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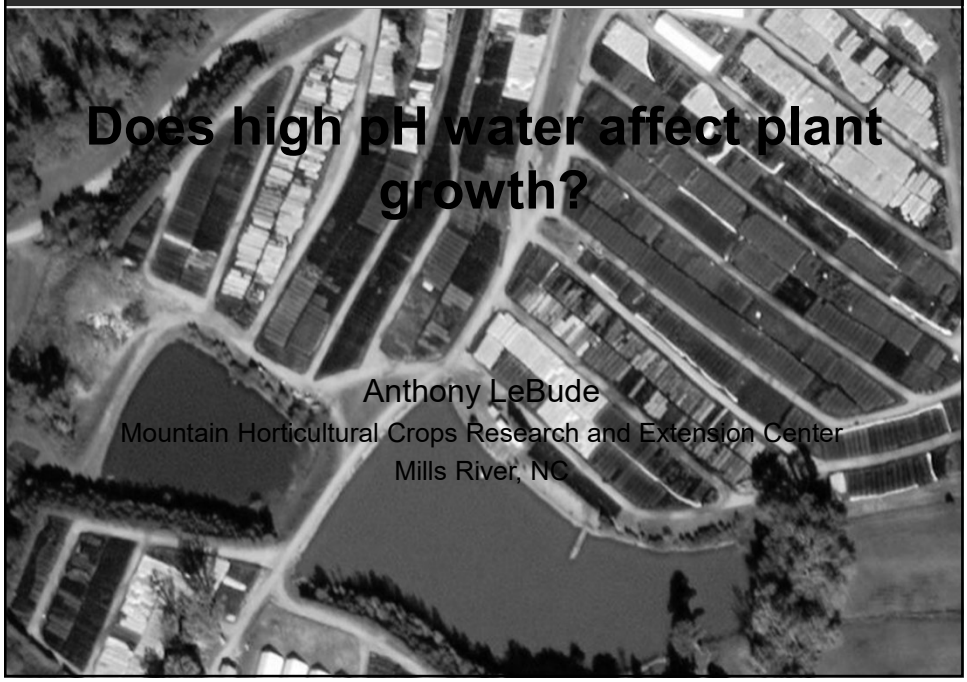
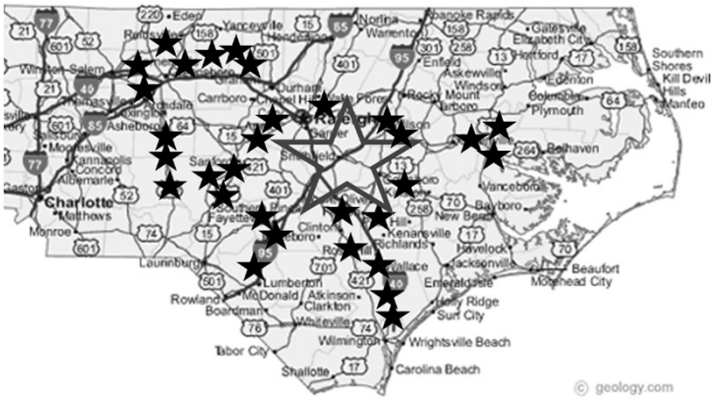


Does high pH water affect plant growth?

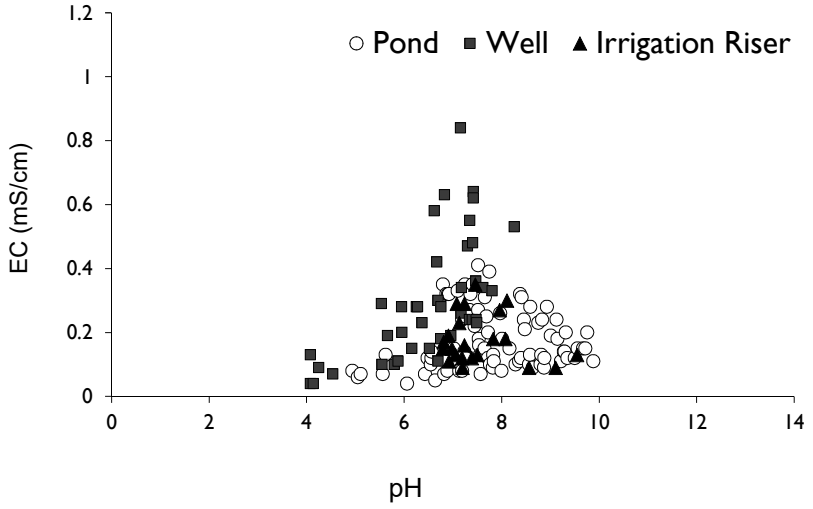
Anthony LeBude
Mountain Horticultural Crops Research and Extension Center
Mills River, NC

Source Water Tour Eastern NC



60 nurseries, 150 samples, 18 counties in NC

Source Water pH and Electrical Conductivity (EC)



Average Water Quality in Eastern North Carolina Nurseries

Source	pH	EC	Alkalinity	Iron
	Units±std	mS/cm	ppm (MEQ)	ppm
Pond	7.8±1.1	0.2±0.1	47±40 (0.9)	0.5±0.7
Well	6.5±1.1	0.3±0.3	90±77 (1.8)	0.6±1.5
Riser	7.7±0.7	0.2±0.1	50±30 (1.0)	0.3±0.3

Results are similar to Meador et al. 2012; Zhang et al. 2016; Copes et al. 2017, 2018;

Summer Stratification in Ponds

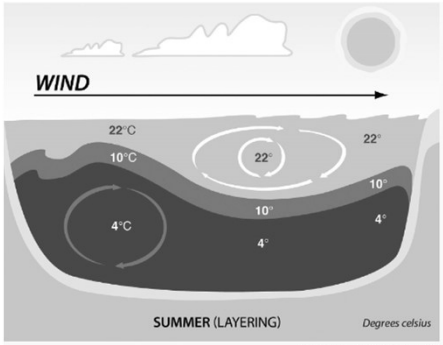


ILLUSTRATION: MICHIGAN SEA GRANT

EPILIMNION

The surface layer of water that is constantly mixed by wind and waves and is warmed by the sun, from late spring to late fall.

METALIMNION

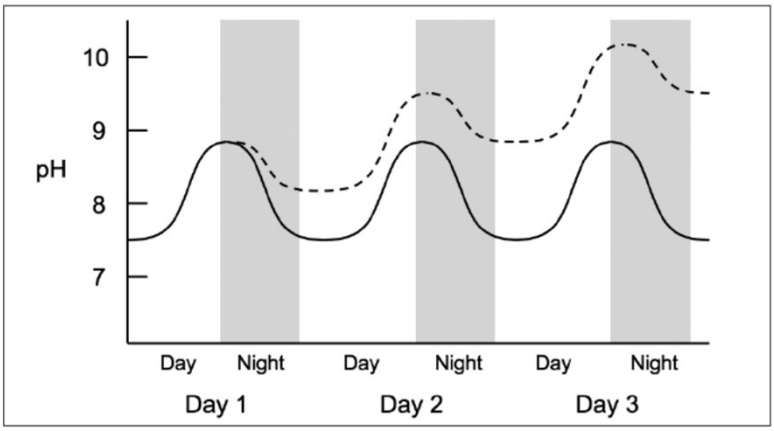
The middle layer characterized by a steep gradient in temperature and demarcated by the regions above (epilimnion) and below (hypolimnion). The metalimnion is the barrier that prevents mixing and heat exchange between the epilimnion and hypolimnion.

HYPOLIMNION

The deepest layer of uniformly cold water that does not mix with the upper layers and has low circulation. The colder water within the hypolimnion is at its maximum density at a temperature of 39.2° F (4° C).

Filamentous "Bottom" Algae and Surface Algae Colonies and Swirls

Effect of Algae on pH Over Time



Tucker and D'Abramo, 2008

"Change the Culture" of the Pond

- Reduce sediment and filter runoff through vegetated strips before it enters the pond
- Nutrients, bright light, and clear water create condition for high pH

Benefits of Floating Wetlands

- Provide habitat for nutrient metabolizing microbes
- Direct filtration of particulate matter from the water
- Enhances nutrient uptake by the plant species

White, S. et al. 2009. Floating wetlands effectively remediate nutrients. Proc. SNA Res. Confer. 54.

Photos | S.A. White

Agricultural Pond Dye

- Prevents light penetration to bottom
  - Bottom algae growth (filamentous) reduced
  - May change ecosystem of algae types in pond
  - Best in deep ponds
- Non-toxic to plants
- $10 per acre foot for 3 months in southeast

Treat EARLY with Copper Sulfate to Control Algae

Amount needed depends:

- Type and size of vegetation
  - Begin in May and June
  - Reapply every 2-4 weeks
- Volume of water in pond
- Water temperature > 60 F
- Water alkalinity
- Water flowing in pond
  - Close outlets while treating

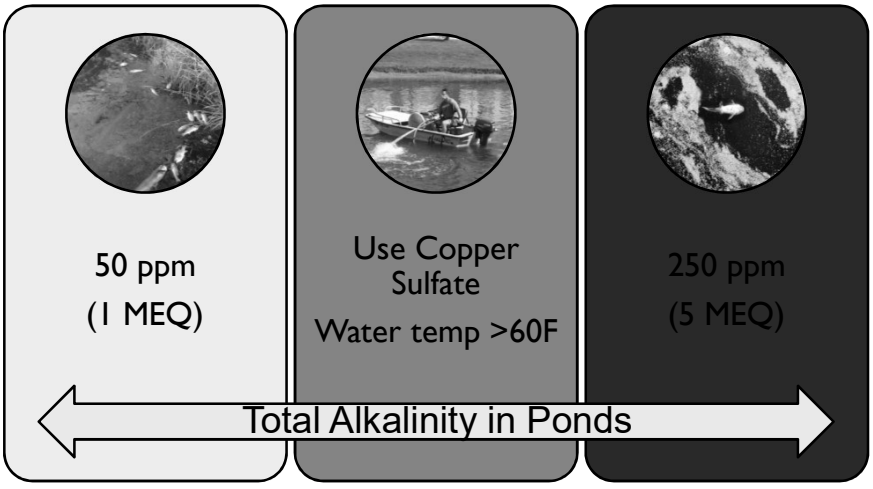
Copper sulfate needed (lbs.)

Pond Vol.		Desired Copper Sulfate conc. (ppm)	
Ac. ft.	Gal.	0.25 (surface)	0.5 (filamentous)
0.6	195 k	0.4	0.8
1.0	326 k	0.7	1.4
4.0	1.3 M	2.7	5.4

3 lb. bag of Copper Sulfate is $15

Storlie, C. 1995. Controlling bacteria, algae, and weeds in irrigation ponds. Rutgers Extension FS796.

When to Use Copper Sulfate to Control Algae



Copper is a Heavy Metal

Heavy metal enthusiasts reminding us all that iron, copper, and zinc are all bivalent (2+) cations

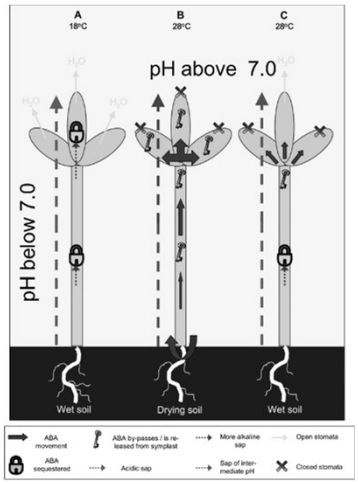
- When used according to label-no adverse effects
  - In an algae IPM program
  - Never decomposes
    - Builds up in sediments
- Relatively inexpensive
- Very effective at controlling algae present
  - Copper resistant algae can be an issue

Drawbacks of Dye and Copper if Water Escapes Nursery During Storm Event

- Abnormal water color found at complaintant's property (B) was discharged from ponds (A)
  - Blue colored water was observed overflowing from ponds into unnamed tributary

- Results of dissolved metals water samples obtained at sampling location A and B revealed elevated levels of cupper in excess of state standards at a hardness of 26 mg/L (See Table 1).

The Pathway Where High pH Might Affect Growth



- Two signals affect stomatal control
  - Abscisic acid (ABA) and high pH

Wilkinson and Davies. 2008. J. Exp. Bot. 59:619-631

Increased Salinity and High pH Decreased Growth of Ranunculus

- Irrigated with pH 6.4 and 7.8 with increased salinity from 2, 3, 4, and 6 dS/m.
- Alkalinity was 160 ppm (CaCo3) or 3.2 meq/L, Riverside, CA municipal water.
- Plants were drip irrigated, no foliage wetted
- Shoot and root growth reduced with high pH water and increased salts

Valdez-Aguilar et al., 2009. HortScience 44:138-144

High pH Overhead vs. Ebb/Flow

Characteristic	unit	Water Source	
		Captured	Well
pH		9.7	7.6
Electrical conductivity	dS/m	0.34	0.37
Alkalinity	ppm	95.0	111.8

Plant	Overhead		Ebb/Flow	
	Captured	Well	Captured	Well
Ficus benjamina	86.9b	95.0b	151.6a	128.8a
Schefflera actinophylla 'Amate'	19.3b	17.4b	24.8a	25.5a
Spathiphyllum 'Petite'	74.8bc	66.8c	91.4a	85.2ab

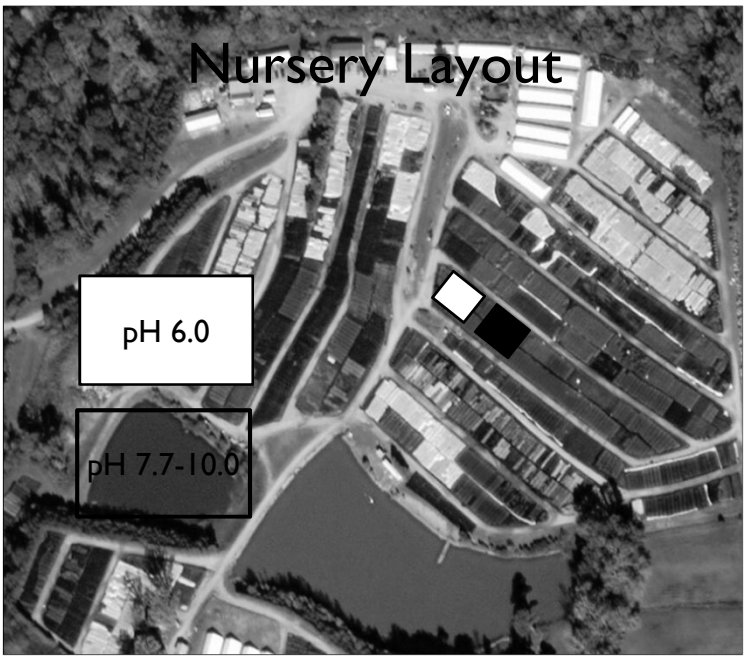
Chen et al. 2003. HortScience 38:228-233.

Ionic Variables of Cooperating Nursery Ponds

Nursery	pH	EC (mS/cm)	Total Alkalinity ppm (MEQ)
A	8.1	0.30	70 (1.4)
B	6.9	0.32	35 (0.7)
C	7.3	0.35	125 (2.5)
D	8.8	0.13	40 (0.6)
E	9.5	0.14	25 (0.3)
F	5.1	0.09	0 (0)
IPP Ranges*	5.2-6.8	0.0-0.30	0-140 (<2.8)

*Irrigation for Plant Production Water Quality (IPP). Robbins, J. 2010. Irrigation water for greenhouses and nurseries. Univ. Ark. Coop. Ext. Serv. Agr. Natl. Res. Bul. FSA6061-PD-5-10RV. Adapted from Copes et al., 2018. Hortscience 53:360-372.

Nursery Layout

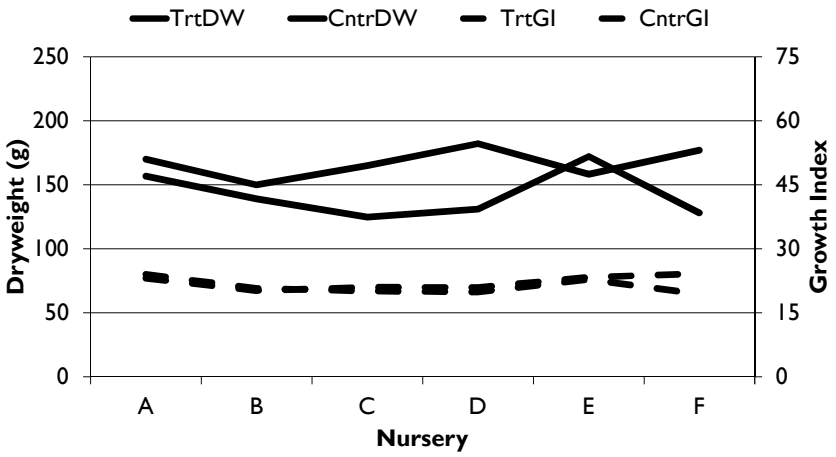


Treatment Layout

Plants Provided by Proven Winners

- *Abelia mosanensis* 'Sweet Emotion'
- *Buddleia* 'Miss Molly'
- *Forsythia* x *intermedia* 'Show Off'
- *Hydrangea paniculata* 'Little Quick Fire'
- *Loropetalum chinense* 'Jazz Hands Bold'
- *Rosa* Oso Easy™ 'Urban Legend'

Mean Dryweight and Growth Index 2017



Growth Comparisons 2017

Loropetalum chinense
'Jazz Hands Bold'

Control Trt

Hydrangea paniculata
'Little Quick Fire'

Control Trt

Preliminary Physiology 2018

Forsythia 'Show Off'	Before Irrigation		After Irrigation (15 m)	
	P_n ($\mu mol\ m^{-2}s^{-1}$)	g_s ($mmol\ m^{-2}\ s^{-1}$)	P_n ($\mu mol\ m^{-2}s^{-1}$)	g_s ($mmol\ m^{-2}\ s^{-1}$)
Control (pH 7.7)	9.1	69.25	9.48	69.0
Treatment (pH 6.0)	12.9	122.9	8.76	65.5

n=2, mn 4 leaves each plant; Ambient conditions 400 umol CO2; 1700 PAR; RH 50-56%; Leaf 32C (86F)

Summary

- High pH occurs in almost every open water pond in the southeast US
- Reduce algae in ponds and monitor water pH
- Reduce production runoff into irrigation ponds
- If chlorinating water, lowering pH would help controlling pathogens and may be beneficial for growth slightly.

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Helping People Put Knowledge to Work

Horticultural Research Institute
The AmericanHort Foundation

North Carolina Nursery & Landscape Association

THE INTERNATIONAL PLANT PROPAGATORS' SOCIETY 1951

got to be NC AGRICULTURE

SNA

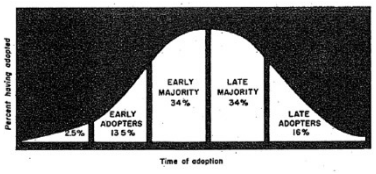
This project received support from the North Carolina Department of Agriculture and Consumer Services as part of the Specialty Crops Block Grant Program

Ionic Variables of Cooperating Nursery Ponds

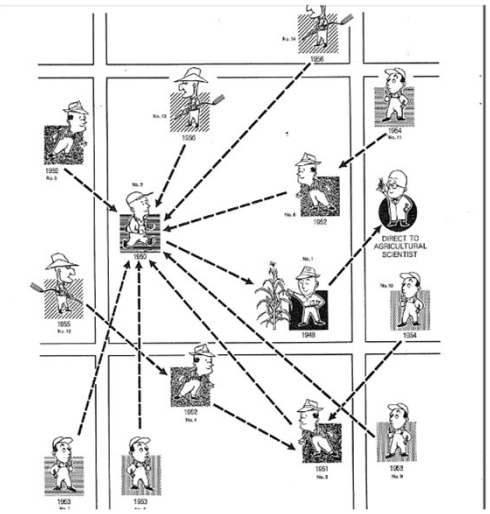
Nursery	pH	Total Alkalinity ppm (MEQ)	EC (mS/cm)	Hardness ppm
A	8.1	70 (1.4)	0.30	99
B	6.9	35 (0.7)	0.32	87
C	7.3	125 (2.5)	0.35	85
D	8.8	40 (0.6)	0.13	30
E	9.5	25 (0.3)	0.14	28
F	5.1	0 (0)	0.09	15
IPP Ranges*	5.2-6.8	0-140 (<2.8)	0.0-0.30	N/A

*Irrigation for Plant Production Water Quality (IPP). Robbins, J. 2010. Irrigation water for greenhouses and nurseries. Univ. Ark. Coop. Ext. Serv. Agr. Natl. Res. Bul. FSA6061-PD-5-10RV. Adapted from Copes et al., 2018. Hortscience 53:360-372.

Who is adopting technology in the area?



- Innovators are not thought of as good growers (1 in 40)
- Early adopters are well respected within the area (1 in 8)
- Early/late majority sets widespread adoption (7 in 10)



Bohlen, J. et al. 1960? Adopters of new farm ideas: Common characteristics and behaviors. North Central regional publication, No. 13.

Preliminary Physiology

Forsythia 'Show Off'	Before Irrigation		After Hand Watering	
	Pn	gs	Pn	Gs
Control	6.49	0.048	10.93	0.102
Treatment	11.4	0.102	7.93	0.06

Barley Prevents Algae Growth (Algastatic), but not Kill It (Algacidic)

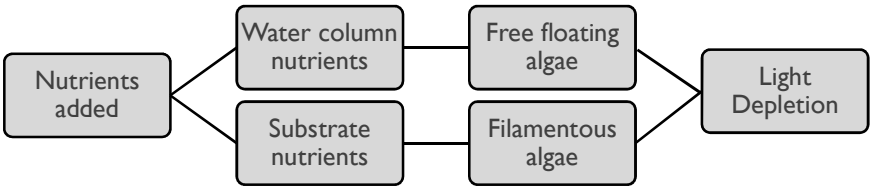
- Began in British ponds
  - U.S. reports conflicting
- Breakdown creates low doses of H_2O_2
  - Pond must be aerated
- Add barley when water temp. is 68 F (Mar-Apr)
  - Lasts 6 months
- Float 225 lbs straw per acre of pond surface

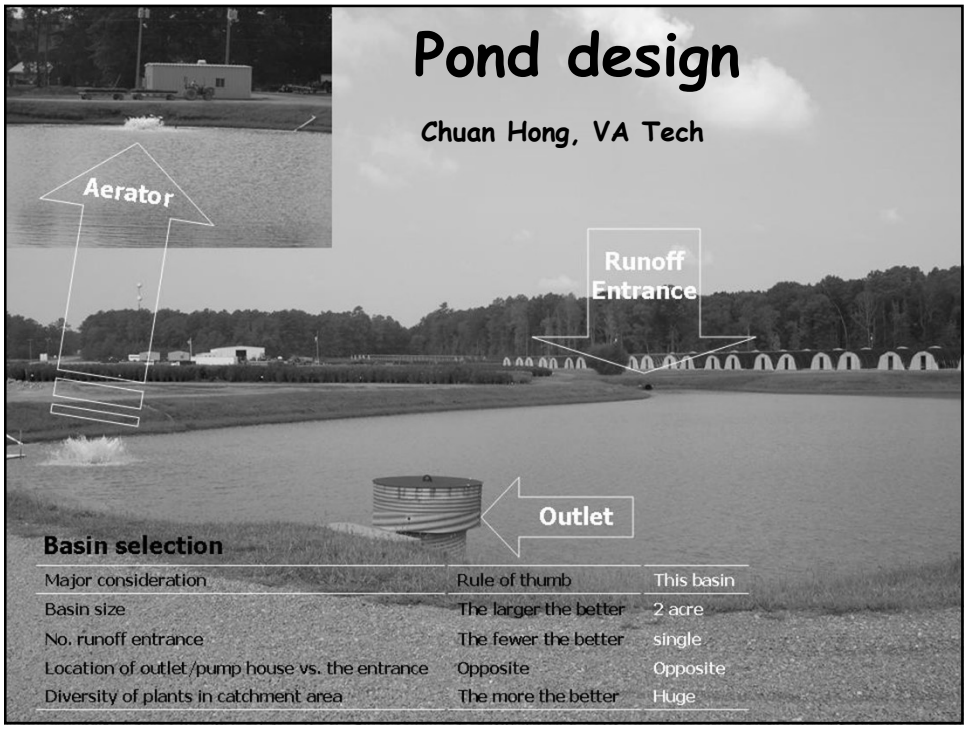
Lembi, C. 2002. Aquatic plant management: barley straw for algae control. Purdue Extension APM-1-W

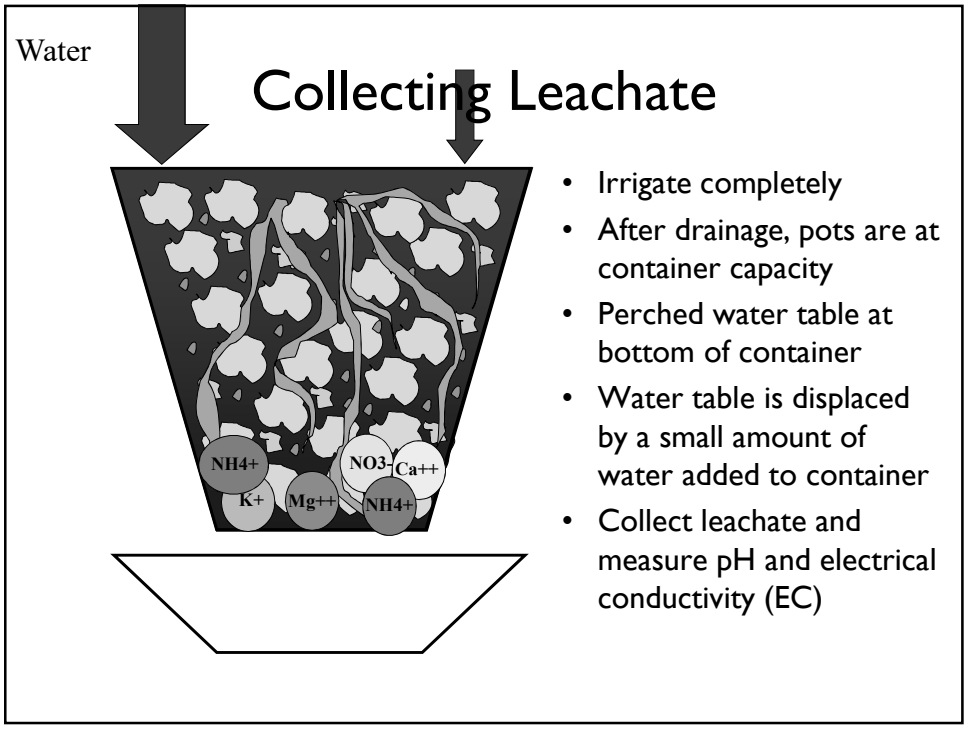
Can Copper Sulfate Be Used Safely

- If total alkalinity < 50 ppm
  - Copper treatments are not recommended because of the high risk of killing fish.
- If total alkalinity is > 250 ppm,
  - Copper sulfate should not exceed 2.5 ppm.

Effects of Nutrients on other Components of a Pond Ecosystem




Pond design
Chuan Hong, VA Tech
Aerator
Runoff Entrance
Outlet
Basin selection
Major consideration | Rule of thumb | This basin
Basin size | The larger the better | 2 acre
No. runoff entrance | The fewer the better | single
Location of outlet/pump house vs. the entrance | Opposite | Opposite
Diversity of plants in catchment area | The more the better | Huge


Water
Collecting Leachate
NH4+
NO3-
Ca++
K+
Mg++
NH4+
• Irrigate completely
• After drainage, pots are at container capacity
• Perched water table at bottom of container
• Water table is displaced by a small amount of water added to container
• Collect leachate and measure pH and electrical conductivity (EC)

pH affects Fungicides

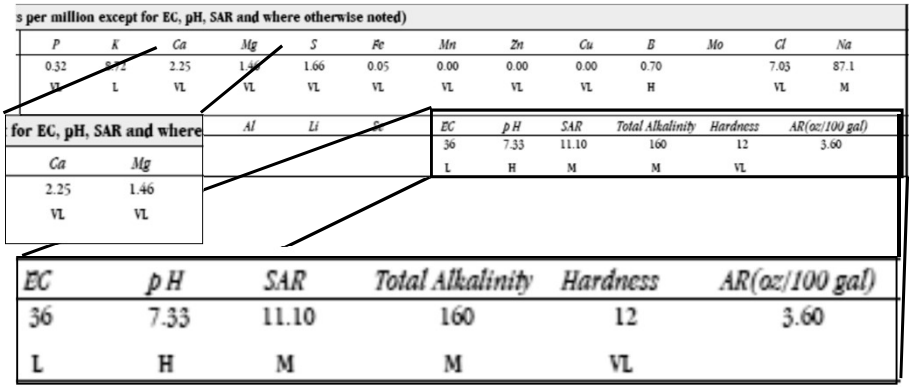
- Chlorothalonil (Daconil) hydrolizes in pH 9 or higher, so it is fairly stable
- Mefenoxam (Subdue) is not affected by pH

The Case of the Mysterious River Birch

Sample Report

- Foliage is scorched
  - Twigs & trunks are completely healthy as are the large roots
- Many small roots are decaying
  - *Phytophthora* was detected, but foliage symptoms not indicative of disease
- Bacterial leaf scorch (*Xylella*) not present
- "Some kind of environmental stress reaction"

Poor Quality Irrigation Water



s per million except for EC, pH, SAR and where otherwise noted)

P	K	Ca	Mg	S	Fe	Mn	Zn	Cu	B	Mo	Cl	Na
0.32	8.72	2.25	1.46	1.66	0.05	0.00	0.00	0.00	0.70		7.03	87.1
VL	L	VL	VL	VL	VL	VL	VL	VL	H		VL	M

for EC, pH, SAR and where

Ca	Mg
2.25	1.46
VL	VL

Al	Li	Se

EC	pH	SAR	Total Alkalinity	Hardness	AR(oz/100 gal)
36	7.33	11.10	160	12	3.60
L	H	M	M	VL	

Sodium Absorption Ratio

$$SAR = \frac{Na}{\sqrt{\frac{(Ca + Mg)}{2}}}$$

- Ability of sodium to dominate the CEC
- Disperses soil particles and creates a heavy, wet soil with low oxygen
- Damages sodium sensitive plants
- High SAR is combated by high calcium and magnesium

High pH Irrigation Water Does Not Always Mean No Ca/Mg Needed

- Better to have low SAR and high EC indicating more calcium and magnesium, but less sodium.
- Calcium and Magnesium
  - Make up about 80% of base saturation
  - Comprise 60% of exchangeable ions in solution
- In the case of the mysterious river birch:
  - Add gypsum ($CaSO_4$) and Epsom ($MgSO_4$) to substrate
  - Neutralize alkalinity in irrigation water by acid and add Ca and Mg to water if necessary
  - Or find new water source!

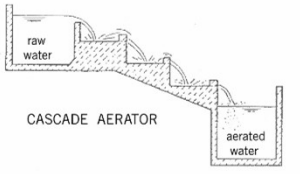
Plants Used in Floating Wetlands

Common Name	Botanical Name
Canna	*Canna* 'Australia'
Cattail	*Typha latifolia*
Common willow	*Salix caroliniana*
Elephant ear	*Colocasia esculenta* 'Black Magic'
Florida canna	*Canna flaccida*
Giant reed	*Arundo donax*
Iris	*Iris laevigata* *Iris ensenata* 'Variegata'
Lizard's tail	*Saururus cernuus*
Maidencane	*Panicum hemitomon*
Napier grass	*pennisetum purpureum*
Red top	*Agrostis* sp.
Soft rush	*Juncus effusus*
Spikerush	*Eleocharis montana*
St. Augustine grass	*Stenotraphrum secundatum*
Swamp mallow	*Hibiscus moscheutos*
Thalia	*Thalia geniculata*
Tifton 85 bermuda grass	*Cynodon dactylon*
Wild millet	*Panicum milliaceum*

- Mixed plantings more effectively removed nutrients May-Sept.
- Aeration helped with establishment but not with nutrient removal

White, S. et al. 2009. Floating wetlands effectively remediate nutrients. Proc. SNA Research Confer.

Aerate Well Water, Increase Resonance Time, then Filter Upon Release



Chlorination Options for Nurseries

- Continuous chlorination set to deliver 2 ppm free chlorine at the farthest sprinklers
  - "Free chlorine" ≤ 2.9 ppm conc. is generally considered safe for most woody crops
  - Water must be low in turbidity and free of organic matter
- 3 forms of chlorine:
  - Gas (Cl_2) – most economical, most dangerous
  - Liquid (sodium hypochlorite) bleach
  - Solid (calcium hypochlorite) tablets

Water Treatment

Solid Chlorine tablet : Accu-Tab

- Water dissolves tablets
- Regulator adjusts chlorine based on volume of water

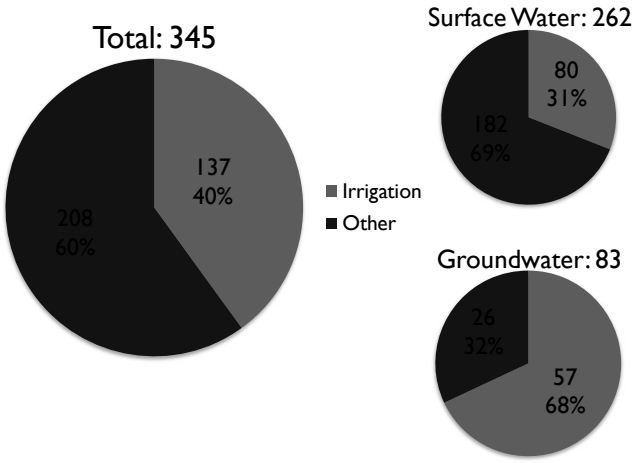
Liquid bleach (Sodium hypochlorite):

Chlorine Resonance Time and pH

- Does this affect free chlorine at different pHs and does that change over the summer when pond pH changes?
- Are all redundant sensors purchased both upstream and downstream to regulate injection?

``\_(“>)_/``

US Fresh water withdrawals, 2000 (in billion gallons per day)



58% of U.S. irrigation withdrawals from surface water
42 % from groundwater

USGS, 2000

USGS, 2000

P. ramorum

- Survives 5-11and is considered more basic loving.
- How does it do with the rest of the pond elements like Do

P. alni, and P. kernoviae

- Survives 3-9 and is considered more acid loving

- Zoospores of P. megasperma, P. nicotianae, P. pini and P. tropicalis
- dissolved oxygen concentrations of 5.3 to 5.6 mg L-1. Zoospore survival rates decreased with increasing and decreasing concentration of dissolved oxygen
- Overall, P. megasperma and P. pini are less sensitive than P. nicotianae and P. tropicalis to hyperoxia and hypoxia conditions.

Cleary's Products and pH

Product Formulation	Best pH
3336 F (thiophanate methyl)	**6 - 7**
Spectro™ 90WDG (thiophanate methyl and chlorothalonil)	**6 – 7**
26/36 Fungicide® (iprodione and thiophanate-methyl) (for turf)	**6.5 – 7**
Endorse® Wettable Powder (Polyoxin D zinc salt)	**6 –7**
Protect™ DF (mancozeb)	**6.5 – 7**
Alude™ (Mono- and dipotassium salts of phosphorous acid in a stable, liquid formulation) (Controls Phytopthora spp.)	**6 – 7**
TriStar® (Acetamiprid) (insects)	**6 – 7**

Reducing Alkalinity

- Add acid to reduce the alkalinity
  - Sulfuric acid (H_2SO_4) Battery acid (35%)
  - Citric acid ($H_3C_6H_5O_7$) (99% but weak)
  - Phosphoric and nitric acids not recommended due to water quality issues.

- H^+ (from acid) + HCO_3^- (in water) → $CO_2 + H_2O$

  Bicarbonate

Adjusting pH in Tanks

- Use a pH meter or strips to test pH.
- Products used to acidify tank solutions may be
  - Straight acidifying agents or used in combination with surfactants or nutrient materials like trace elements or fertilizer products
  - Miller spray-aide® compatibility-acidifying-surfactant agent
  - Cleary's Acidifying Agent

Water Quality Guidelines

Individual Macro Elements	Irrigation water
Nitrogen (N)	---
Nitrate-N (NO_3-N)	10 ppm
Ammonium-N (NH_4-)	2-10 ppm
Phosphorus (P)	<1 ppm
Potassium (K)	<10 ppm
Calcium (Ca)	<60 ppm
Magnesium (Mg)	<6-24 ppm
Sulfur (S)	<24 ppm

Individual Micro Elements	Irrigation water
Iron (Fe)	0.2-4.0 ppm
Manganese (Mn)	<0.5-2 ppm
Zinc (Zn)	<0.3 ppm
Copper (Cu)	<0.2 ppm
Boron (B)	<0.5 ppm
Molybdenum (Mo)	<0.1 ppm
Aluminum (Al)	0.05-0.5 ppm
Fluoride (Fl)	<1 ppm
Sodium (Na)	<3 meq/L or <50 ppm
Chloride (Cl)	<70 ppm

Nurserycropscience.org

Put my results into perspective

- Use the various papers Copes and Zhang to place my results within the canon.
- Why are mine higher – where I took the measurements and when I took them
  - Not all growers can water in the morning due to pressure, volume, and capacity of the system and the size of the enterprise.

Drawbacks of Dye and Copper if Water Escapes Nursery During Storm Event

- Al
  pr
- Bl
  fr
- W
  dc

Resources (DWR) conducted a site inspection in response to a complaint from a private citizen regarding unusual water color in a stream. The subject stream is an unnamed tributary (UT) [redacted] Class C Nutrient Sensitive (NSW) Waters in the Neuse River Basin.

The following observations were noted during the DWR inspection:

- The abnormal water color found at the complainant's property was found to be caused by the discharge of water from the ponds [redacted]
- Blue colored water was observed overflowing from the ponds via channels and discharging into the unnamed tributary [redacted]
- Water samples were taken downstream in the unnamed tributary [redacted] and at the outlet of [redacted] Nursery.
- Analytical results of these samples revealed elevated levels of total copper.

- Results of dissolved metals water samples obtained at sampling location A and B revealed elevated levels of cupper in excess of state standards at a hardness of 26 mg/L (See Table 1).

Production Recycle and Well Refill

Runoff carries nutrients and sediments

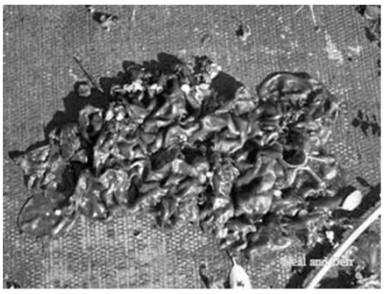
Well water may have high iron, hardness or alkalinity

Filter Water and Lower Pond Intake for Minor Algae Problems

Overhead versus drip

Float around 18-30 inches

Algae in Production



Alkalinity Affects Pesticides

- Pesticide decomposes to an inactive form if spray solution is alkaline
  - Water of pH 7.5-9.0 may result in poor insect control
  - Most effective pH 6 to 7
  - Time and high temperature increase decomposition

Iron and the Bacteria That Love Them on the Next Jerry Springer!

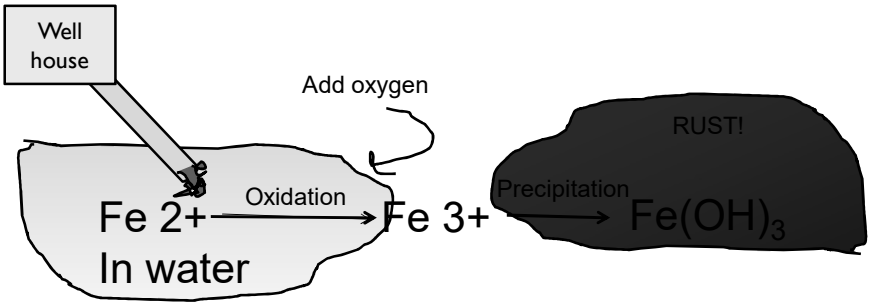
Iron browns everything

Iron bacteria turns plants shiny, and bluish green

Mineral (ppm)	Well	Pond	Riser
Iron	0.6	0.5	0.3

Emitters clogged at 0.1, stains at 0.3 ppm

Iron Oxidation and Precipitation



Pond Nursery

Rate of Oxidation in Water

- Time required for oxidation reduces with
  - High pH, temperature, and dissolved oxygen

pH of Pond water	Time required for 90% iron oxidation at 70 F
6.0	100 hours
7.0	1 hour
8.0	30 seconds

- Dissolved oxygen concentration > 2 ppm
  - Clean, open water usually 7 ppm, less if algae

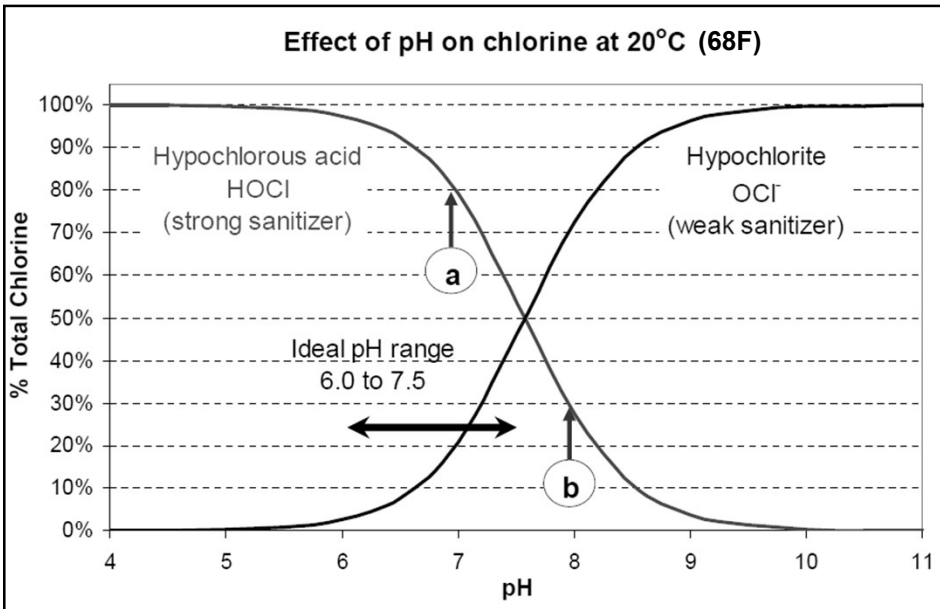
Zinati, G. and X. Shuai. 2005. Management of iron in irrigation water. Rutgers Fact Sheet FS516.

Removing Iron (and Pathogens) in Irrigation Water by Injecting Chlorine

Filter sediment
- Sand or Disc
- Inject acid to adjust pH <7.5

Chlorinate
- Gas
- Liquid
- Tablets

Filter Again
- Resonance time for iron to precipitate



The pH of the water chlorinated impacts efficacy.
A pH of 6.0-7.5 prior to treatment is recommended.

Chlorine Toxicity Over Time

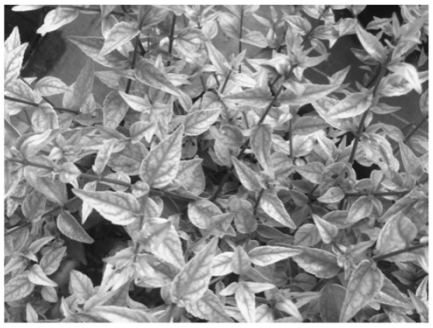
- Chlorine injection system installed 10 years ago
  - Same Cl injection ratio
- Sediment filter installed recently
  - Vegetated buffer strips also matured over 10 years
  - Didn't adjust Cl injection
- Many plants have chlorine toxicity symptoms

Species Sensitive to Chlorine

- Boxwood crapemyrtle, dogwood, gardenia, hibiscus, hydrangea, juniper, rhododendron, rose, sugar maple, spruce, and viburnum.
- Grow these plants the farthest from chlorine injection possible.
- Retest chlorine injection ratios yearly or biennially, and test ppm seasonally.

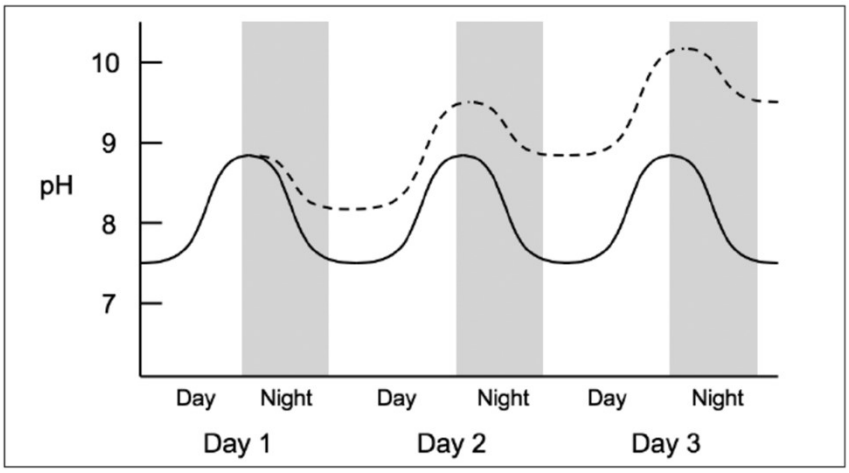
What Effect Does High pH Water Have on Plant Growth?

Abelia **Loropetalum**

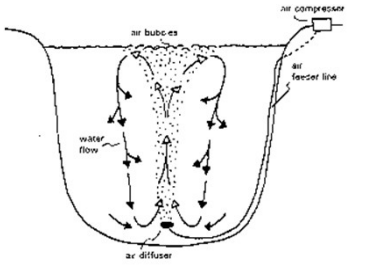


Watered with well water containing high alkalinity and substrate had low fertility

Effect of Algae on pH Over Time



Bottom Aeration to Decrease Summer Stratification



Floating Wetlands to Filter Incoming Production Runoff

Photos | S.A. White

- Use Zhang and bleyaneh RIR articles to show pH is high and find out where the intake it for some ponds when downeast. They are taking from the high pH portion of the pond regardless.
- Average depth of intake
- Average depth of ponds for all nurseries

Water Quality Characteristics of Ponds

Top to 0.5 m depth

- Temperature is hot on top when air is warmer and light does no penetrate
- Higher dissolved oxygen

Bottom to 2.5 m below surface

- Cooler

- What if the mimictic limnology is important for keeping the pond healthy.
- Light penetrates the water and stratification decreases
  - DO increases everywhere to kill pathogens
  - Air temperature is colder which also kills pathogens
  - pH decreases so acid loving phytophthora persist

Observations

- Ponds were at their lowest water levels and worst quality for the year
- There were algae plumes in every pond (Copes et al. 2018)
- Ponds capturing 100% production runoff and using that for irrigation had most challenges
  - Many nurseries
- Nurseries with a pond system or series of ponds to move water had fewer challenges
  - Few nurseries

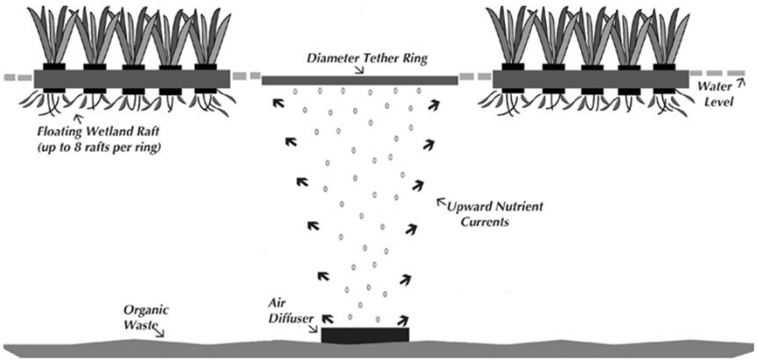
Irrigation Water Quality
pH 5.4 to 7.0 | EC 0.02 to 2.0 mS/cm

- Total alkalinity on soil solution report is the sum of carbonates and bicarbonates
  - Alkalinity is the buffering capacity of water and affects how much acid is needed to lower the pH
  - CO_3^{--} and $\mathbf{HCO_3^-}$ (usually the problem in NC)
  - 50 ppm equals 1 meq

Does high pH affect plant growth?

- Most reports say that it does not

Floating Wetlands Remove Nutrients Aeration Decreases Stratification



Aeration/Circulation multiplies the pollution removal power of the Floating Wetlands.

Charleston aquatics