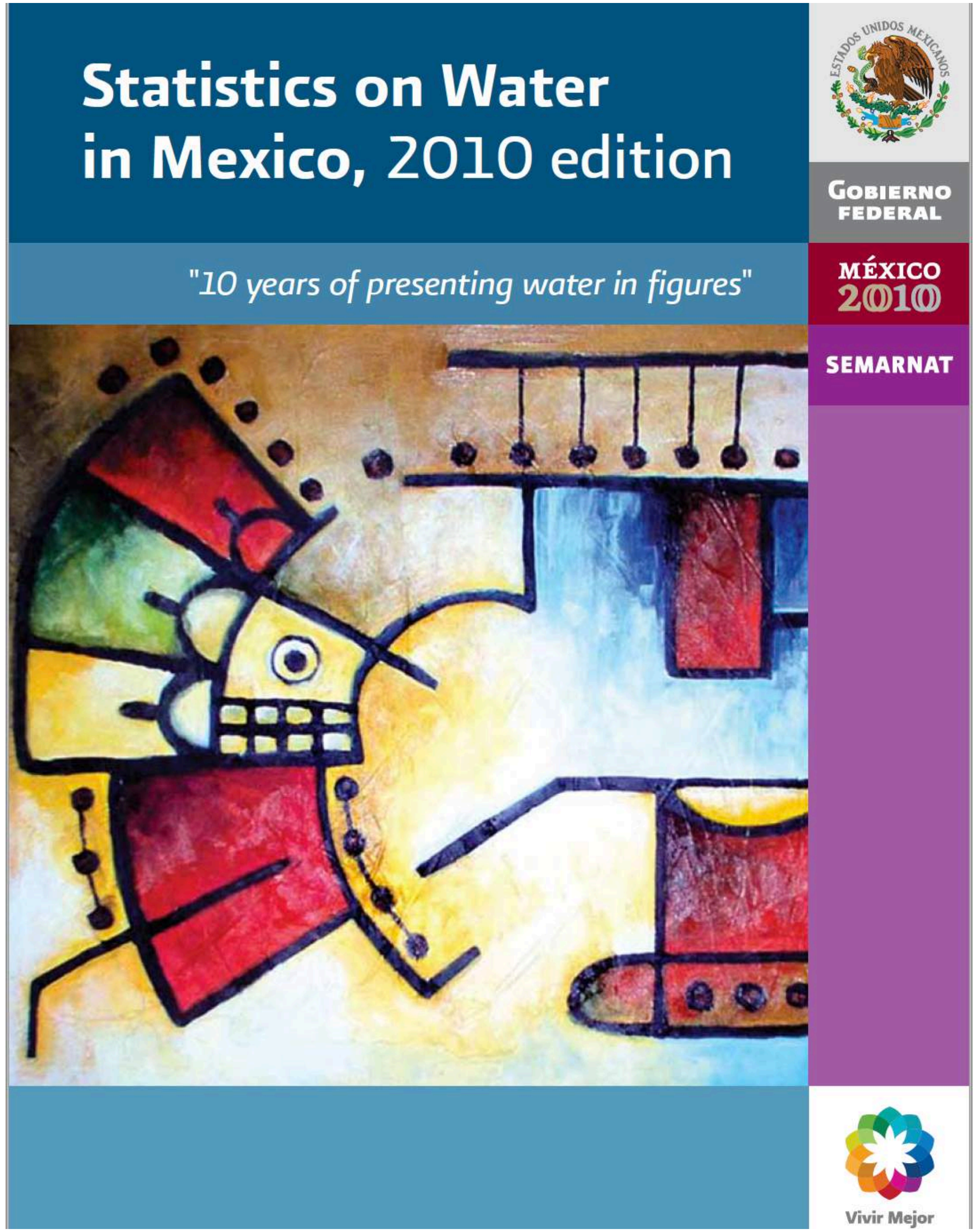
1. Healthier plants – having a near-perfectly balanced diet
2. Healthier consumers – less need to use herbicides, fungicides, and pesticides
3. Higher Yields – without water and nutrient stresses, plants grow faster and can be grown more compactly
4. **Conservation – uses less water and prevents evaporation and runoff**
5. Year-round production schedule

1. Initial set up costs can be high

1. Because plants share nutrient fluids, diseases and pests can quickly move from plant to plant
2. Maintenance requirements can increase, depending on the system used and crop
3. A power outage can destroy a crop
4. Initial set up requires technical knowledge, time, and commitment

Statistics on Water in Mexico, a Compendio of Water Banks Administration and other resources are available for download on the Web.



Offstream* Uses of Water

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T3.1 Offstream uses, according to the type of source of withdrawal, 2008 (billions of cubic meters, km^3)

Use	Origin		Total volume	Percentage of withdrawal
	Surface water	Groundwater		
Agriculture[a]	40.7	20.5	61.2	76.8
Public water supply[b]	4.2	7.0	11.2	14.0
Self-supplying industry[c]	1.6	1.6	3.3	4.1
Thermoelectic plants	3.6	0.4	4.1	5.1
TOTAL	50.2	29.5	79.8	100.0

NOTE: 1 km^3 = 1 000 hm^3 = one billion m^3.
The data corresponds to volumes allocated as of December 31st, 2008.
[a] Includes the agricultural, livestock, aquaculture, multiple and "others" headings of the REPDA classification. Also includes 1.30 km^3 of water corresponding to Irrigation Districts awaiting registration.
[b] Includes the public urban and domestic headings of the REPDA classification.
[c] Includes the industrial, agro-industrial, service and trade headings of the REPDA classification.
SOURCE: CONAGUA. Deputy Director General's Office for Water Management.

*water withdrawn or diverted from a groundwater or surface

Volumes of water allocated for offstream uses by hydrological region

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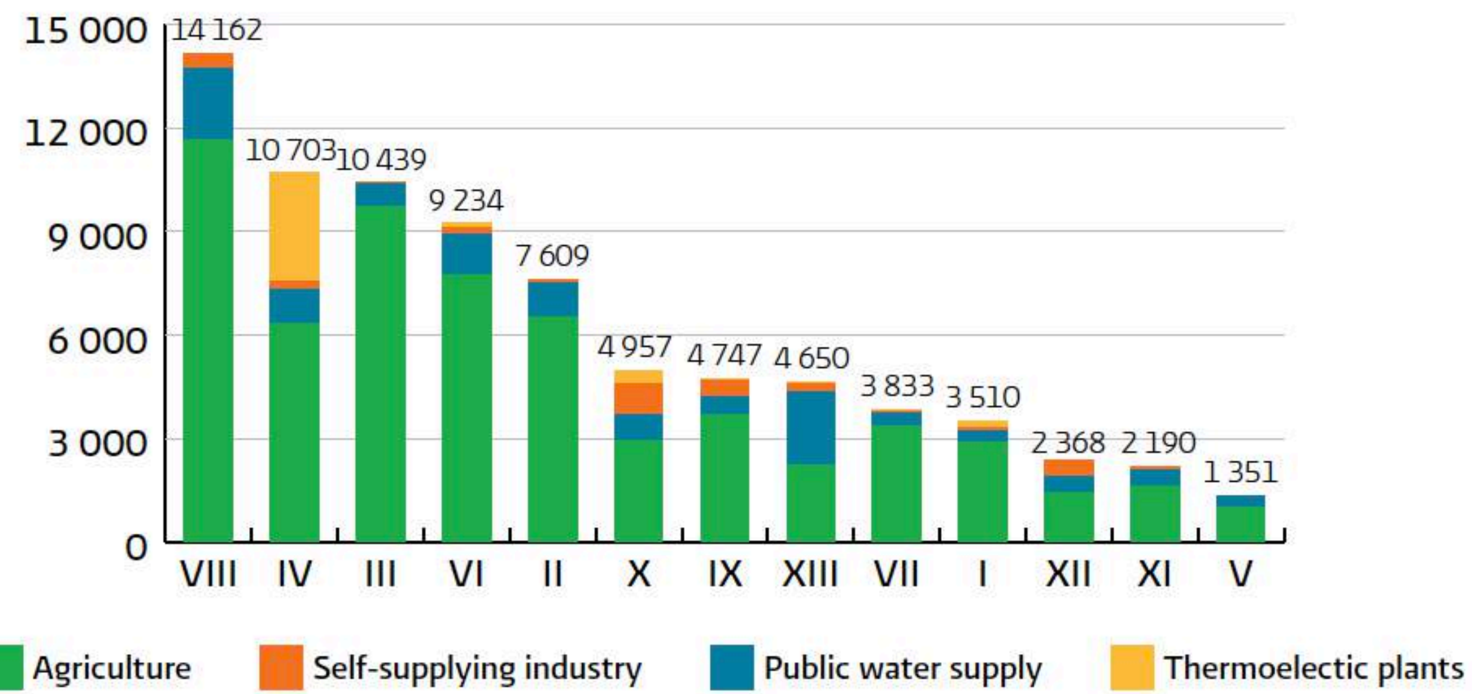
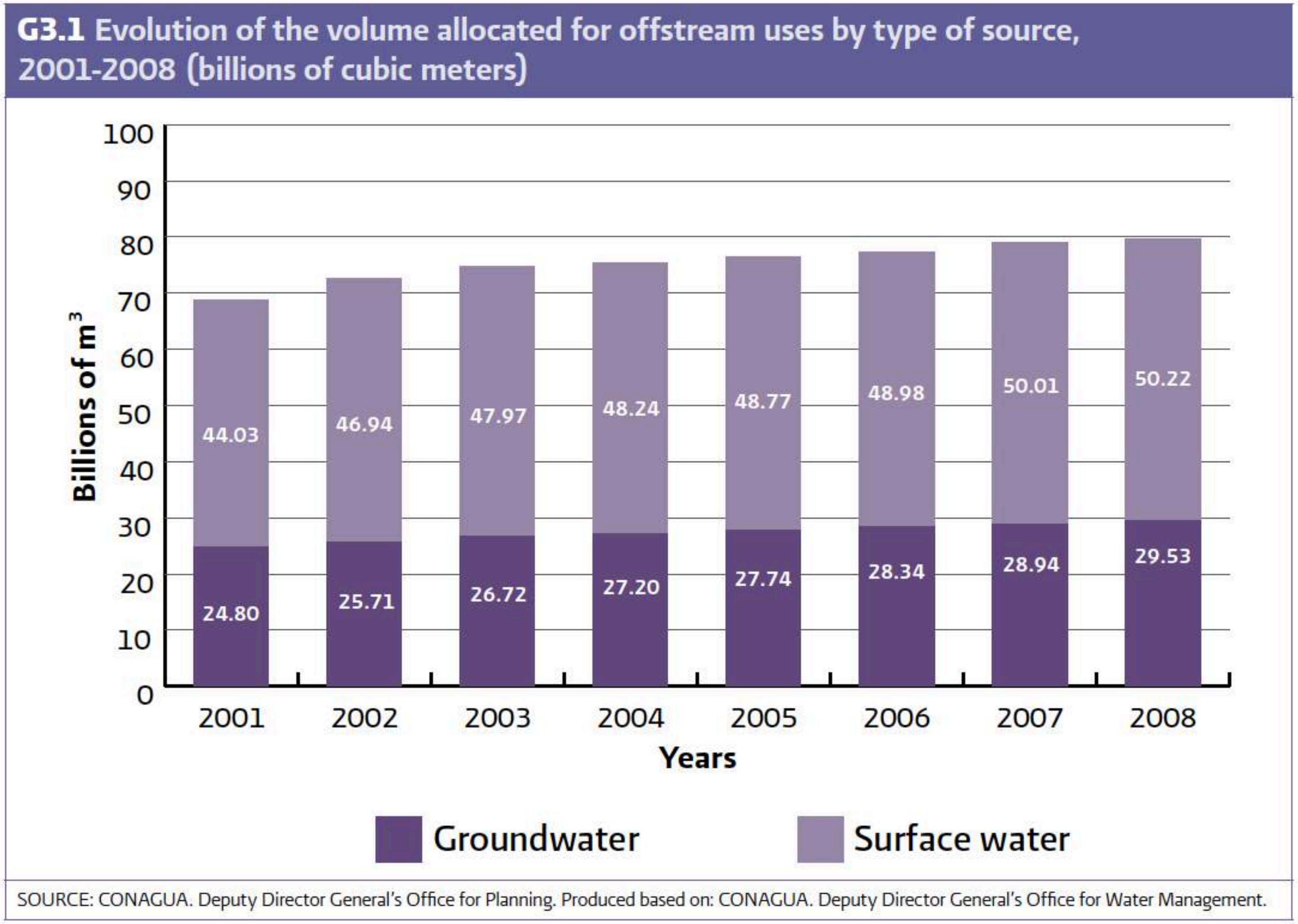
G3.2 Volumes allocated for offstream uses by Hydrological-Administrative Region, 2008 (millions of cubic meters)

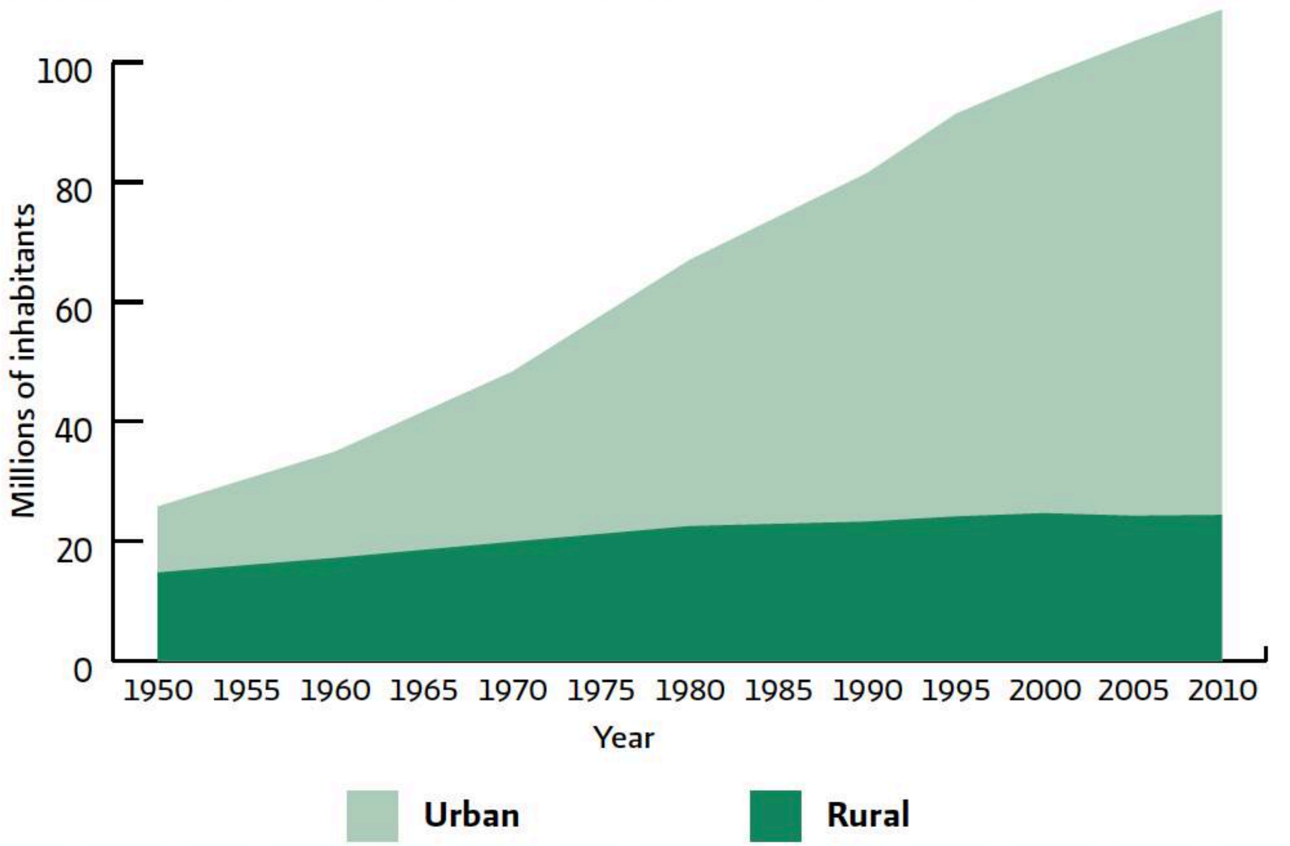


NOTE: The regionalization of volumes was carried out based on the location of the use as registered in the REPDA, rather than the area of jurisdiction of the corresponding deeds.
SOURCE: CONAGUA. Deputy Director General's Office for Planning. Produced based on:
CONAGUA. Deputy Director General's Office for Water Management. Volumes registered in the REPDA as of December 31st, 2008.



The water on the Earth's **surface**—**surface** water—occurs as streams, lakes, and wetlands, as well as bays and oceans. **Surface** water also includes the solid forms of water— snow and ice. The water below the **surface** of the Earth primarily is **ground water**, but it also includes soil water.

G1.2 Evolution of Mexico's urban and rural population, from 1950 to 2005, and projection to 2010 (millions of inhabitants)



Year	1950	1955	1960	1965	1970	1975	1980	1985	1990	1995	2000	2005	2010
Urban	11.02	14.39	17.76	23.10	28.43	36.45	44.47	51.34	58.21	67.25	72.98	79.20	84.38
Rural	14.80	16.02	17.23	18.58	19.93	21.24	22.55	22.93	23.30	24.16	24.71	24.28	24.42
TOTAL	25.82	30.41	35.00	41.68	48.36	57.69	67.02	74.27	81.51	91.41	97.69	103.49	108.81

NOTE: For the years from 1950 to 2005, the population was interpolated on December 31 of each year based on the data from the censuses. (Translator's Note: In Mexico there are two types of Census, referred to as "Censo" and "Conteo". Both are carried out every ten years, the "Censo" in years ending with 0 and the "Conteo" in years ending in 5. For the purpose of this publication, they will only be referred to by the English term "Census".)
The rural population is considered as that which lives in localities of less than 2 500 inhabitants, whereas the urban population refers to populations of 2 500 inhabitants or more.
The population projected to 2010 includes the growth rates from CONAPO (the National Population Council).
SOURCE: CONAGUA. Deputy Director General's Office for Planning. Produced based on:
INEGI. General Censuses on Population and Housing.

M2.5 Drought conditions at the end of the dry season, 2008

SOURCE: CONAGUA. Deputy Director General's Office for Planning. Produced based on:
CONAGUA. Deputy Director General's Office for Technical Affairs. Coordination of the National Meteorological Service.
Consulted on http://smn.cna.gob.mx/productos/sequia/ (15/07/2009).

M3.2 Water stress by Hydrological-Administrative Region, 2008

SOURCE: CONAGUA. Deputy Director General's Office for Planning. Produced based on:
CONAGUA. Deputy Director General's Office for Technical Affairs
CONAGUA. Deputy Director General's Office for Water Management.

M2.8 Overdrafted aquifers by Hydrological-Administrative Region, 2008

SOURCE: CONAGUA. Deputy Director General's Office for Technical Affairs. Groundwater Department.

Why Is This Important to Water Quality for Hydroponics?

Water-saving Potential of Hydroponics

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- Mexico is the ranked six worldwide in terms of area with agricultural irrigation infrastructure (6.46 million hectares)
- One third of the water allocated for agricultural uses (agriculture, aquaculture, livestock, etc.) comes from groundwater
- "Hydroponic greenhouses use about 10 times less water than a field crop," Pat Rorabaugh, University of Arizona's Controlled Environment Agriculture Center.

How does Hydroponics Save Water?

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- Hydroponic greenhouses use about 10 times less water than a field crop, said Pat Rorabaugh, who works at the University of Arizona's Controlled Environment Agriculture Center.
- However, even hydroponics wastes water. Using data from a greenhouse at the center shows just how much water can be saved.

Ways Hydroponics Can Save Water

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1. Use less water to grow plants
2. Capture the water vapor in the air
3. Reuse the excess water that plants didn't use
4. Harvest local rainwater
5. Use wastewater rather than freshwater

Steps 2-4 save about half the water used ina greenhouse, yielding almost a 95% water saving over field crops.

"Including the treated sewage, the [hydroponic] greenhouse becomes a poster child for conservation,"
B. Merrill (May, 2011)

What About Water Quality?

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- Different plants have different water and nutrient requirements.
- Depending on what crops you want to grow, your water quality requirements will vary accordingly.

How Good Is Your Water Source?

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How is Public Water Quality Measured?

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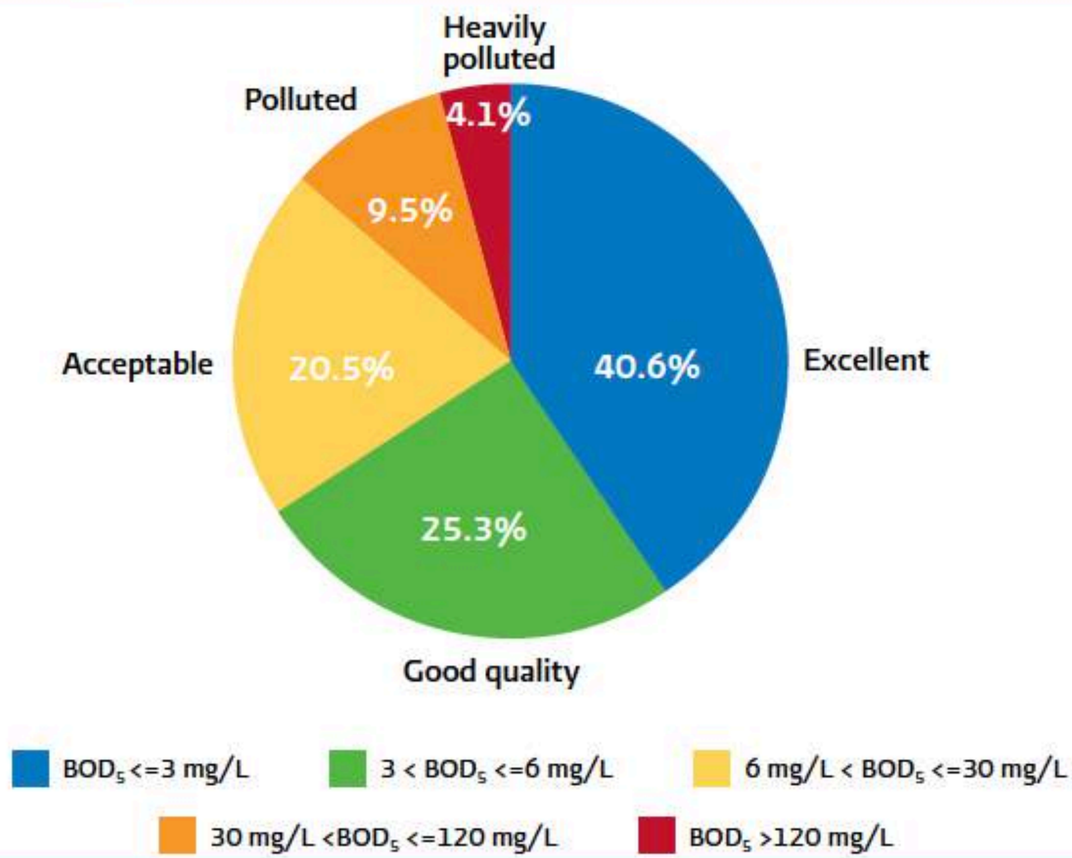
Physical-chemical and biological determinations of water quality

A. Five-day Biochemical Oxygen Demand (BOD) [quantity of biodegradable organic matter]
B. Chemical Oxygen Demand (COD) [total quantity of organic matter]
C. Total Suspended Solids (TSS).

A + B determine quantity of organic matter present from wastewater discharges.

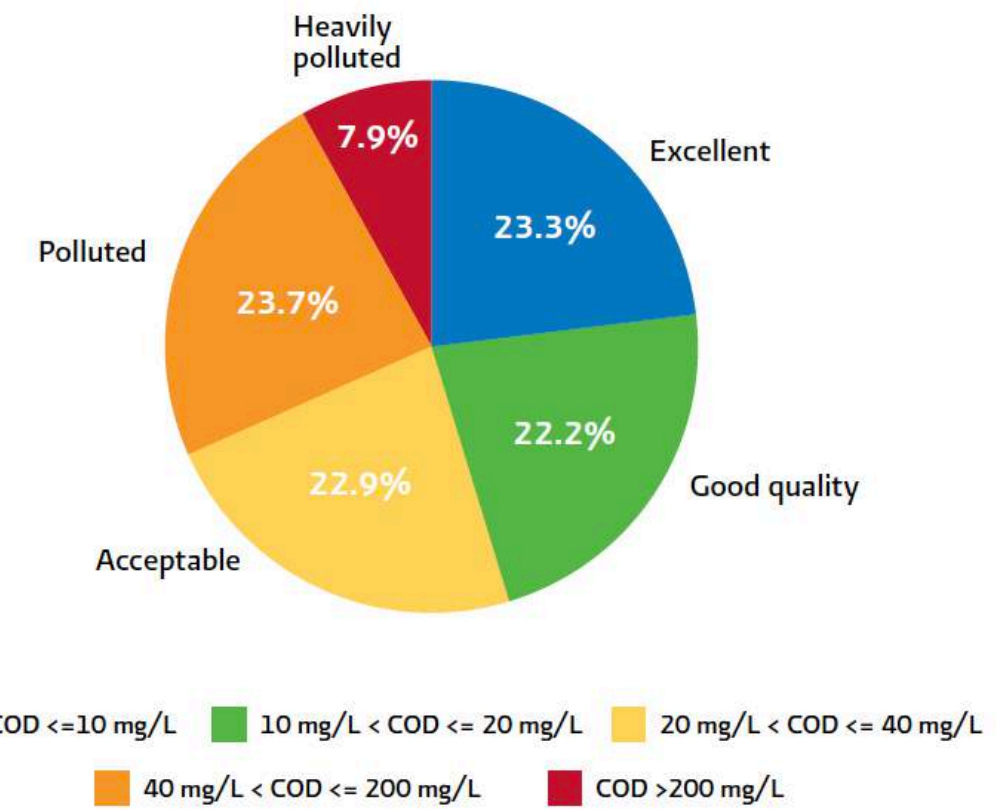
TSSs originate in wastewater and through soil erosion. Increased TSS impacts aquatic life

G2.8 Percentage distribution of surface water quality monitoring sites, by category of BOD_5, 2008



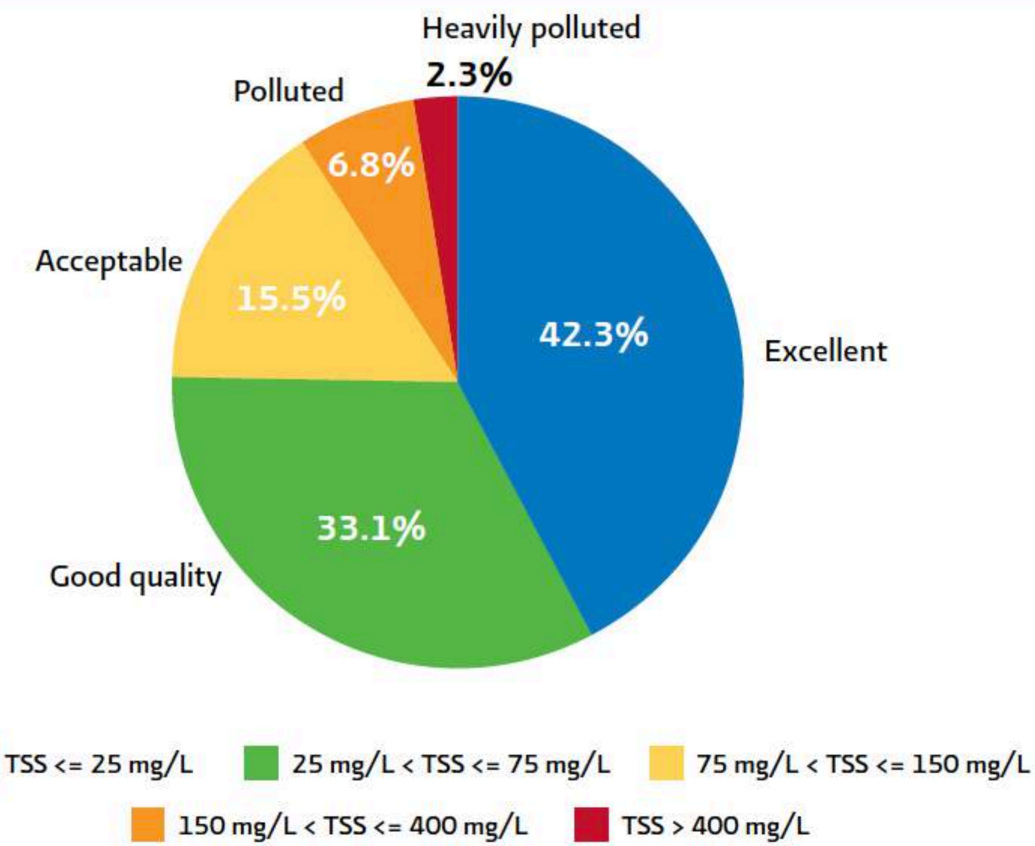
SOURCE: CONAGUA. Deputy Director General's Office for Technical Affairs.

G2.9 Percentage distribution of surface water quality monitoring sites, by category of COD, 2008



SOURCE: CONAGUA. Deputy Director General's Office for Technical Affairs.

G2.10 Percentage distribution of surface water quality monitoring sites, by category of Total Suspended Solids (TSS), 2008



SOURCE: CONAGUA. Deputy Director General's Office for Technical Affairs.

What you should know about your water

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- What is your water source?
- pH?
- alkalinity? (HCO3-, CO32-liquid limestone)
- EC (electrical conductivity)?
- Specific elements? (Ca, Mg, Na, Cl)

General Water Quality Guidelines

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Recommended upper limits for water source

pH	5.4-7.0 acceptable
Alkalinity	100 ppm $CaCO_3$
EC	< 1 dS/m
Sodium	< 70 ppm
Chloride	< 70 ppm
Sulfates	< 90 ppm
Boron	< 0.5 ppm
Fluoride	< 1.0 ppm
Iron	< 5.0 ppm

Adapated from: Bailey et al., 1999

What is pH?

- pH is a measure of the acidity of water based on its hydrogen ion concentration.
- A pH is mathematically defined as the negative logarithm of the hydrogen ion concentration, or

  pH = -log[H+],

  the brackets around the H+ symbolize *concentration*
- The pH of a material ranges on a logarithmic scale from 1-14, where pH 1-6 are acidic, pH 7 is neutral, and pH 8-14 are basic.
- Lower pH corresponds with higher [H+], while higher pH is associated with lower [H+].

pH Scale

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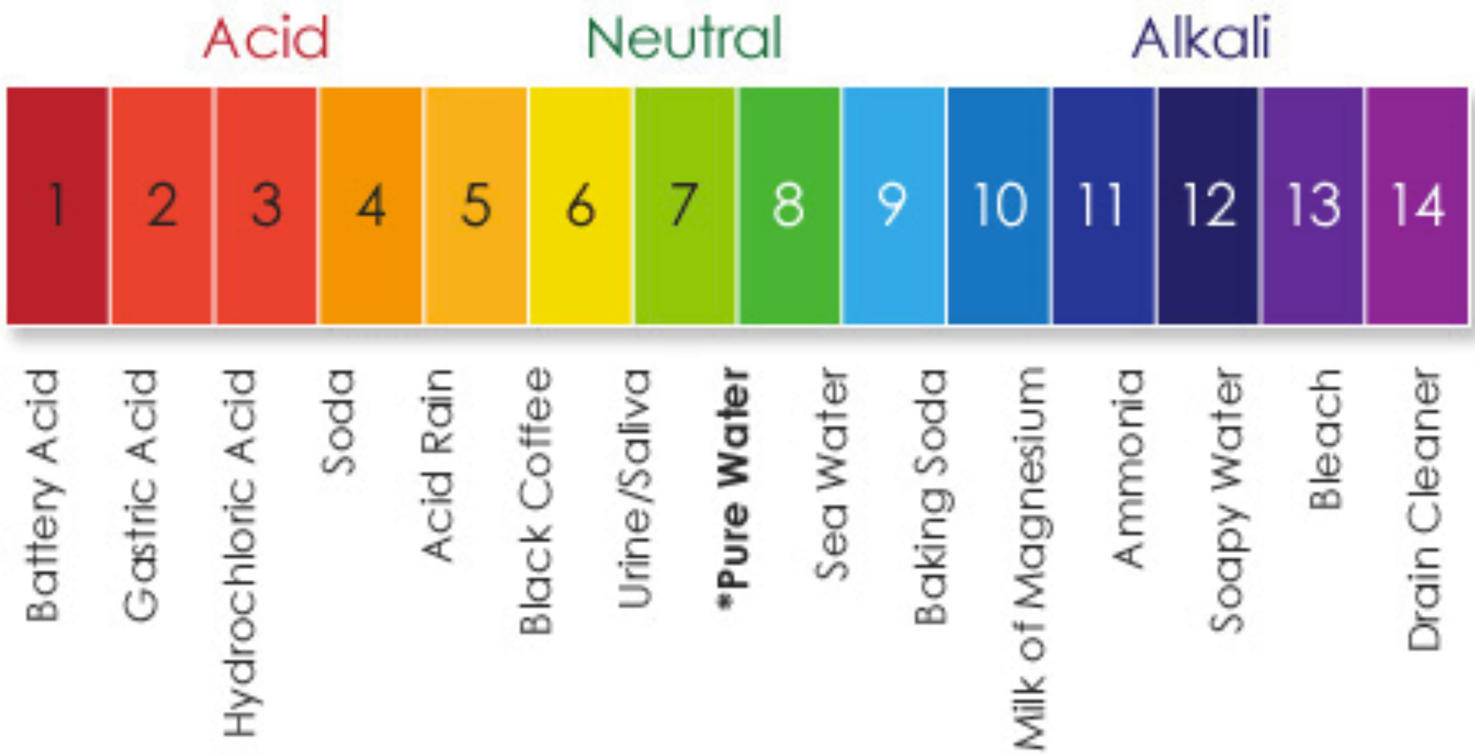

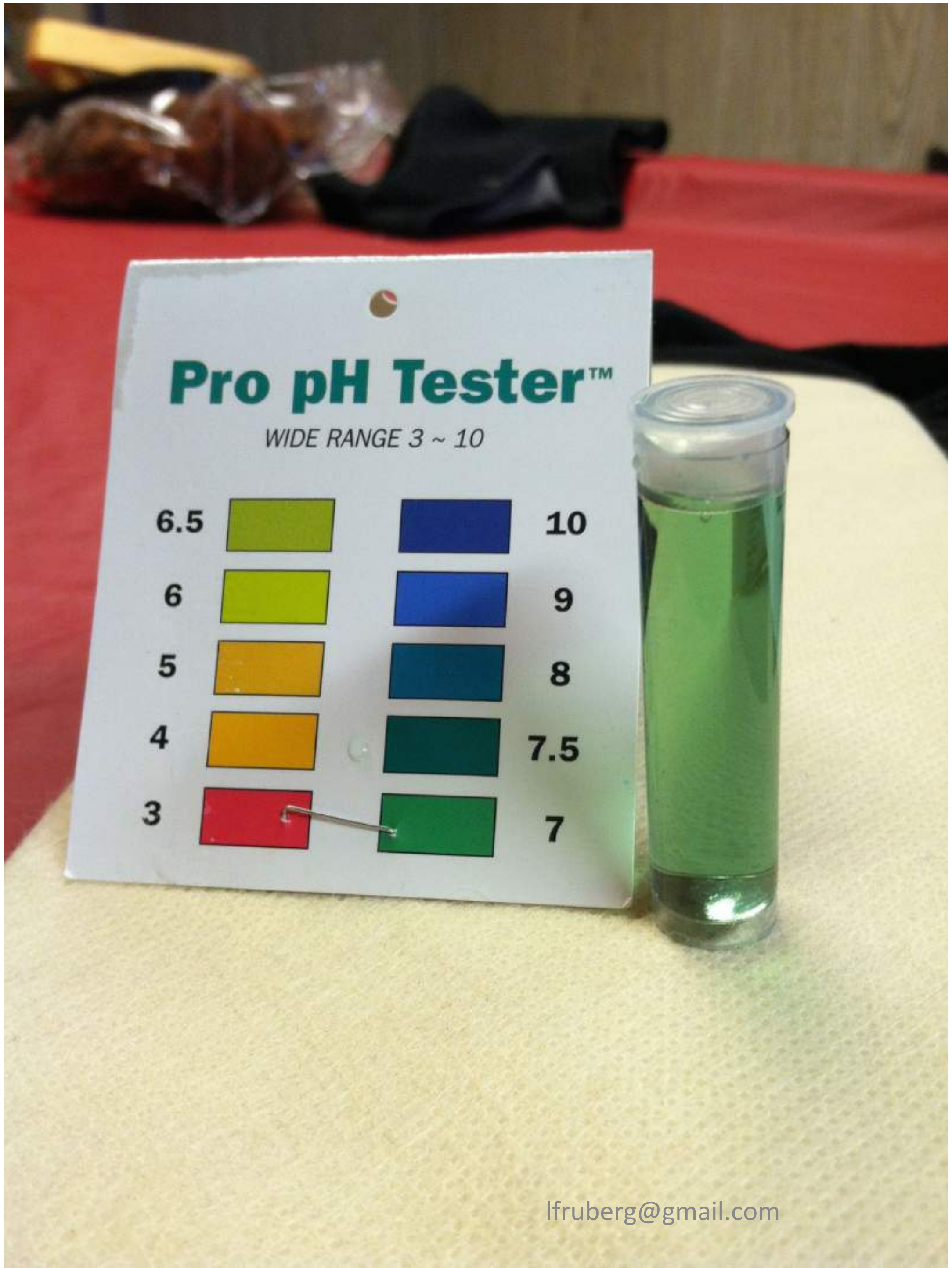

Explore water quality analysis using simple and/ or more complex technology tools.

Automated Monitoring System

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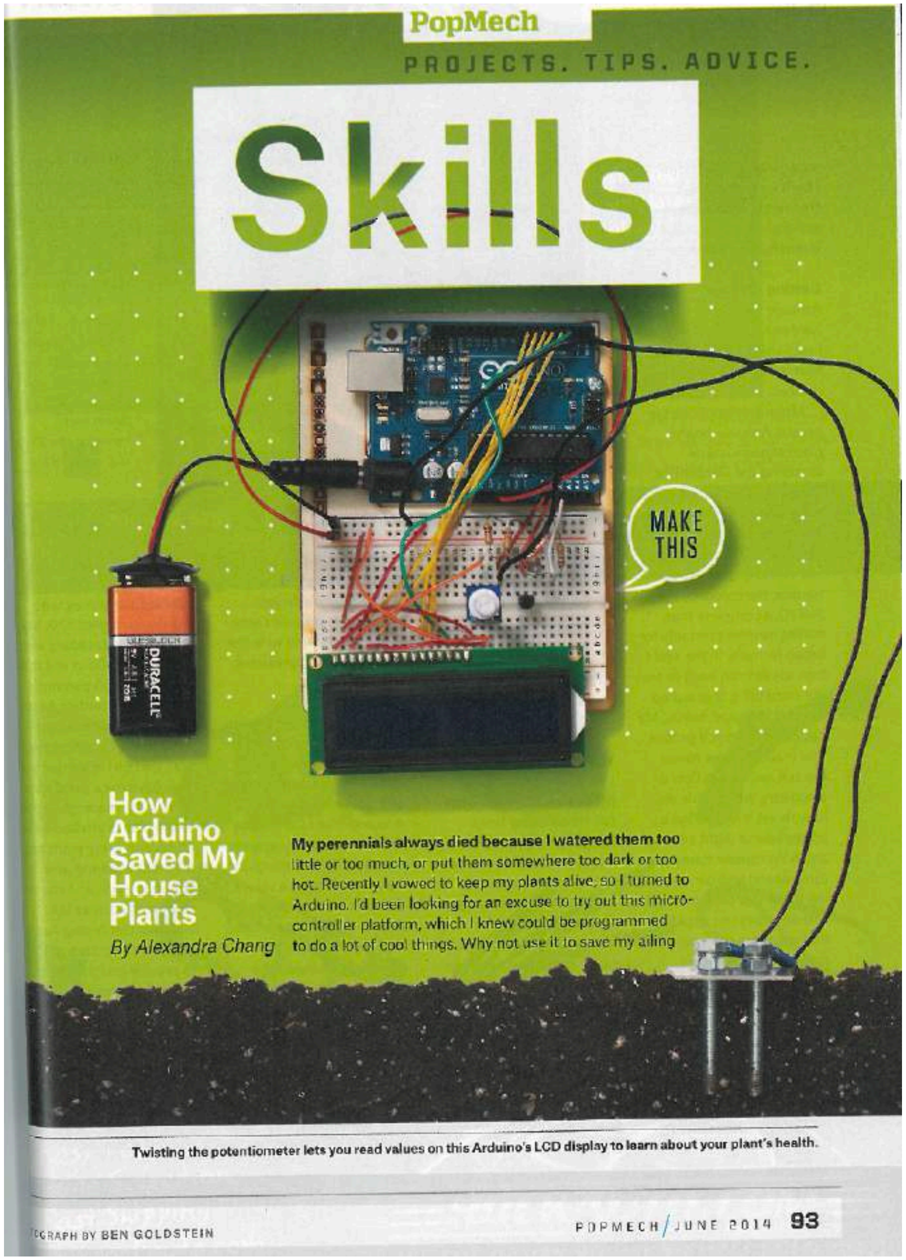
PopMech

PROJECTS. TIPS. ADVICE.

Skills

MAKE THIS

How Arduino Saved My House Plants

By Alexandra Chang

My perennials always died because I watered them too little or too much, or put them somewhere too dark or too hot. Recently I vowed to keep my plants alive, so I turned to Arduino. I'd been looking for an excuse to try out this micro-controller platform, which I knew could be programmed to do a lot of cool things. Why not use it to save my ailing

Twisting the potentiometer lets you read values on this Arduino's LCD display to learn about your plant's health.

OGRAPH BY BEN GOLDSTEIN

POPMECH/JUNE 2014 93

You may want to design your own **Arduino controls** to monitor hydroponic system functions and processes such as:

- pH
- Temperature
- Electrical conductivity
- Water level
- Data logging

DIY pH probe

See video at: https://www.youtube.com/watch?v=yKigsN8046k

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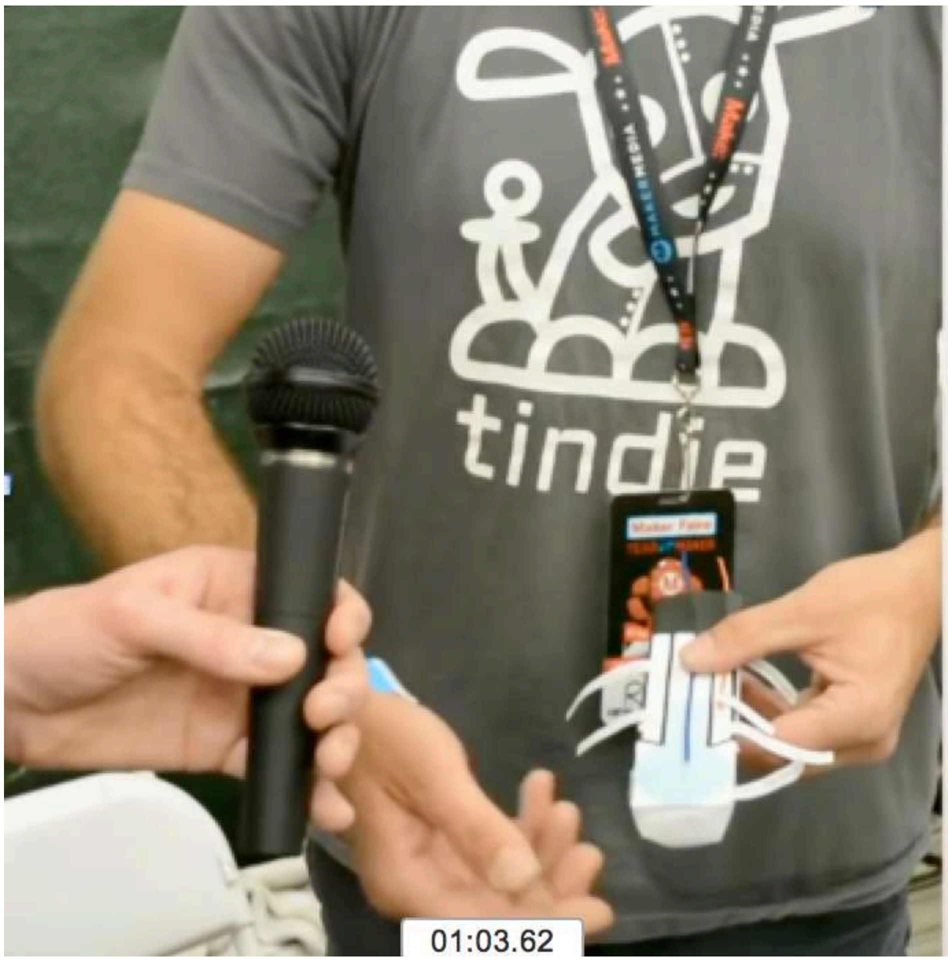

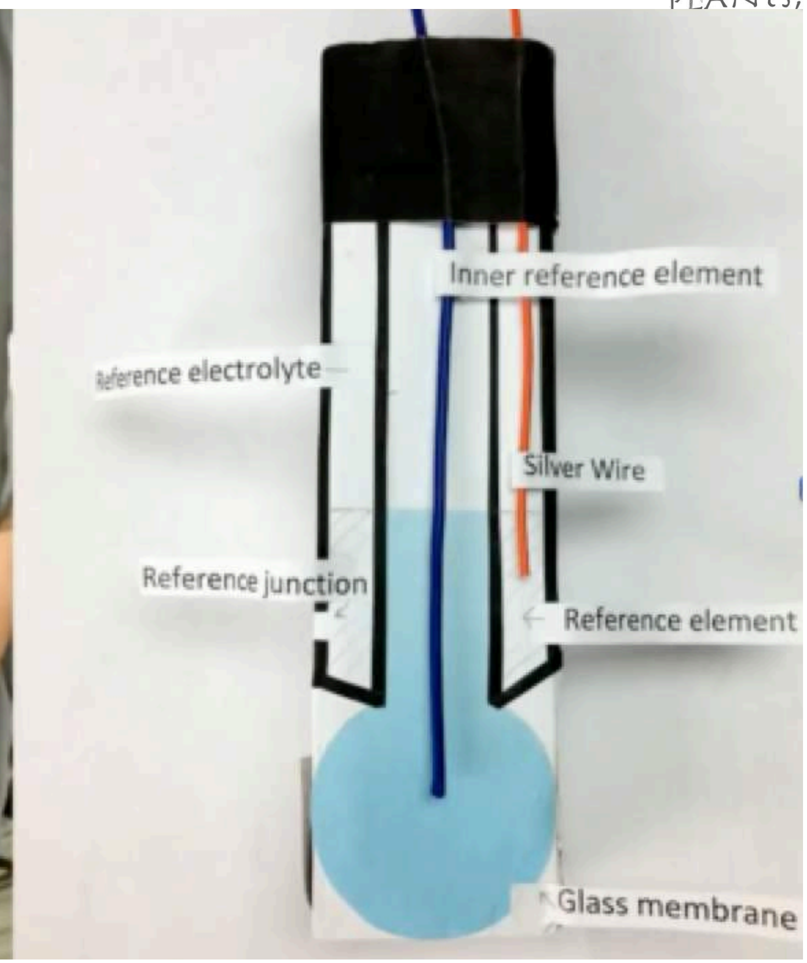

Factors that affect root zone pH

- the alkalinity of the tap water -carbonates/ bicarbonates which will increase the pH of the container media over time
- fertilizers that are used
- ammonium or urea based fertilized tend to acidify the root media
- nitrate based fertilized tend to increase the root media pH
- Use of acids to decrease pH

What is Electrical Conductivity?

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- Electrical conductivity (EC) is a measurement of the dissolved material in an aqueous solution.
- An EC measure reflects the ability of the material to conduct electrical current through it.
- EC is measured in units called Seimens per unit area (e.g. mS/cm, or miliSeimens per centimeter).
- The higher the dissolved material in a water sample, the higher the EC will be in that material.

EC Meter detects Salt Concentration

EC - Demo

Na^{+}

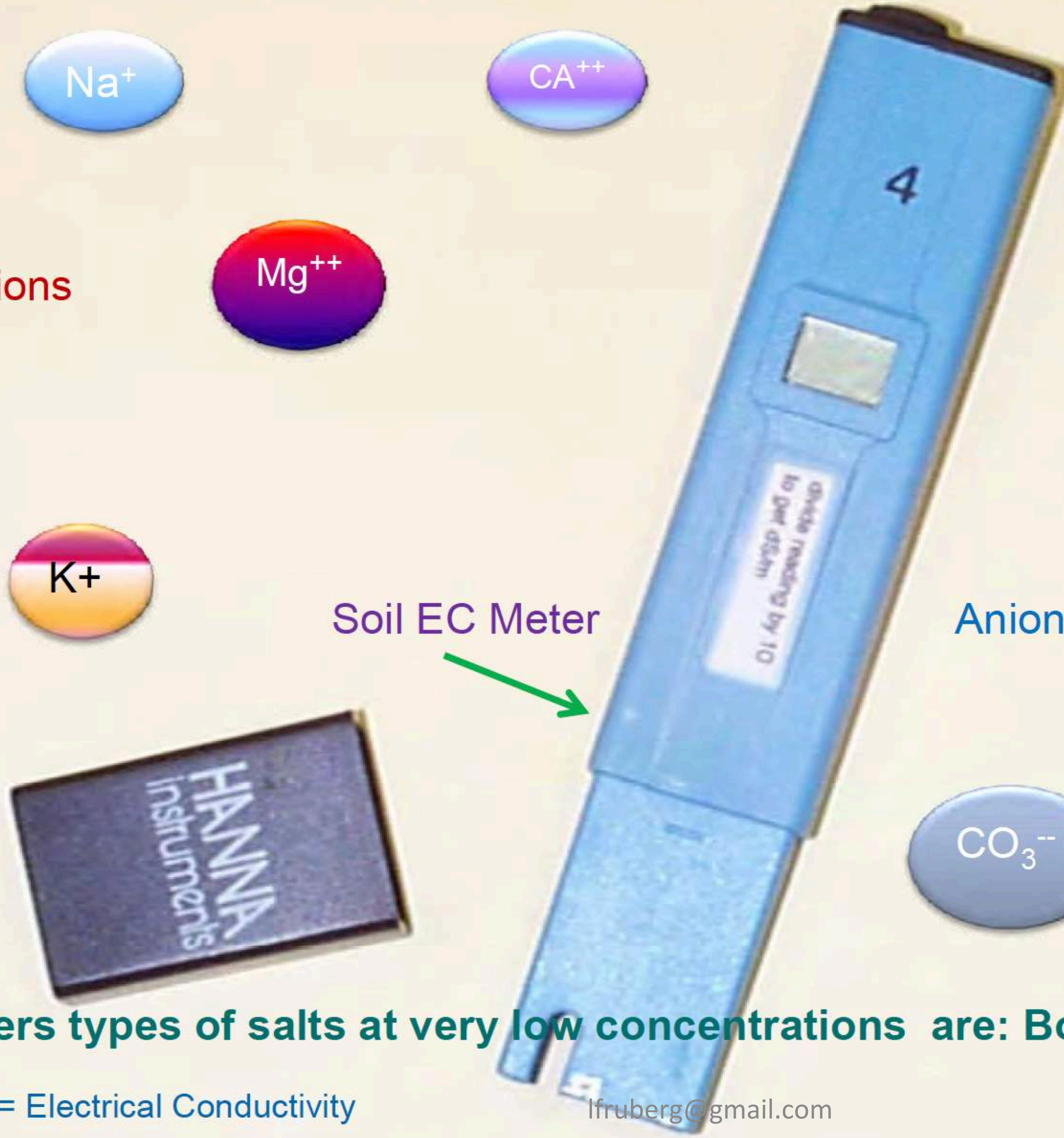
CA^{++}

Cations

Mg^{++}

$K+$

Soil EC Meter



Anions

SO_4^{--}

Cl^{-}

HCO_3^{-}

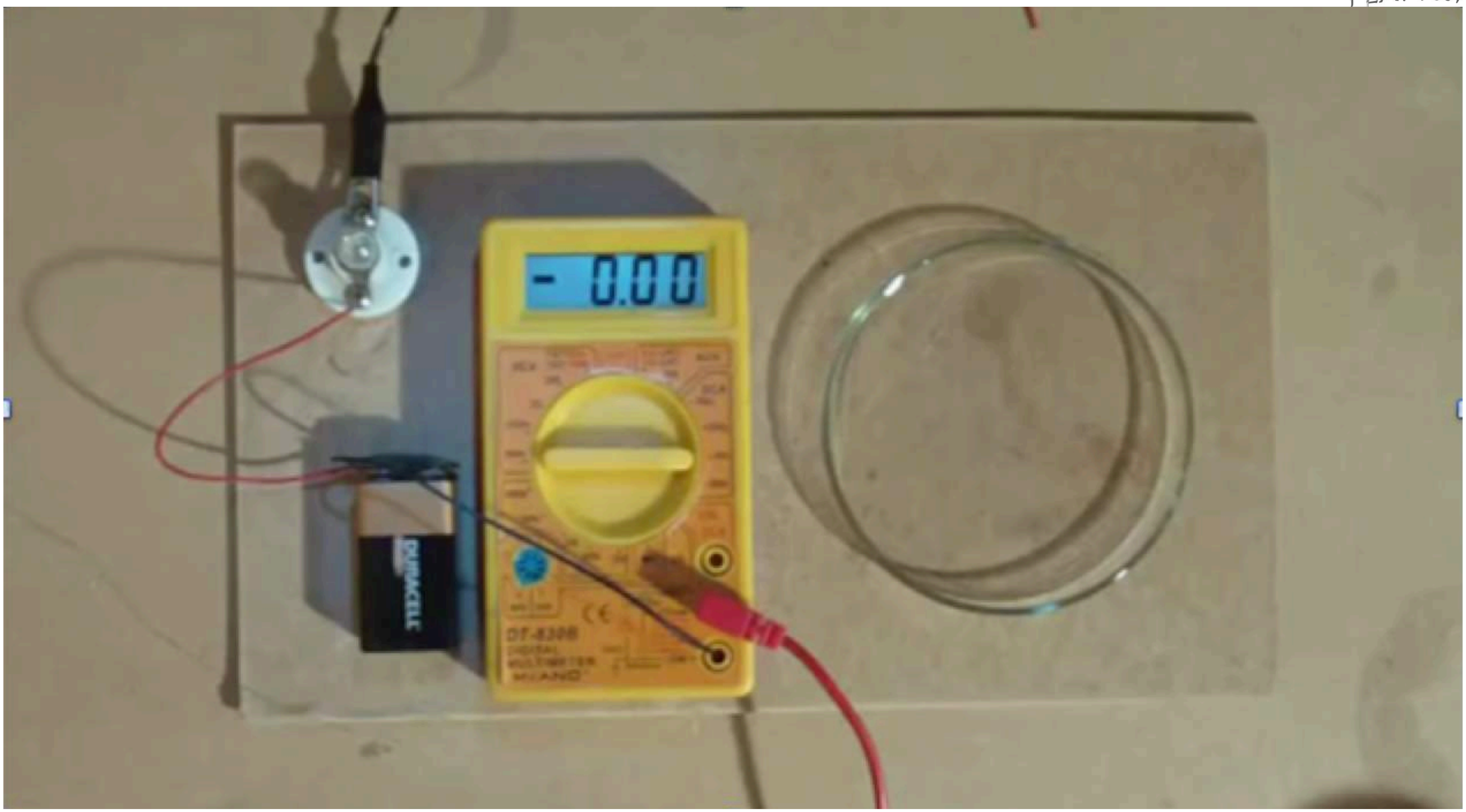
CO_3^{--}

Others types of salts at very low concentrations are: Boron, Silicates, etc…

EC = Electrical Conductivity

Conductivity of Water

See video at: https://www.youtube.com/watch?v=-QF27bncXAQ



TDS, PPMs, and EC Explained

See video: http://www.dailymotion.com/video/x2szqpw

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Temperature, EC, pH Meter

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HI98129 Low Range	HI98130 High Range
0.00 - 14.00 pH	0.0 - 14.0 pH
0 - 3999 µs/cm	0.00 - 20.00 ms/cm
0 - 2000 ppm	0.00 - 10.00 ppt

± 0.05 pH Accuracy

± 2% EC/TDS Full Scale

2 Point Calibration

Replaceable pH Electrode

HANNA instruments

Calibrating Probe


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Alkalinity

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Alkalinity–the ability of water to neutralize acids

- due to the presence of dissolved alkalis: $Ca(HCO_3)_2$, $NaHCO_3$, $Mg(HCO_3)_2$, $CaCO_3$
- Do not confuse with "Alkaline" which means pH level greater than 7
- Reported in terms of ppm $CaCO_3$(or meq; 50 ppm = 1 meq $CaCO_3$)
- Typically varies from 50-500 ppm

Correcting High Alkalinity

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1)Change or blend the water source

•Ex: rainwater (very low alkalinity) with moderate alkalinity well water

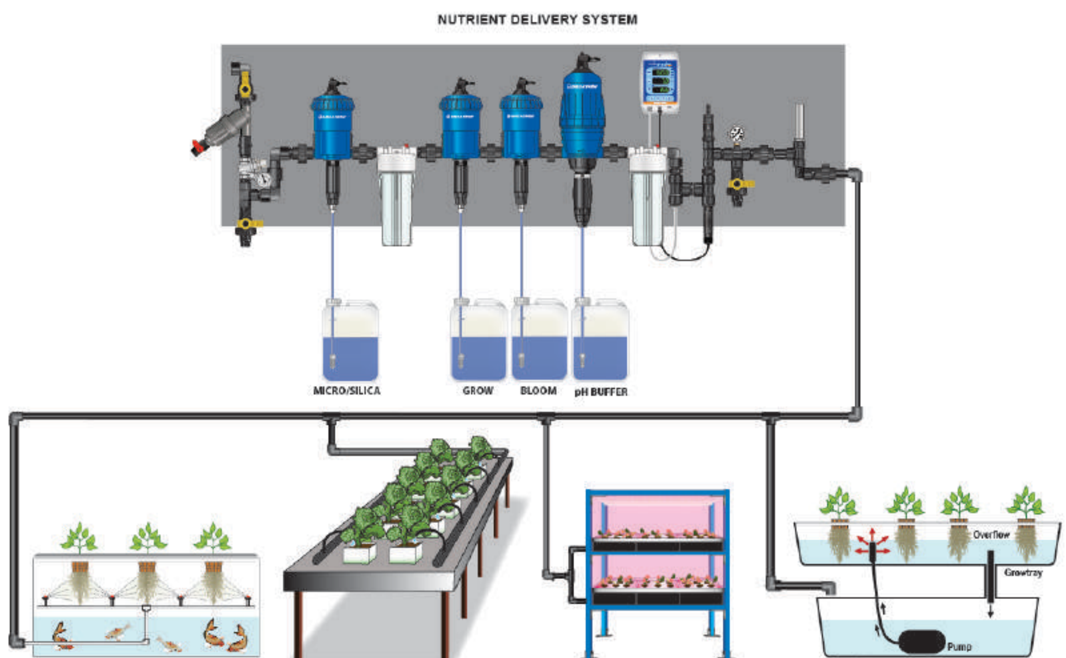
2)Use an acidic fertilizer

•Fertilizers with ammonium-nitrogen

3)Inject acid into irrigation water

Acid Injection

- Acidification reduces the amount of carbonates and bicarbonates
- H+(from acid) + HCO3-(in water) →CO2+ H2O



Which Acid to Use?

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Safety

- Nitric acid is very caustic and has harmful fumes
- Sulfuric, Phosphoric, Citric relatively safe
- Cost
- Sulfuric is cheapest, others are 2-4 times more expensive
- Nutrients from Acid
- Sulfuric provides S
- Nitric provides N
- Phosphoric provides P (but can be too much if equilibrating >100 ppm alkalinity

Correcting Poor Water Quality

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No simple, single solution
- Change source
- Municipal? Well?
- pond water
- rainwater
- Reverse Osmosis water
- Ion exchange demineralization

(Or some combination of blending the above with your current water source)

Chiapas, Mexico

Case Study

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Hydroponic lettuce greenhouse –after several years felt that poor quality municipal water resulted in a 20% reduction yield

- Reverse Osmosis system would have cost several thousand dollars and had lots of waste water
- They could not properly dispose of the waste water

Ion Exchange Demineralization

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Two canisters –one traps positively charged molecules, the other negatively charged

- Example from *Culligan®*
- $25 per month take rental
- $125 per recharge
- With the fairly poor water of this grower –recharge every 4500 gallons
- Compared to reverse osmosis no real upfront cost, less space
- Perhaps a good choice for smaller/seasonal growers

Case Study – Water Softener Binghamton University

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	Unsoftened	Softened
pH	7.6	7.5
EC (mhos/cm)	0.5	0.5
Ca (ppm)	80	**12**
Mg (ppm)	15	**3**
Na (ppm)	25	**130**
Cl (ppm)	65	65
Alkalinity (ppm)	200	200

Concerns

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- Alkalinity is still a problem!
  - Consider injecting acid to neutralize alkalinity
- High sodium is now a problem
  - Regular leaching required
- Now low calcium and magnesium may be a problem
  - Switch to a calcium and magnesium containing fertilizer (ex: 15-5-15 Cal Mag)

Water Quality Needs Depend on…

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- What crop is grown
- How closely the fertilizer used matches crop needs
- Making nutrients added match nutrient needs; otherwise, nutrient imbalances can build up to toxic levels
- Whether the water is captured and reused and how how many times it is reused

Open vs. Closed Irrigation

Open system: any excess water leaches to floor/ground

- If excess water applied this can control the build up of salts
- Can use poorer quality water
- Closed system: excess water captured and reused
- disinfestation to control pathogen spread
- nutrient imbalances and salt build up over time
- saves water and fertilizer
- start with better quality water

Caution when mixing fertilizers

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Some fertilizers can't be mixed together!

- Incompatibility –blending of fertilizers results in a precipitate
- Don't mix calcium with phosphate or sulfates

3 Tank System –addresses the precipitation problem

Tank A
- •Calcium nitrate
- •½ potassium nitrate
- •Iron chelate
- •(Nitric acid)

Tank B
- •½ potassium nitrate
- •Potassium sulfate
- •Monopotassium phosphate
- •Magnesium sulfate
- •All other micronutrients
- •Monoammoniumphosphate
- •Ammonium nitrate
- •(sulfuric acid)
- •(phosphoric acid)

Tank C
- •Acid, used to drive down pH (or base if very pure waters, acidic N source)
- •Or Sulfuric/Phosphoric in tank B (NOT with calcium)
- •Nitric in Tank A (with calcium)

Image credit: Crop King

Use greenhouse Grade Fertilizers

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- To avoid having to deal with not standard grade
- To achieve higher purity/solubility
- To avoid getting a greasy coating of calcium nitrate

More In-depth Fertilizer Info

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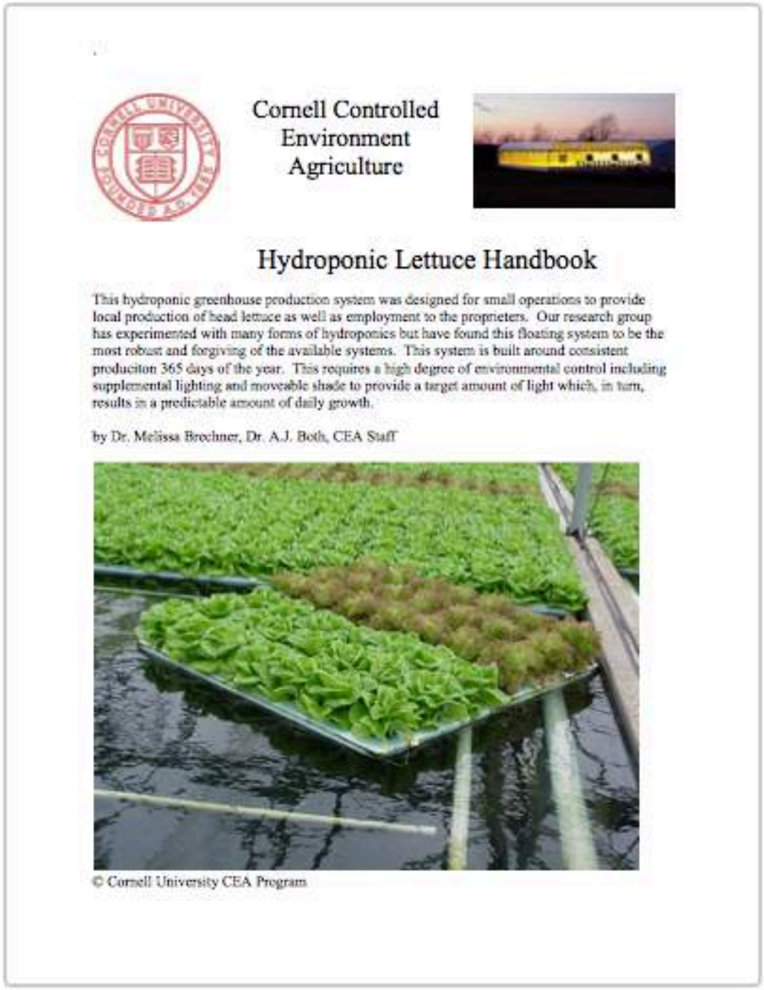
Download this article:

A Recipe for Hydroponic Success

By Neil Mattson and Cari Peters

http://www.greenhouse.cornell.edu/crops/factsheets/hydroponic-recipes.pdf

Handbooks for Free Download



Cornell Controlled Environment Agriculture

Hydroponic Lettuce Handbook

This hydroponic greenhouse production system was designed for small operations to provide local production of head lettuce as well as employment to the proprieters. Our research group has experimented with many forms of hydroponics but have found this floating system to be the most robust and forgiving of the available systems. This system is built around consistent produciton 365 days of the year. This requires a high degree of environmental control including supplemental lighting and moveable shade to provide a target amount of light which, in turn, results in a predictable amount of daily growth.

by Dr. Melissa Brechner, Dr. A.J. Both, CEA Staff

© Cornell University CEA Program

Cornell Controlled Environment Agriculture

Hydroponic Spinach Production Handbook

Baby spinach has become a very popular produce item in the last decade. Hydroponic production methods allows for the production of consistent high quality produce anywhere in the world. This handbook describes the method we have developed for the production of spinach whose leaves are small enough to be considered 'baby spinach'. A significant barrier to hydroponic spinach production is a water-borne pathogen called *Pythium aphanadermatum* that attacks the roots and causes poor crop quality and crop death. We have devoted significant time to investigating ways to prevent and treat this disease and that method is described in this handbook.

Dr. Melissa Brechner and Dr. David de Villiers

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Table 3. Target nitrogen feed rates (in ppm N) for several hydroponic crops.

Type	Propagation	Production
Buttercrunch/Boston Bibb	125	150
Romaine, Red and Green leaf	125	150
Basil	125	175
Culinary Herbs	125	150
Cole Crops	125	175
Garlic and Scallions	125	150
Tomatoes	125	200
Peppers	125	150
Cucumber	125	175
Heavy Feeders cabbage, kale, spinach, Swiss chard, mustard greens, mizuna, escarole	125	175 - 200
Light Feeder Lettuce arugula, watercress, spring mix	125	125 - 150

* Adapted from data collected at J.R.Peters Laboratory and Smithers Oasis Inc. 2012-2013

Fertilizer Recipes for Leafy Greens and Herbs

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- Simple, 1-3 bags
- Base feed macros/micros
- Calcium nitrate
- Magnesium sulfate
- Complex, 11 ingredients

How do they stack up?

	16-4-17	5-12-26 + Cal. Nit.	9-7-37 + Cal. Nit. + Mag. Sulf.	Sonneveld's solution
Nitrogen	**150**	**150**	**150**	**150**
Phosphorus	16	39	12	31
Potassium	132	162	122	210
Calcium	38	139	133	90
Magnesium	14	47	42	24
Iron	2.1	2.3	2.0	1.0
Manganese	0.47	0.38	0.75	0.25
Zinc	0.49	0.11	0.75	0.13
Boron	0.21	0.38	0.36	0.16
Copper	0.131	0.113	0.20	0.023
Molybdenum	0.075	0.075	0.04	0.024

Element	UA-CEAC A (Tomato at Stage 1)	UA-CEAC B (Tomato at Stage 2)	UA-CEAC C (Tomato at Stage 3; or Multi-crop)
NO_3-N	**90**	**120**	**190**
NH_4-N	0	0	0
P	47	47	47
K	**144**	**350**	**350**
Ca	**144**	**160**	**200**
Mg	60	60	60
S	116	116	116
Cl	89	89	89
Fe (EDTA)	2	2	2
Mn	0.55	0.55	0.55
Zn	0.33	0.33	0.33
Cu	0.05	0.05	0.05
B	0.34	0.34	0.34
Mo	0.05	0.05	0.05

What to do if have only one injector?

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- Prepare the two stock tanks
- But use only 1 at a time
- Alternate days (ideal) or half of week
- Concentration of fertilizer should be doubled
- As plants receive each only ½ of the time

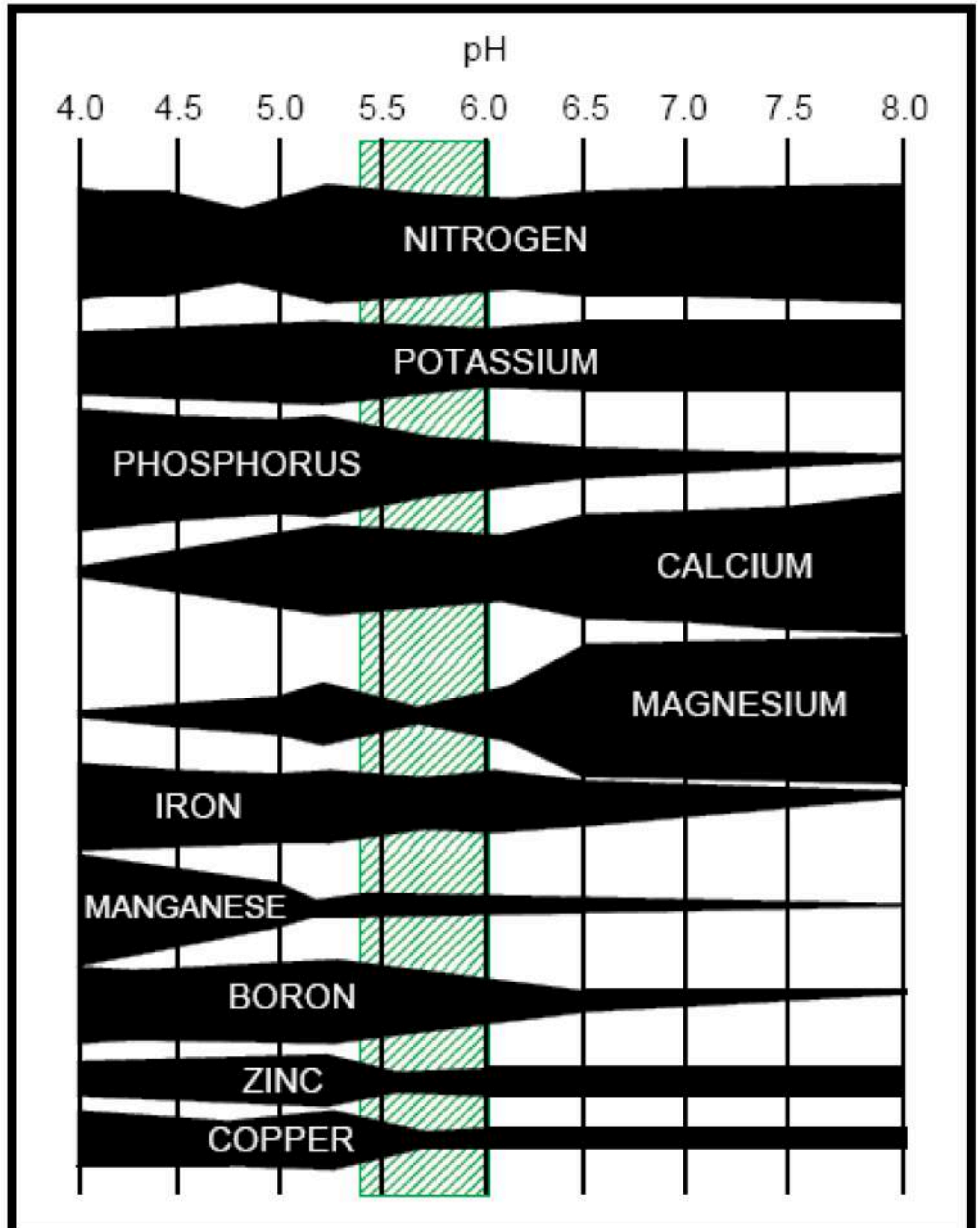
Hydroponic growing requires vigilance!

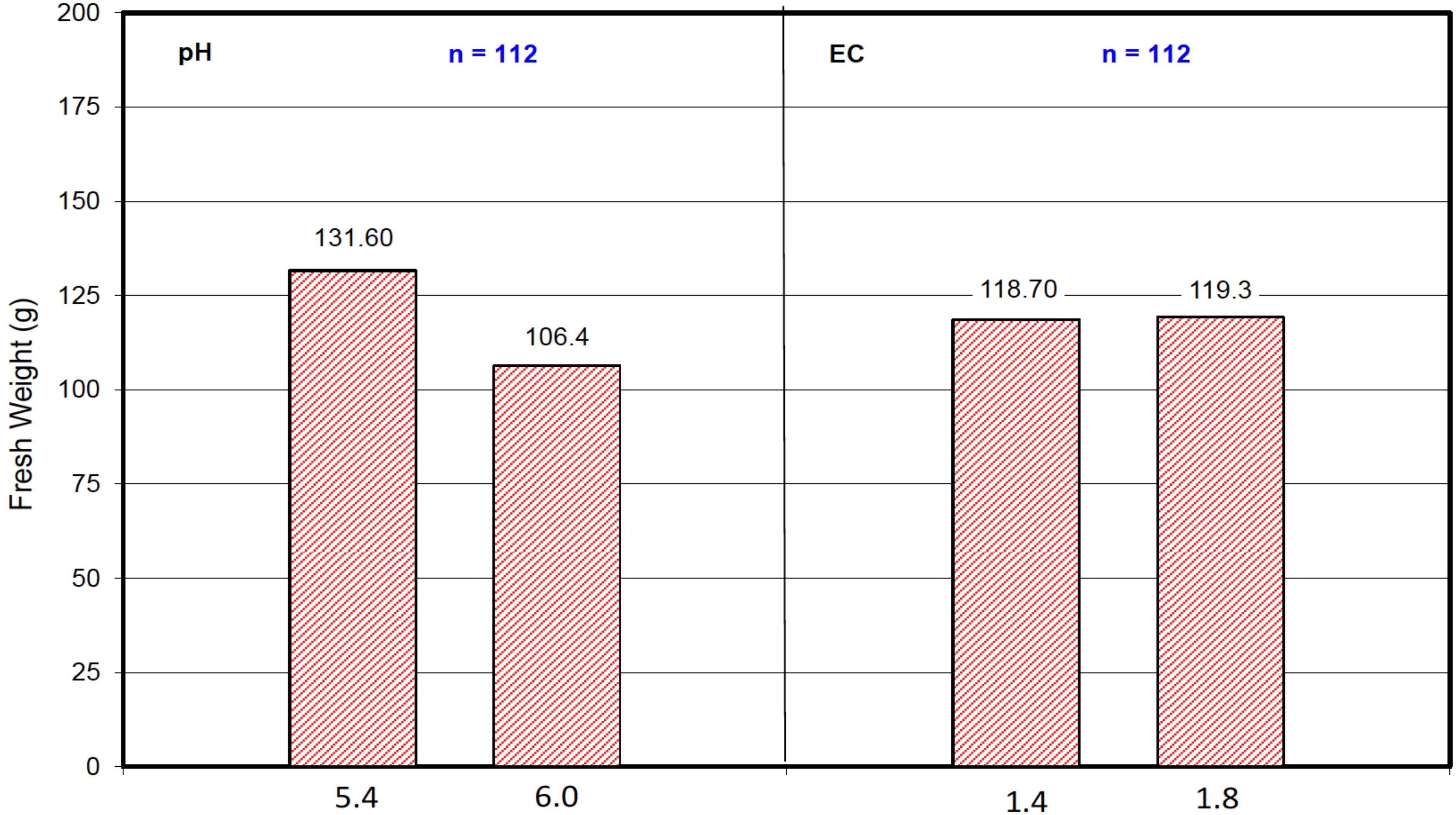
pH and Electrical conductivity (EC) testing

- Test early, test often
- How often to test depends on your system
- In hydroponics: every day
- In bag culture: perhaps 1-2 times per week

pH / EC: What Is Optimal?

pH: effects plant nutrient availability
•optimal: 5.5 –6.5
•in hydroponics a bit lower is better: 5.4-6.0
EC depends on crop
•in general 1-2 dS/m (=1-2 mhos/cm) from the fertilizer
•avoid salt build up in the root zone > 4.0





pH and EC effect on hydroponic lettuce

pH 5.4 → 24% higher yield, Robert Hansen, 2008

Fertilizer (EC) and pH Control

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Manual –check and adjust by hand

- Ex: Pond (pH adjusted daily), fertilizer tested every two weeks and adjusted

Automated, pH and EC sensors control pumps with dilute acid/base, and fertilizer stock

- Sensors drift, important to check and calibrate!

Automated Control examples

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Adjust reservoir/pond

Hanna HI 2500

- 3 peristaltic pumps
  - 1 dilute acid
  - 2 fertilizer stocks

Adjust fertilizer water

Hanna HI 10,000

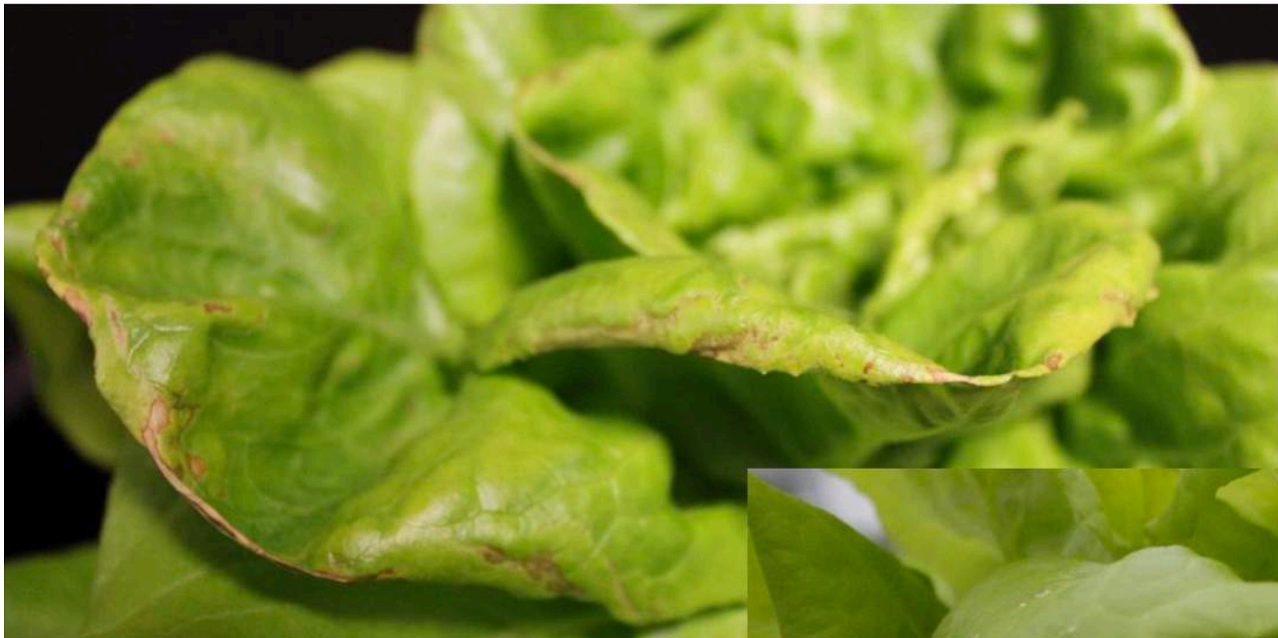
- 5 injectors
  - 1 for dilute acid
- 5-300 gpm flow rate

Common Nutritional Disorders & Corrections

Nitrogen deficiency: Yellow lower leaves; reduced biomass

Iron deficiency

Magnesium Deficiency –interveinal chlorosis of LOWER leaves



Phosphorus (P) deficiency

Create a Water Monitoring Plan

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- Design a monitoring plan based on the needs of the plants you're growing and the requirements of your hydroponic system.
- Outline monitoring activities that are practicable and meet your plant production goals.

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