Managing nutrient solutions for hydroponic crops

Ryan Dickson, Ph.D.
ryand@uark.edu

DIVISION OF AGRICULTURE
RESEARCH & EXTENSION
University of Arkansas System

Different types of hydroponic systems

- Nutrient film technique (NFT)

- Deep water culture

- Slab or soilless substrate culture

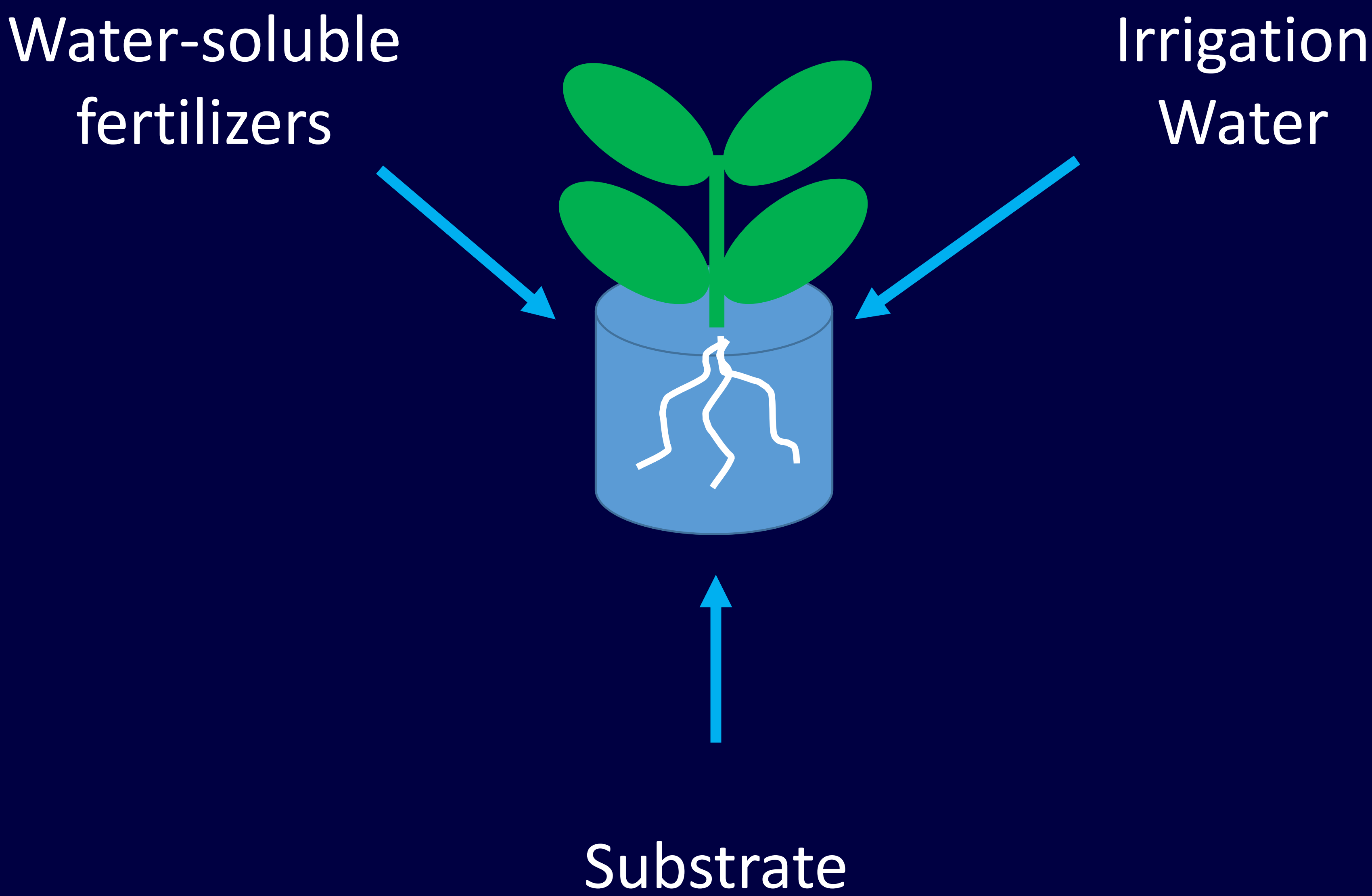
Outline

- Supplying all essential elements and managing nutrient levels in hydroponic solution
- The effects of nutrient solution pH on nutrient availability and preventing high and low pH problems

Before we get too far…

- Nutrient and pH management is not complex
- Supply all essential nutrients in a moderate amount, keep pH between 5.5 and 6.4, and you should be fine
- But this is a nutrition lecture, so more info…

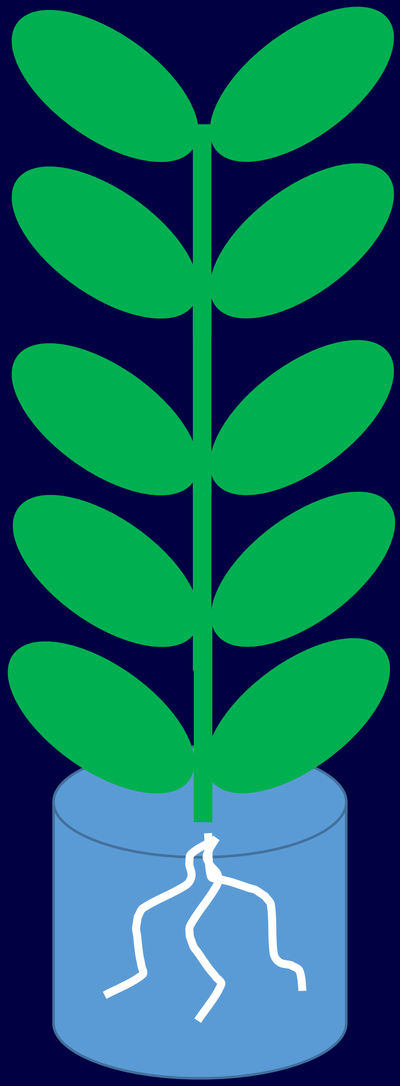
Nutrients come from multiple places



Examples of greenhouse water results from lab

Greenhouse	Well #1	Well #2	Target ranges	
			Min	Max
pH	7.6	7.1	5.0	7.0
Alkalinity (ppm $CaCO_3$)	35	242	40	120
EC (mS/cm)	0.11	1.0	0.0	1.0
NO3-N (ppm)	0.9	0.0	0	10
P (ppm)	<0.1	0.3	0	20
K (ppm)	2	17	0	150
Ca (ppm)	4.1	167	0	150
Mg (ppm)	2.3	8	0	75
SO4-S (ppm)	11	180	0	120
Fe (ppm)	<0.1	0.0	0.00	2.0
B (ppm)	0.001	0.1	0.05	5.0
Na (ppm)	15	28	0	100
Cl (ppm)	5.7	57	0	70

Mobility of nutrients



Immobile Nutrients

Calcium (Ca)
Iron (Fe)
Manganese (Mn)
Zinc (Zn)
Copper (Cu)
Boron (B)

Mobile Nutrients

Nitrogen (N)
Potassium (K)
Phosphorus (P)
Magnesium (Mg)

Partially Mobile

Sulfur (S)
Molybdenum (Mo)

Deficiency with an immobile nutrient: Iron (Fe)

New leaves = deficient

Fe cannot be mobilized to new growth

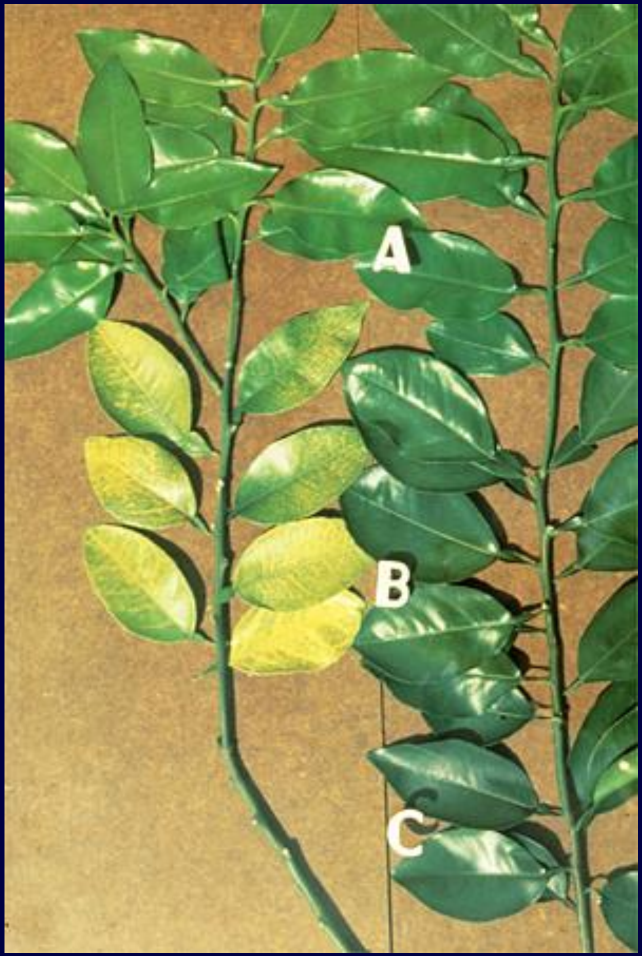
Old leaves = healthy

Deficiency with a mobile nutrient: Nitrogen (N)

New leaves = healthy

N is mobilized to new growth

Old leaves = deficient



N-deficient Normal

Deficiency: Low fertilizer stunts growth, pale foliage

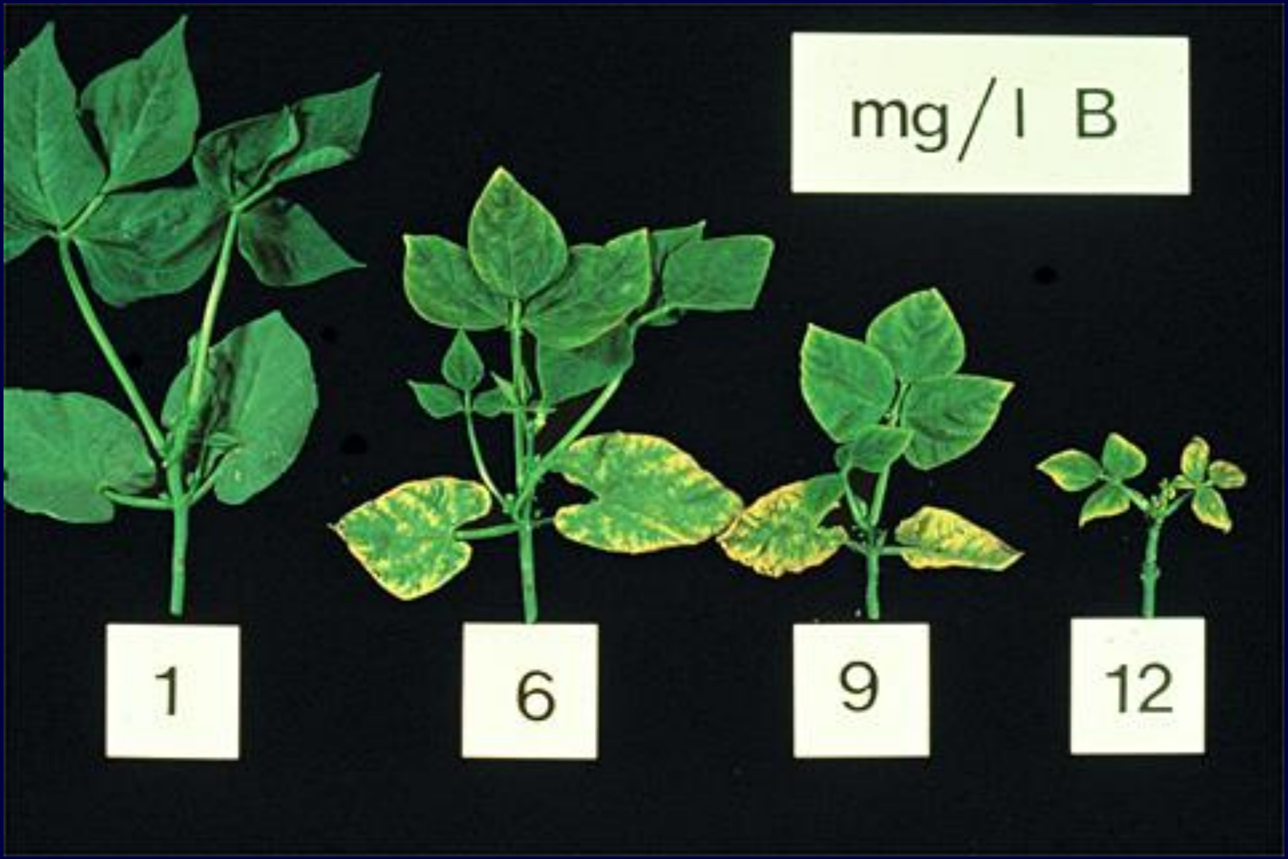
25ppm N 150ppm N

Toxicities: nutrients tend to accumulate in older tissue because of leaf age

Example: boron (B) toxicity

New leaves

Old leaves



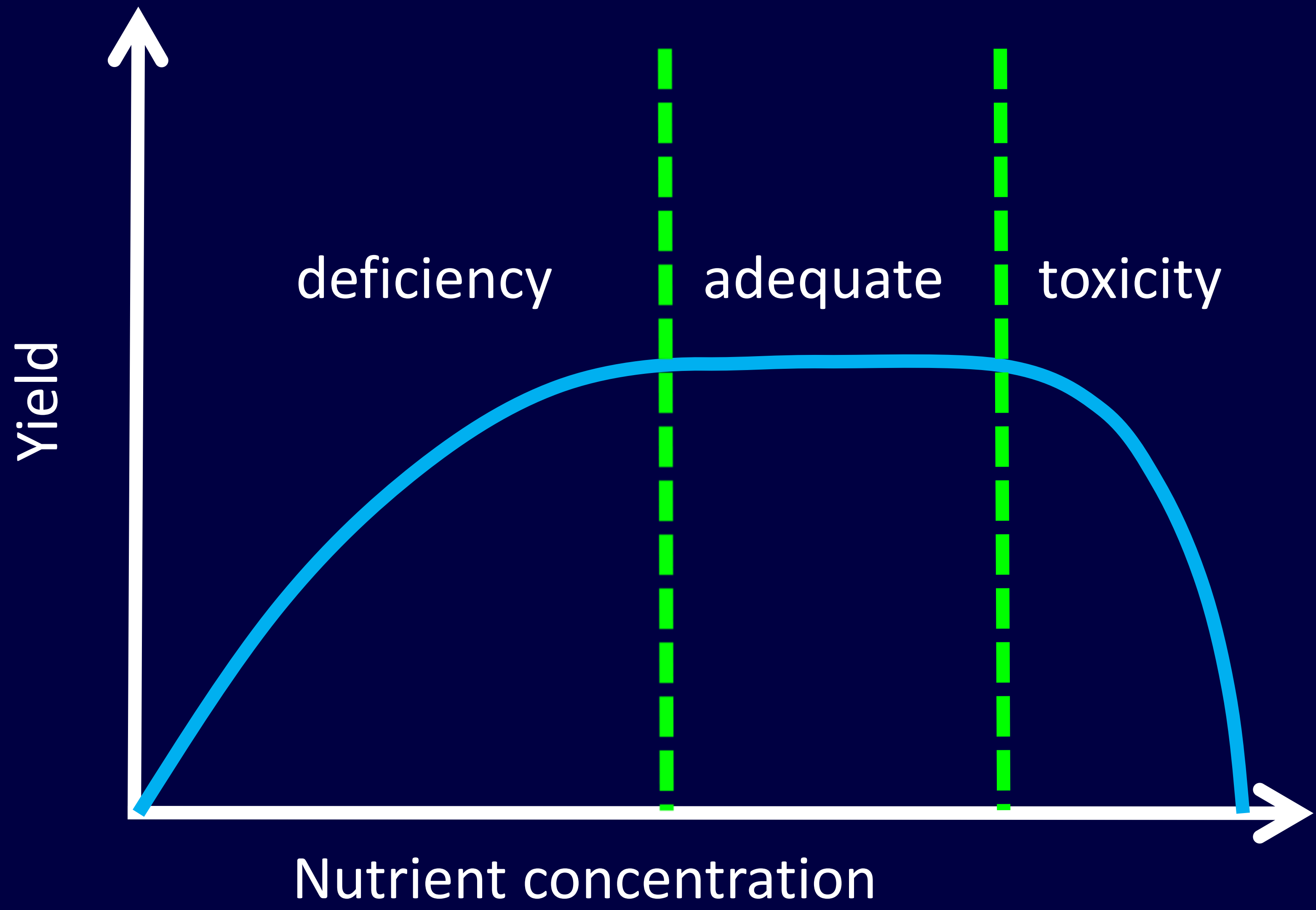
Toxicity: High fertilizer salts (EC) burn

Dark green and “hard” foliage, stunted growth

Wilting

Leaf scorch, dying roots

Effect of nutrient supply on plant growth



Calcium-related disorders: Deficiency

“Blossom end rot” and “tip burn”

Calcium not moved quickly enough to expanding fruit or young leaves

Occurs even with adequate Ca supply

Correct by increasing calcium movement within the plant

- Increase fertilizer calcium
- 400ppm-Ca foliar sprays
- Increase transpiration (increase air-flow,decrease relative humidity)

Calcium-related disorders: Toxicity

"Gold fleck" on tomato

Excess calcium precipitates in tissue

Cultivars differ in susceptibility

Correct by decreasing calcium uptake

- Lower applied fertilizer calcium (Ca)
- Increase K:Ca ratio in fertilizer

University of Maryland Extension

Nutrient deficiencies and toxicities

- Deficiency or a toxicity results from too little or too much nutrient for healthy growth
- Deficiencies can occur from:
  - Low fertilizer
  - Poor root health
- Toxicities can occur from:
  - Essential elements
  - Other contaminants (e.g. Al, Na, metals, pesticides)
- Symptoms vary:
  - Depends on mobility in plant, plant species
  - Check out detailed information at e-GRO.org

We measure nutrients as total salt concentration

- Electrical conductivity (EC) in mS/cm, or Total Dissolved Solids (TDS) in ppm

- 1 mS/cm = 1 dS/m = 100 mS/m
  = 1 mmho/cm = 1000 microS/cm

- 1 mS/cm of EC = approx. 700 ppm TDS
  (but this varies between meters)

In greenhouse production, we mainly use EC units

- You need an EC meter to measure
  - EC of irrigation water (is the salt/contaminant level changing?)
  - EC of the substrate (are nutrients deficient or salts too high?)
  - EC of fertilizer solution (is the injector calibrated, are you supplying the right amount of water-soluble nutrients?)

Invest in a quality EC/TDS meter

Regular monitoring of crop fertility, take corrective action before problems are severe

Expect to spend at least $100

- Well worth the investment

How often do you calibrate?

P. Fisher, Univ. of Florida

Reading the fertilizer label (water-soluble fertilizer)

- Fertilizer formula
- Nitrogen forms
- pH effect
- Macronutrients
- Micronutrients

- Application
  - Mixing rates
  - EC chart

20-10-20

Guaranteed Analysis

FOR CONTINUOUS LIQUID FEEDING PROGRAMS

Total Nitrogen (N) 20%
 8.0% Ammoniacal Nitrogen
 12.0% Nitrate Nitrogen
Available Phosphate (P_2O_5) 10%
Soluble Potash (K_2O) 20%

Boron (B) 0.025%
Copper (Cu) 0.025%
Iron (Fe) 0.100%
Manganese (Mn) 0.050%
Molybdenum (Mo) 0.010%
Zinc (Zn) 0.050%

Derived from: ammonium nitrate, ammonium phosphate, boric acid, copper EDTA, iron EDTA, manganese EDTA, potassium nitrate, sodium molybdate, and zinc EDTA.

Potential acidity: *425 lbs. Calcium Carbonate Equivalent per Ton.*

Directions for Mixing

Amount to use (in ounces) per gallon of stock

	1:15 ratio	1:100 ratio	1:200 ratio	1:400 ratio
50 ppm N	0.5	3.3	6.7	13.3
100 ppm N	1.0	6.7	13.3	26.7
200 ppm N	2.0	13.3	26.7	53.4
400 ppm N	4.0	26.7	53.4	106.7

EC Chart (in mS/cm)

ppm N	50 ppm N	100 ppm N	200 ppm N	300 ppm N	400 ppm N
EC	0.32	0.64	1.28	1.92	2.56

Nutrition strategy for hydroponic greens

ppm in nutrient solution

Nutrient	ppm
N	150
P	29
K	194
Ca	100
Mg	31
Fe	1.75
Mn	0.38
Zn	0.25
B	0.24
Cu	0.08
Mo	0.05

Average of 4 different commercial fertilizer recipes

Nutrition strategy for hydroponic greens

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B	0.24
Cu	0.08
Mo	0.05

Consider extra micros

Adjust to nutrients in irrigation water

16-4-17

Nutrient	ppm
N	150
P	16
K	132
Ca	38
Mg	14
Fe	2.10
Mn	0.47
Zn	0.49
B	0.21
Cu	0.13
Mo	0.08

Blending nutrient solutions from individual fertilizer salts

- A little more complicated…
- Solubility and precipitation issues
- Tanks A and B
- Work with the fertilizer supplier or university extension specialist

Neil Mattson, Cari Peters

Managing nutrient levels in recirculating systems

EC level on target for desired ppm-N

Replenish transpired water with…

- Normal EC solution

Managing nutrient levels in recirculating systems

EC level higher than target for desired ppm-N

Replenish transpired water with…

- Clear water
- Lower EC solution

Managing nutrient levels in recirculating systems

EC level lower than target for desired ppm-N

Replenish transpired water with…

- Higher EC solution

Some nutrients/salts can accumulate in recirculating hydroponics

Accumulation depends on

- Plant uptake (species, growth stage)
- Nutrient supply
- Water quality
- Contaminants (Na, Cl, metals)

Risk of nutrient imbalance or toxicity

Fine-tune nutrient solution recipe

“Bleed” or replenish solution periodically

Nutrient strategies for fruiting crops

Complete nutrient solution at 200ppm-N is a good starting place

Adjust N:K ratio for vegetative and reproductive growth

- N:K ratio near 1:1 during vegetative growth
- N:K ratio of 1:1.5 or 1:2 during fruit development

Supply high calcium (>150ppm) and magnesium (>50ppm), typically increase during fruiting

Nutrient strategies for improving plant and fruit quality

Consider calcium foliar sprays

- Reduce "blossom-end rot", "tip-burn"
- Weekly 400ppm-Ca from $CaCl_2$, not $CaNO_3$
- Trial on small number of plants

Increase soluble salts (EC)

- High N:K ratio in winter
- Gradually increase to allow plants to acclimate

Consider increasing micronutrients

- "Water roots" less efficient at uptake, metal micronutrients may precipitate on roots

Check out "A Recipe for Hydroponic Success" by Drs. Neil Mattson and Cari Peters

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

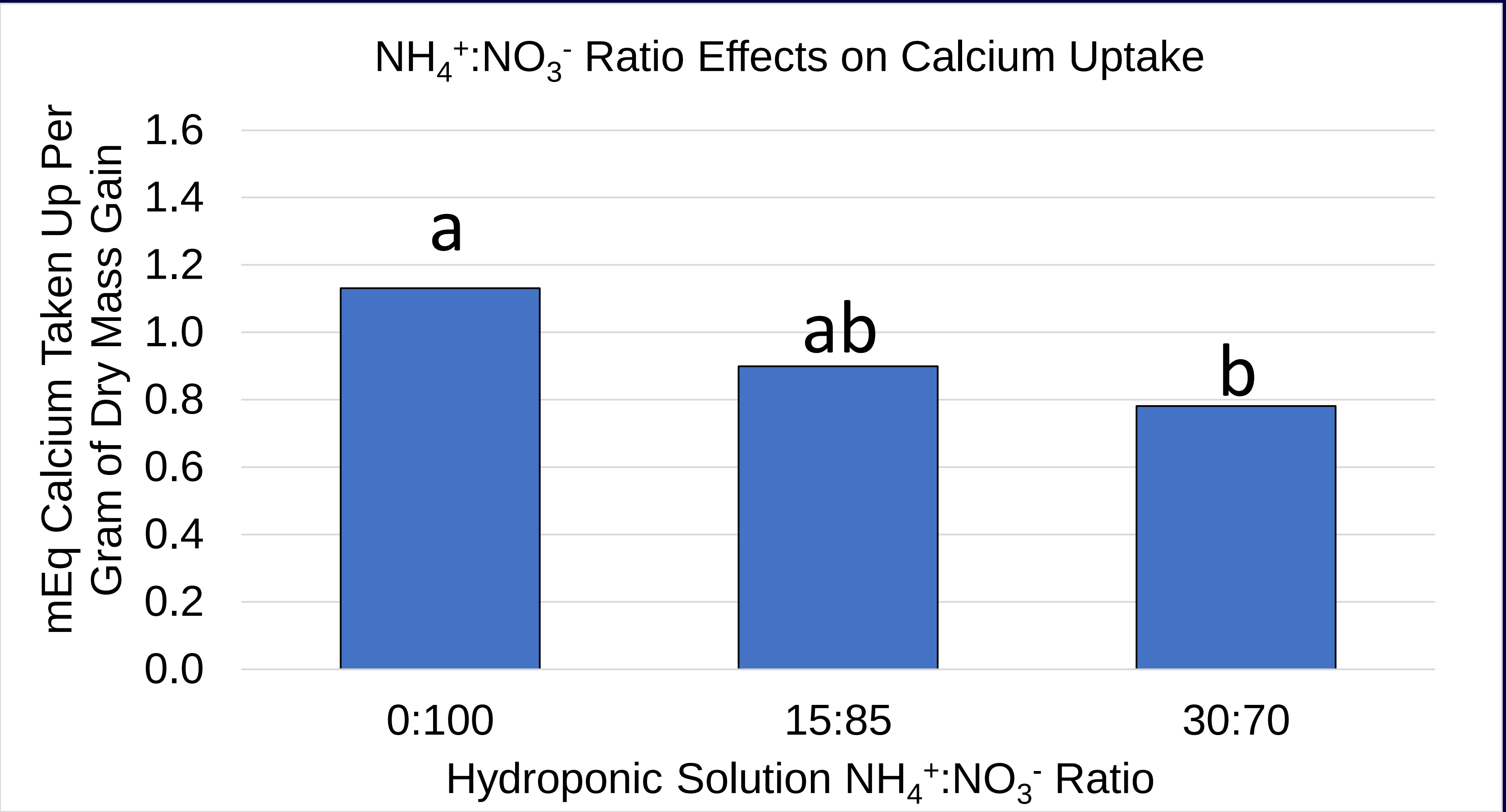
Nitrogen forms

Nitrate (NO_3) preferred in hydroponics. Increases calcium uptake and plant tone. Causes solution-pH to increase, need acid injection. Most costly N form.

Ammonium (NH_4) darkens foliage color and can promote plant growth in small amounts. Root uptake is energetically favored over nitrate. Too much promotes "blossom end rot" and "tip burn", ammonium toxicity, and soft growth. Decreases pH.

Urea ($CO(NH_2)_2$) similar to NH4, decreases pH. Too much can be toxic, result in poor quality growth. Must be converted into NH_4 or NO_3 before used in plants. Most inexpensive N form.

Increasing NH_4^+ to 30% of total N decreased Ca^{2+} uptake by 30%



- Arugula, basil, lettuce, tomato, cucumber, eggplant, spinach, pepper, oregano

Honing your nutrient program

- Measure nutrients regularly in raw irrigation water, nutrient solution, and plant tissue
- Be the detective, adjust based on nutrient accumulation/depletion
- Work with a university extension specialist or fertilizer supplier

Take home message for supplying nutrients

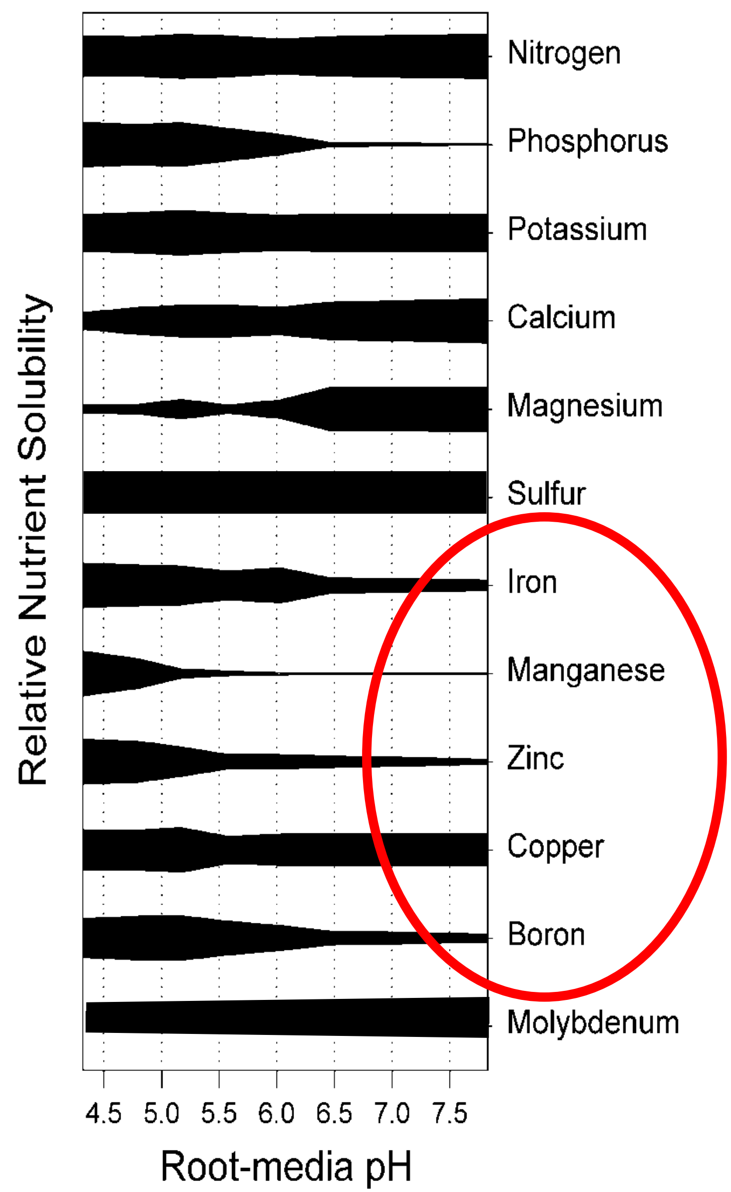
- Provide all the essential nutrients in a moderate amount

- Use electrical conductivity or total dissolved solids as an on-site test

- Use complete nutrient analysis at a lab when problems arise, fine-tune nutrient recipe

pH of the nutrient solution ("solution-pH") affects…

- Nutrient solubility
- Uptake by roots
- Plant health
  - Too much = toxicity
  - Too little = deficiency



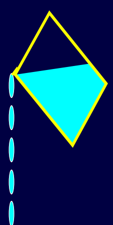
J. Peterson

Several factors affect solution-pH

Nitrate NO_3^-

Ammonium NH_4^+

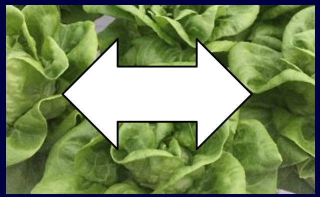
Alkalinity



Acid

Species

Arugula



Lettuce

BASIC Factors (Raise pH)

pH balance

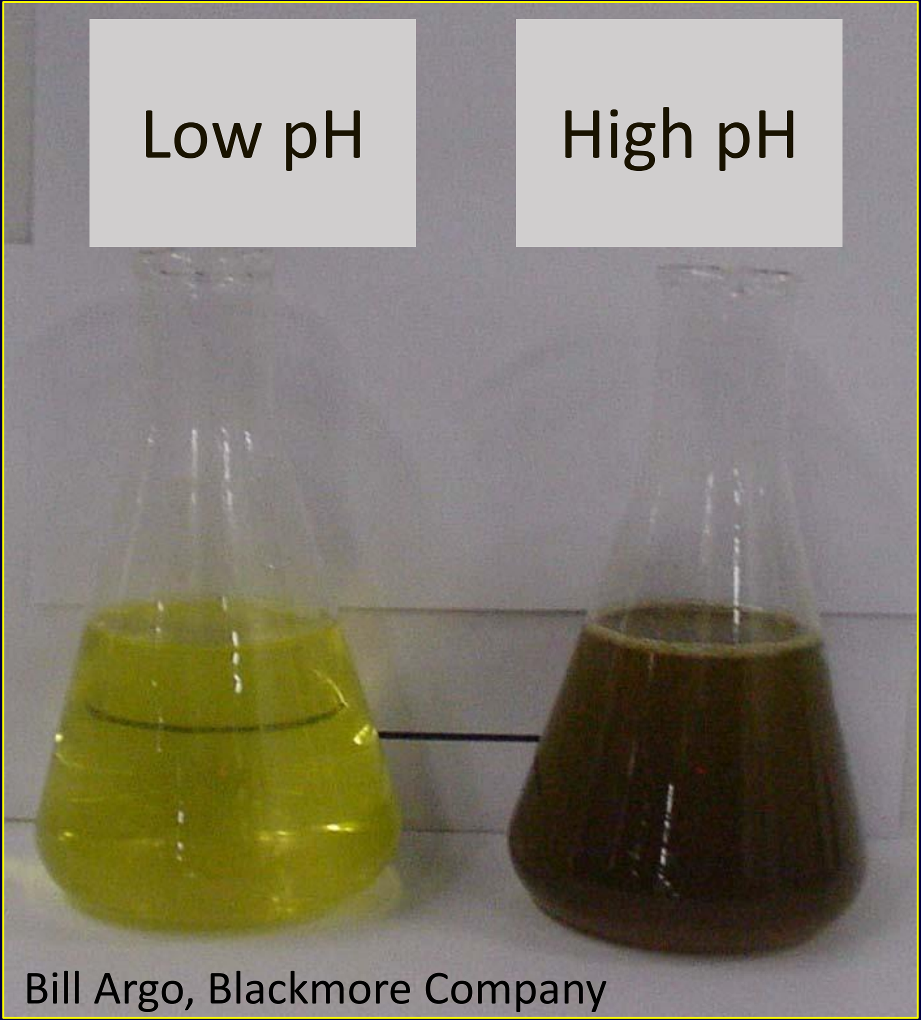
ACID Factors (Lower pH)

Paul Fisher, Univ. of Florida

Water quality: Solution-pH

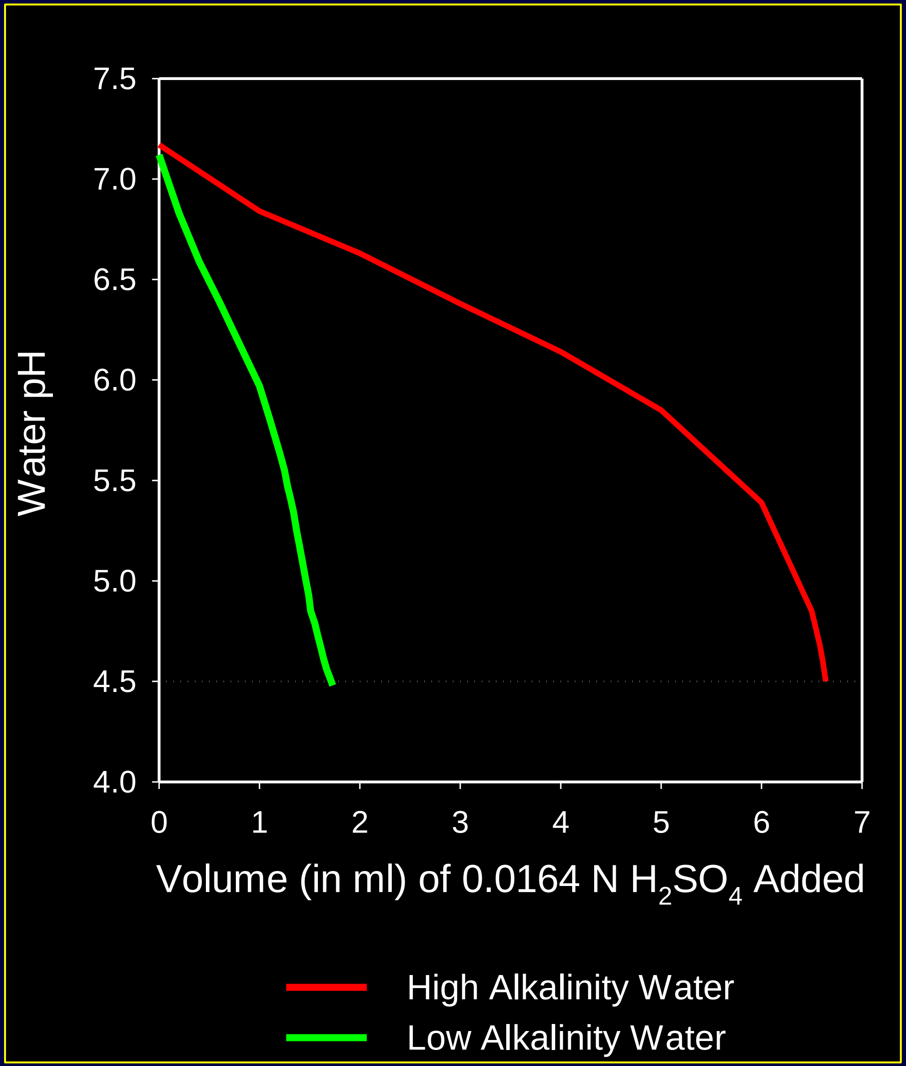
- Can be measured with a pH meter
  - Neutral = 7
  - Acid < 7
  - Basic > 7

- Affects solubility of nutrients in the nutrient solution



Water quality: Alkalinity raises solution-pH

- Alkalinity is <u>NOT</u> measured with a pH meter
- Often termed bicarbonates
- Think dissolved lime

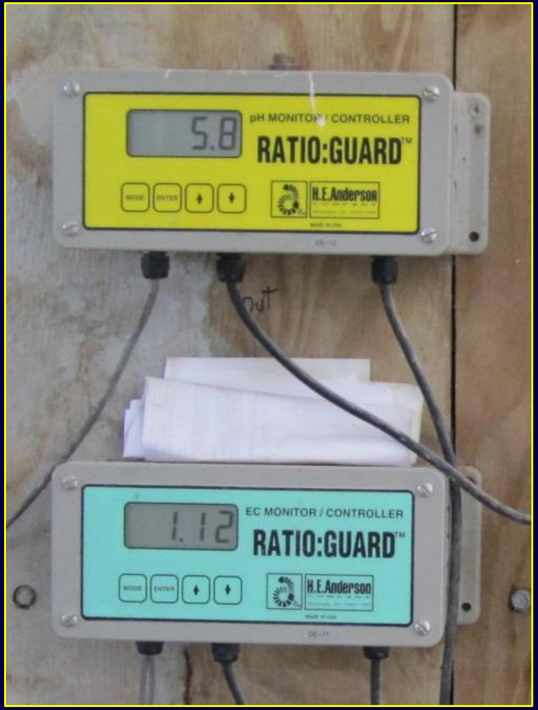


Different alkalinity units

Milli-Equivalents alkalinity (mEq/L)	ppm alkalinity ($CaCO_3$ or CCE)	ppm bicarbonate (HCO_3^-)
1	50	61
2	100	122
3	150	183
4	200	244
5	250	305

How much acid to control alkalinity?

- Online AlkCalc from the University of New Hampshire
- Sulfuric (adds S)
- Phosphoric (adds P)
- Nitric (adds N)
- Citric acid (organic)
- Acidify water down to a pH of ~ 6

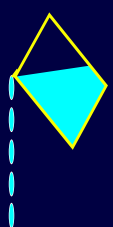


Several factors affect solution-pH

Nitrate NO_3^-

Ammonium NH_4^+

Alkalinity



Acid

Species

Arugula

Lettuce

BASIC Factors (Raise pH)

pH balance

ACID Factors (Lower pH)

P. Fisher, Univ. of Florida

GUARANTEED ANALYSIS F1313

Total nitrogen (N)	16%
3.50% ammoniacal nitrogen	
12.50% nitrate nitrogen	
Available phosphate (P_2O_5)	4%
Soluble potash (K_2O)	17%
Calcium (Ca)	4%
Magnesium (Mg),	2.0%
2.0% water soluble magnesium (Mg)	
Boron (B)	0.0160%
Copper (Cu)	0.0090%
0.0090% chelated copper (Cu)	
Iron (Fe)	0.1000%
0.1000% chelated iron (Fe)	
Manganese (Mn)	0.0500%
0.0500% chelated manganese (Mn)	
Molybdenum (Mo)	0.0080%
Zinc (Zn)	0.0400%
0.0400% chelated zinc (Zn)	

Derived from: ammonium nitrate, monopotassium phosphate, potassium nitrate, calcium nitrate, magnesium nitrate, boric acid, iron EDTA, iron DTPA, iron EDDHA, manganese EDTA, zinc EDTA, copper EDTA, ammonium molybdate

Neutral: 0 lb. Calcium carbonate equivalent per ton.

Information regarding the contents and levels of metals in this product is available on the internet at: http://www.aapfco.org/metals.html

WARNING: This product contains Molybdenum (Mo) and may be harmful to ruminant animals foraging on grass where applications have been made

$$\frac{\text{3.5\% ammonium}}{\text{16.0\% total N}} = \text{22\% N in the ammonium form}$$

Neutral: 0 lb. Calcium carbonate equivalent per ton.

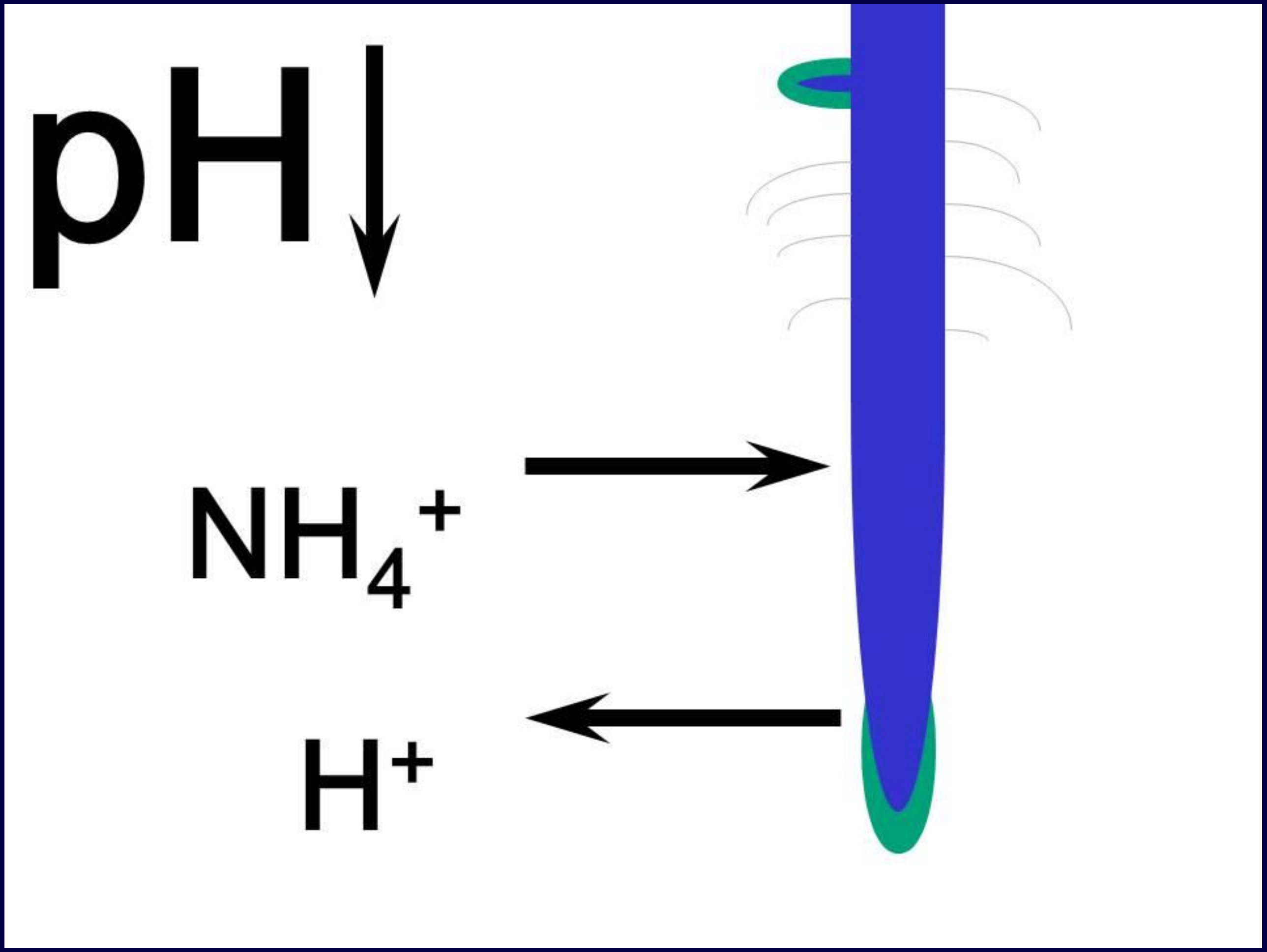
GUARANTEED ANALYSIS F1313

Total nitrogen (N) 16%

3.50% ammoniacal nitrogen

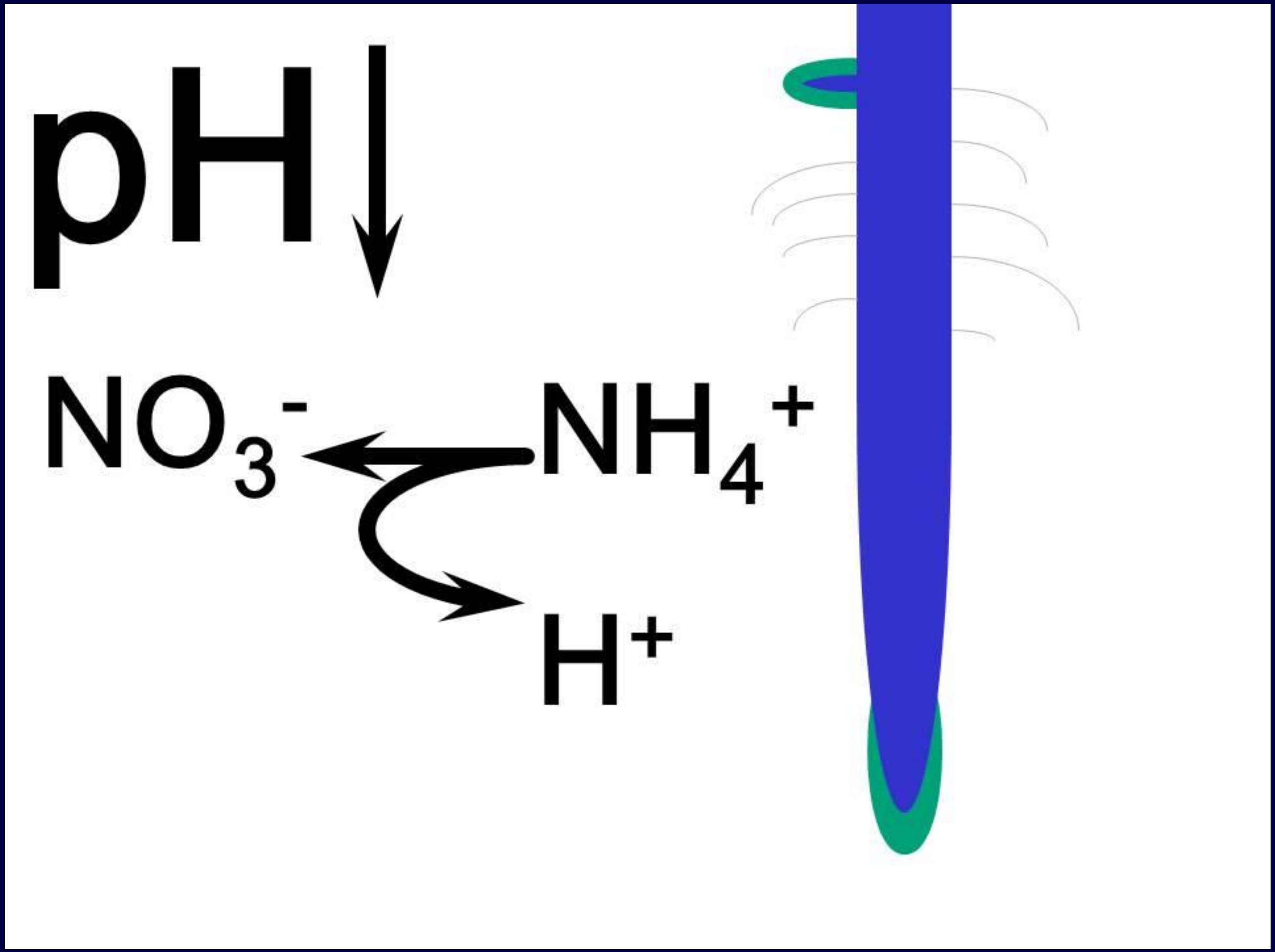
12.50% nitrate nitrogen

Ammonium (NH_4^+) nitrogen is an acid



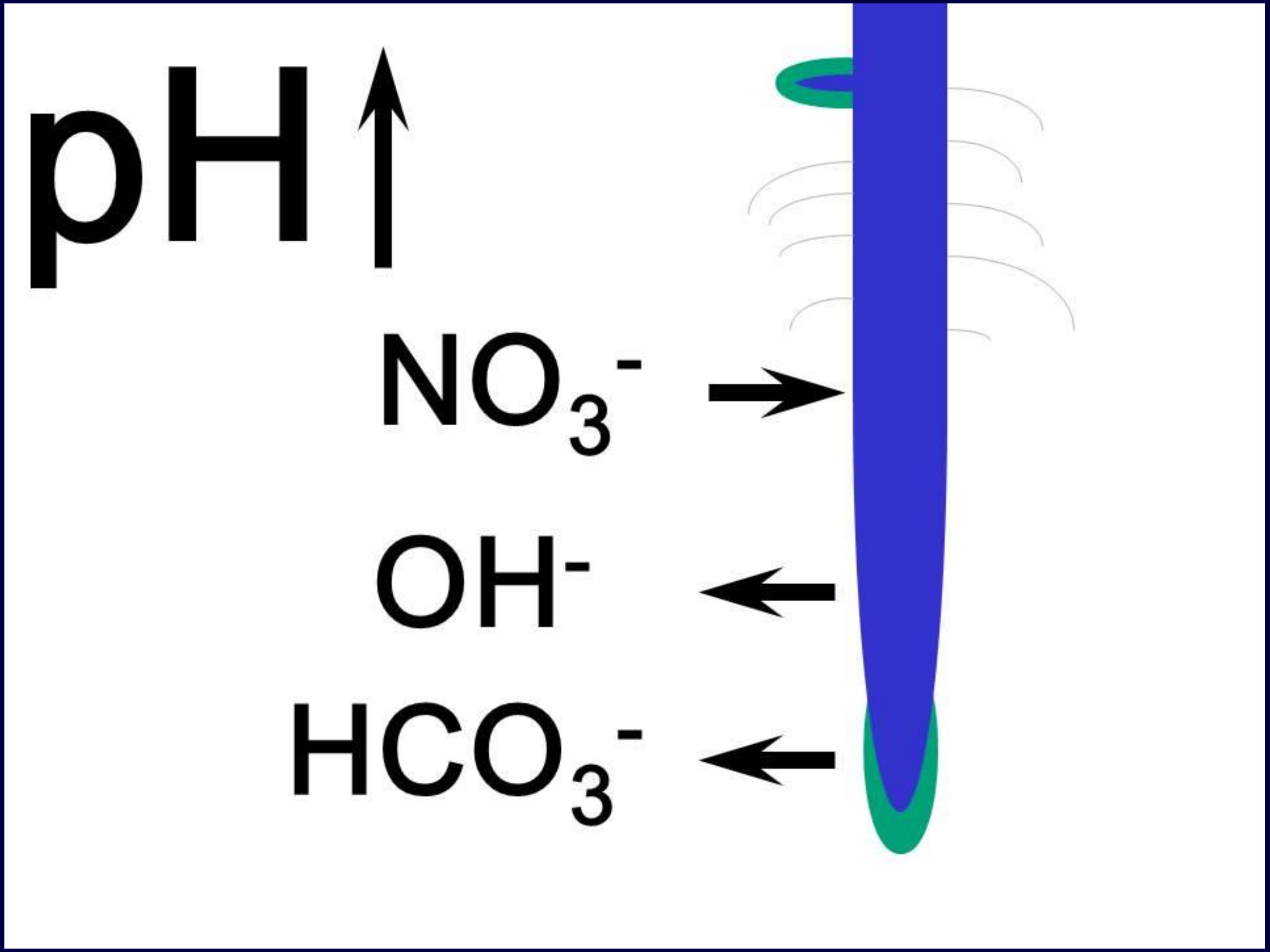
- Plant uptake (charge balance)

Ammonium (NH_4^+) nitrogen is an acid



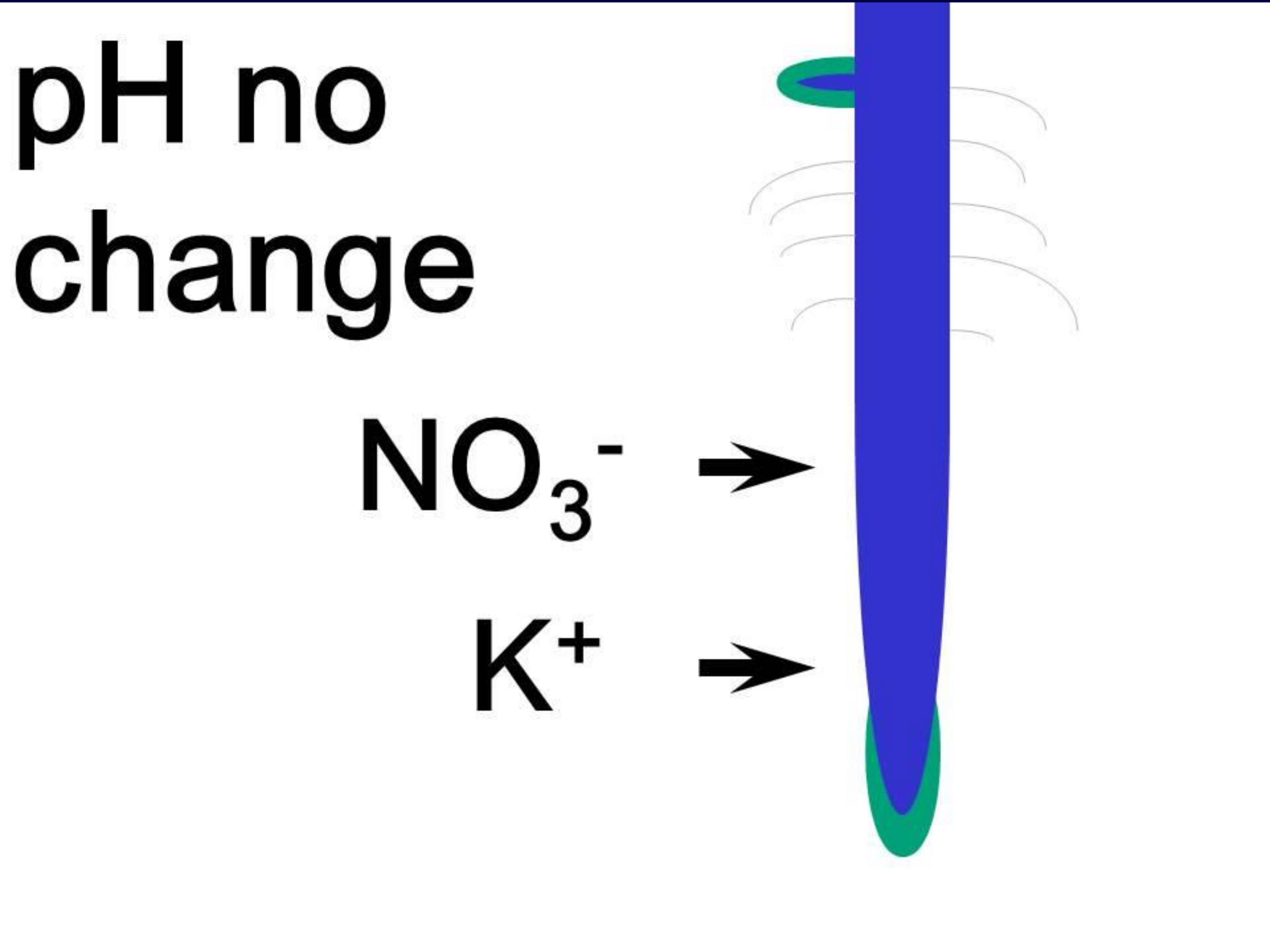
- Nitrification by soil microbes

Nitrate (NO_3^-) nitrogen is a base



- Weakly basic

Uptake does not always change pH



- Balanced uptake (charge balance)

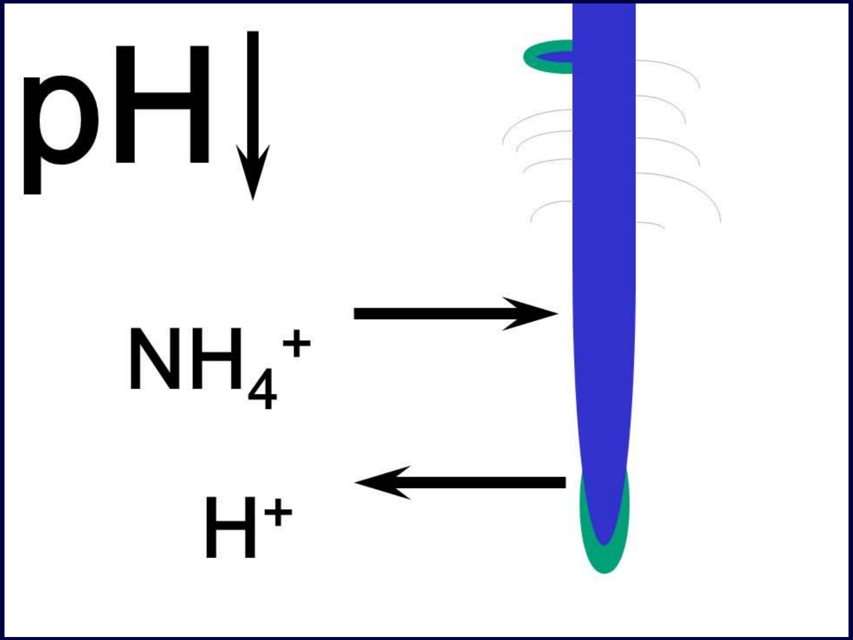
Ammonium is a stronger acid than nitrate is a base

For example, ammonium nitrate (NH_4NO_3) is 50% ammonium (NH_4^+) and 50% nitrate (NO_3^-)

Ammonium nitrate is acidic because…

- Many plants favor NH_4^+ over NO_3^-, releasing acid

- Nitrification

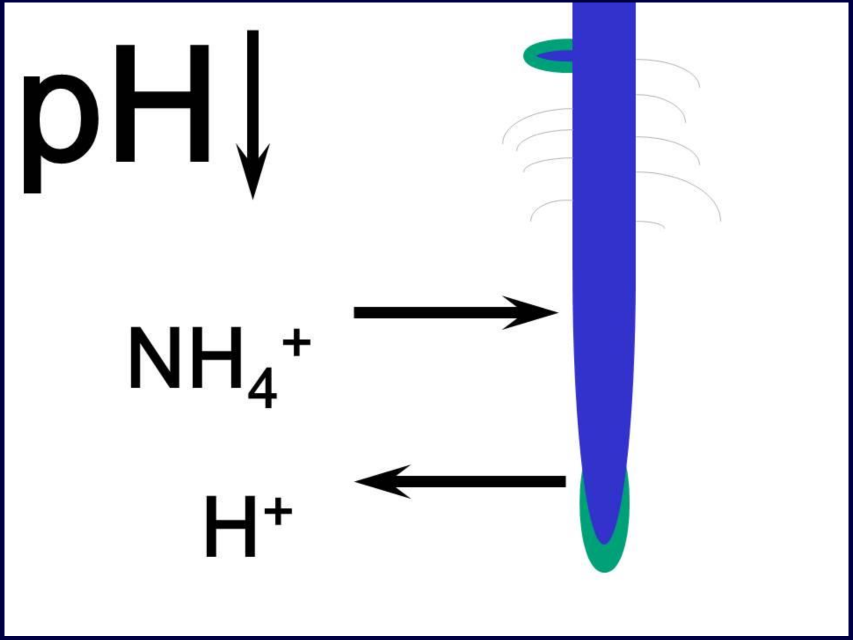


Potassium nitrate is a base

Potassium nitrate (KNO_3) is 50% potassium (K) and 50% nitrate (NO_3^-)

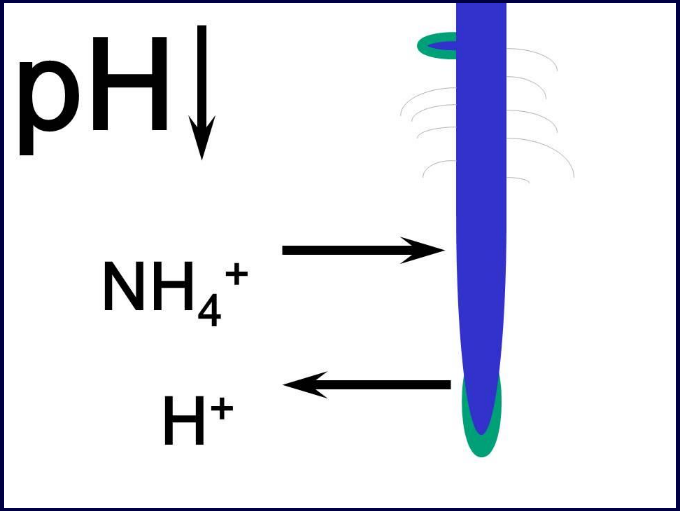
KNO_3 is basic because…

- Roots take up NO_3^- and efflux base

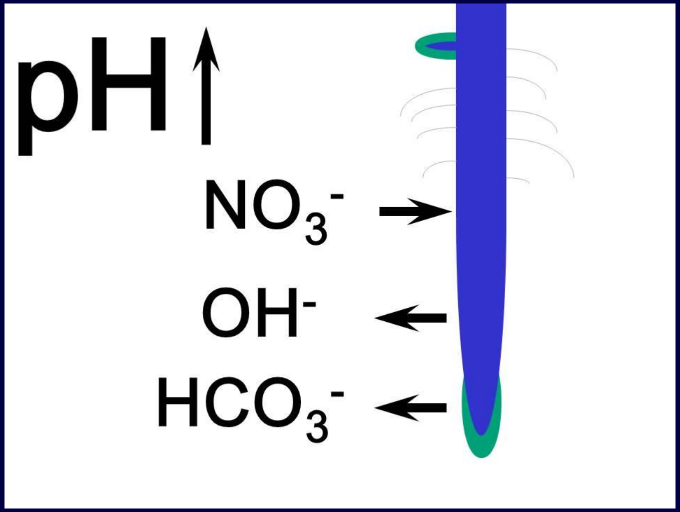


Did you know: Plant species affect the pH of the nutrient solution?

Species that prefer positive charge nutrients are acidic



Species that prefer negative charge nutrients are basic



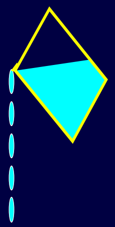
Increasing ammonium makes plants more acidic

Several factors affect solution-pH

Nitrate NO_3^-

Ammonium NH_4^+

Alkalinity



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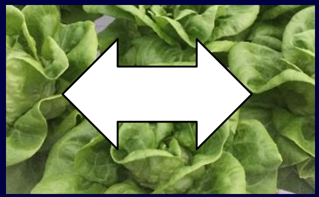


Lettuce

BASIC Factors (Raise pH)

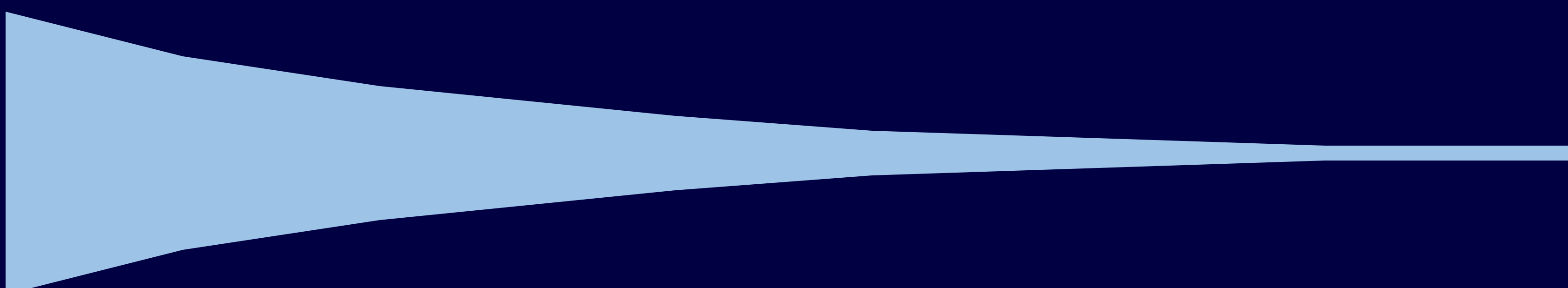
pH balance

ACID Factors (Lower pH)

P. Fisher, Univ. of Florida

	0% ammonium-N (100% nitrate-N)	20% ammonium-N (80% nitrate-N)	40% ammonium-N (60% nitrate-N)
Arugula	Strong basic effect (raised pH rapidly)	Basic effect (raised pH)	Basic effect (raised pH)
Pepper	Basic effect (raised pH)	Basic effect (raised pH)	Acidic effect (lowered pH)
Spinach	Basic effect (raised pH)	Basic effect (raised pH)	Acidic effect (lowered pH)
Eggplant	Basic effect (raised pH)	Neutral effect (pH was stable)	Acidic effect (lowered pH)
Tomato	Basic effect (raised pH)	Neutral effect (pH was stable)	Acidic effect (lowered pH)
Basil	Basic effect (raised pH)	Acidic effect (lowered pH)	Strong acidic effect (lowered pH rapidly)
Lettuce	Basic effect (raised pH)	Acidic effect (lowered pH)	Strong acidic effect (lowered pH rapidly)
Cucumber	Neutral effect (pH was stable)	Acidic effect (lowered pH)	Strong acidic effect (lowered pH rapidly)

Effects of pH on iron solubility

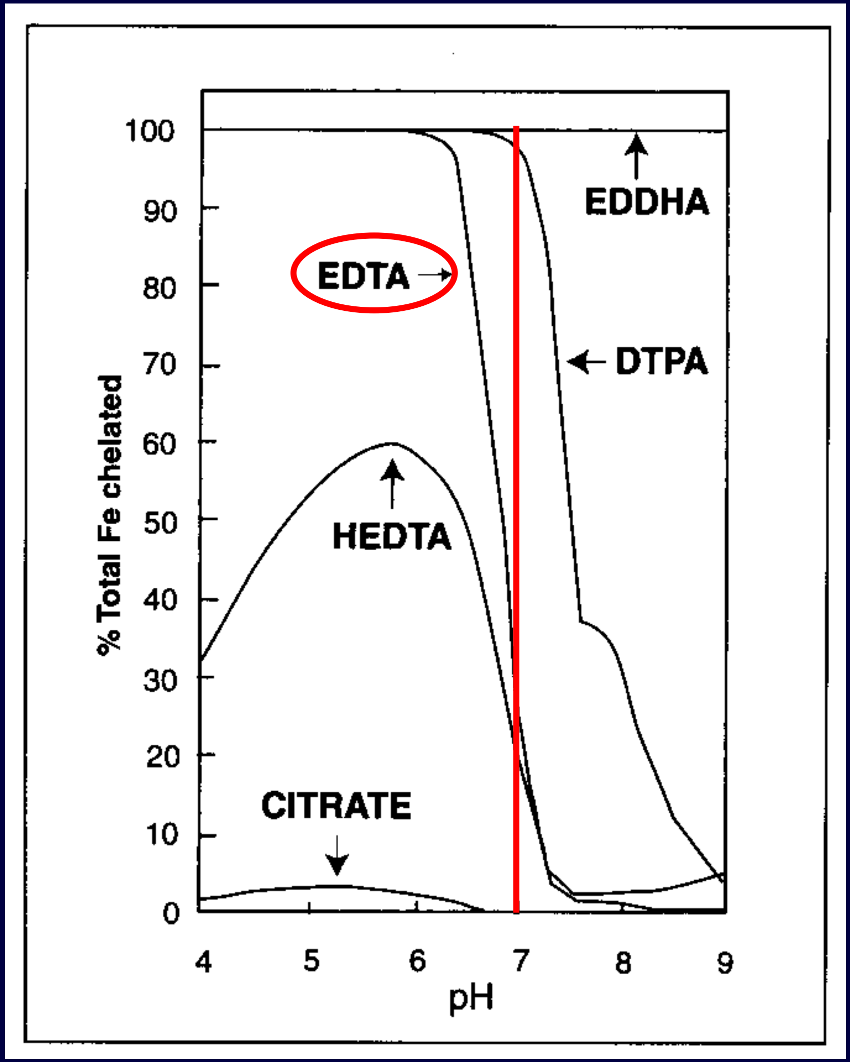


pH 4
Highly soluble
Fe^{3+}, Fe^{2+}

pH 7
Highly insoluble
$Fe(OH)_3$

Iron solubility

- Synthetic chelates
- $FeSO_4$ and Fe-EDTA used on a continual basis
- Fe-DTPA and Fe-EDDHA used to correct iron deficiency



Norvell, 1991

pH management strategies for hydroponics

- Vary ammonium:nitrate ratio for different crops and alkalinity

Concept

- Plants that are basic (arugula) need more ammonium
- If pH is low, use more nitrate (basic)
- If pH or alkalinity is high, use more ammonium (acid)

Potential downsides

- Need for multiple fertilizer recipe
- Possible ammonium toxicity, soft growth
- Calcium levels may decrease as ammonium increases, blossom end rot and tip burn

pH management strategies for hydroponics

- For recirculating hydroponics, have 1 tank for multiple species rather than individual tanks

<u>Concept</u>

- Simple system
- pH and fertilizer uptake differences evened out

<u>Potential downsides</u>

- May be to simple
- Not able to optimize fertilizer EC and pH needs for crops

pH management strategies for hydroponics

- If root zone pH is high, inject mineral acid (sulfuric, nitric, phosphoric) or citric acid into the nutrient solution

Concept

- Acid neutralizes alkalinity (raises pH)
- University of New Hampshire Alk Calc
- Automated acid dosing controller (doses small amounts)

Potential downsides

- Need chemical injector, inline pH meter, safety training
- Changes nutrients (for example, nitric acid adds N)
- May over or under-shoot

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pH management strategies for hydroponics

- If solution pH is low, and irrigation water alkalinity is naturally high, turn off the acid injector

Concept

- Use natural water alkalinity in fresh water to raise pH

Potential downsides

- Not an option if irrigation water alkalinity is low (for example, reverse-osmosis water)

pH management strategies for hydroponics

- When solution pH is low, and irrigation water alkalinity is low, increase alkalinity with basic chemicals such as potassium bicarbonate ($KHCO_3$) and potassium carbonate (K_2CO_3)

Concept

- Alkalinity raises pH and buffering
- 1.3 ounces per 100 gal $KHCO_3$ gives 50ppm alkalinity
- 0.9 ounces per 100 gal K_2CO_3 give 50ppm alkalinity

Potential downsides

- Need chemical injector, inline pH meter, safety training
- Changes nutrients balance
- May over or under-shoot

pH management strategies for hydroponics

- Inline pH meter plus regular manual pH testing every 1 to 2 weeks

Concept

- Monitor and act before plants are stressed
- Manual pH meter is a check that inline pH meter is working correctly

Potential downsides

- Need trained labor, inline and manual pH meters
- Need maintenance and calibration schedule

pH management strategies for hydroponics

- Use chelated iron-DTPA or iron-EDDHA fertilizers for crops sensitive to high pH, rather than iron-DTPA or iron sulfate (which are less soluble at high pH)

Concept

- Supplementing micronutrients compensates for decreases solubility at high pH. 1 to 3ppm of iron is typically required on a constant basis

Potential downsides

- Increased fertilizer cost
- pH also affects other micronutrients for nutrient imbalance (e.g. boron)

pH management strategies for hydroponics

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Potential downsides

- Increased fertilizer cost
- pH also affects other micronutrients for nutrient imbalance (e.g. boron)

pH management strategies for hydroponics

- Periodically dump nutrient solution

Concept

- Avoids major drift in nutrient level and pH over time

Potential downsides

- Wasteful, increasing fertilizer cost and possible environment impact

Take away messages for pH

- Keep pH between 5.5 and 6.4, and you should be fine
- Use a pH meter for on-site testing
- Use a commercial lab for complete nutrient analysis when problems arise