Nutrient and rootzone management in hydroponics

Chieri Kubota
Ohio Controlled Environment Agriculture Center
The Ohio State University

Horticultural Research Institute

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Optimizing rootzone environment is a key for high crop productivity

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Characteristics of root-zone environment

- **Chemical properties**
  - pH; EC; O_2 availability; ionic compositions (micro/macro nutrients, chlorine, etc.); alkalinity; *cation exchange capacity**
- **Physical properties**
  - Volume; container geometry; surface color; porosity* (air porosity and total porosity); water content*; hydraulic conductivity*
- **Biological properties**

*Soilless substrate properties

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pH, EC, and ionic concentrations

- Critical parameters that need to be maintained in an optimum range through the crop production
- Affect plant nutrient uptake
- Affected by plant nutrient uptake

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Water pH

- Measurement of the concentration of hydrogen ions (H^+) in a solution.

$$pH = -\log_{10}[H^+]$$

[H^+]: Molar concentration of hydrogen ions (mol/L)

- More acidic = lower values

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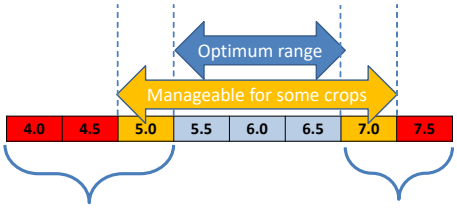
pH



- *Toxicity** of micronutrient(s) in substrate culture
- Deficiency of macronutrients (cations)
- Deficiency of micronutrient(s)

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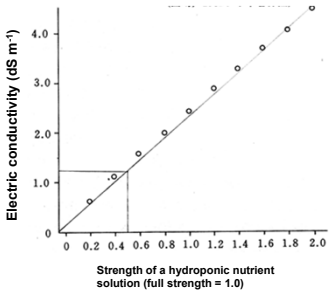
EC – Electrical Conductivity

- EC indicates the strength (overall concentrations) of nutrient solution
- Unit for EC
  dS m^{-1} (= mS cm^{-1} = 1,000 µS cm^{-1})
- Typical nutrient solution used in greenhouses has 1-3 dS m^{-1} EC.
- High EC means high salt concentrations
- Can be converted to TDS (total dissolved solids; ppm or mg/L) if the formula is known.



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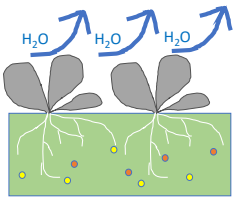
Mass balance to understand rootzone EC

- Hydroponics rootzone management includes monitoring rootzone EC and pH.
- When plants take up more water and leave nutrients behind, the **rootzone EC increases**.
- When plants take up nutrients at a greater rate than water, the **rootzone EC decreases**.
- Changes in EC cannot tell which nutrients are accumulating or depleting (lab analysis is needed – once in 2 weeks recommended for recirculating hydroponics).



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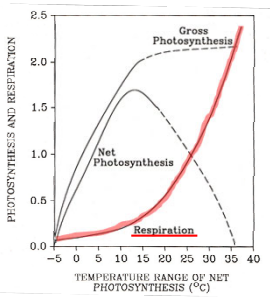
Dissolved oxygen (DO) and root respiration

- Roots absorb O_2 and release CO_2 to extract energy, critical for both maintaining roots and supporting new root growth
- Some nutrient uptake requires energy (respiration)
- Roots in hydroponics take up dissolved oxygen (DO)
- Respiration rate is limited at low DO conc.
- Respiration rate increases with increasing temperature



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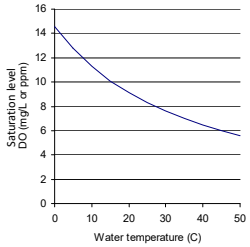
Dissolved oxygen (DO) saturation concentration declines with water temperature



- ✓ At high temperatures, DO tends to be lower due to high root respiration and low saturation points.
- ✓ DO should NOT be below 5 ppm in DWC

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Essential elements added to the nutrient solution

- Macronutrients
  Primary: N, P, K,
  Secondary: Ca, Mg, S
- Micronutrients
  Fe, Mn, Zn, Cu, B, Mo, Cl
- Essential but not applied as fertilizers
  C, H, O

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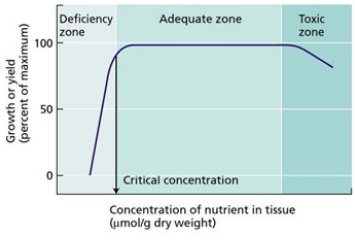
Nutritional disorders

- Deficiency – less nutrient is available than required in tissue
- Toxicity – Excessive amount of nutrient in tissue



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Cations and anions in nutrient solution

- Cations (positively charged ions)
  Ammonium (NH_4^+), Potassium (K^+), Calcium (Ca^{2+}), Magnesium (Mg^{2+}), Iron (Fe^{2+}, Fe^{3+}), Manganese (Mn^{2+}), Zinc (Zn^{2+}), Copper (Cu^{2+})
- Anions (negatively charged ions)
  Phosphorus (HPO_4^{2-}, $H_2PO_4^-$), Nitrate (NO_3^-), Sulfur (SO_4^{2-}), Boron (BO_3^{2-}), Molybdenum (MoO_4^{2-}), Chloride (Cl^-)

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Cation competition (antagonism)

- Typically, between Ca^{2+}, Mg^{2+}, and K^+
- High concentrations of NH_4^+ or H^+ can also cause competition with other cations (Ca^{2+}, Mg^{2+}, and K^+)
  - Increasing cations should be carefully done (e.g., maintaining ratios)

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Effects of pH on ion uptake

- pH affects forms of available ions
  - e.g., $H_2PO_4^-$ vs. HPO_4^{2-}
- pH affects solubility of salts
- pH affects individual ion uptake
- Ion uptake affects pH of the solution.
  - Cation (+) uptake causes decrease in pH.
  - Anion (-) uptake causes increase in pH.

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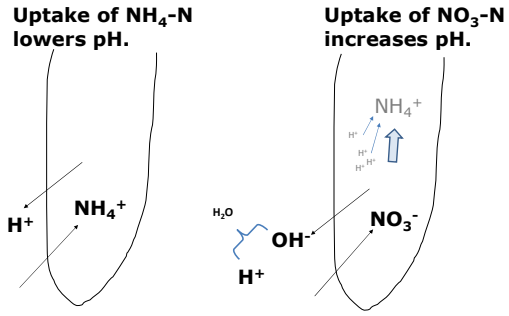

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Fertilizer selection

- Fertilizer **N-P-K information is not helpful** for selecting hydroponic formula (ppm or mM of 13-14 elements)
- Select high quality hydroponic grade
- Pre-mixed fertilizers for convenience
- Mixing at least two fertilizers (Part A and Part B) into water (almost all in one plus Ca-containing fertilizer, e.g. $Ca(NO_3)_2$)
- Formula should be crop and growth stage specific

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Pros and cons of making up vs. using pre-mix fertilizers

Your options	Pros	Cons
Make up your own based on a crop-specific recipe (developed by researchers)	**Flexibility** You can adjust as you need based on your water quality, acid use, and crop response. **Recirculation** This will allow recirculation of nutrient solution. **Costs** Lower costs.	**Availability** Some salts are difficult to get at small quantity. **Human errors** Risk of making careless mistakes in mixing many salts for stock solutions
Get a **pre-mix** fertilizer with necessary adjustment (with one or more additional salts)	**Convenience** Simpler calculations to mix needed fertilizers (lower risk of careless errors). *Custom mix* is optional for additional costs to accommodate recirculation need (However, it needs to re-adjust the formula frequently).	**Limitation** You may need to compromise, hoping that your recipe works as well as the original recipe. **More waste** Pre-mix users must dump nutrient solutions more often (= environmental issue)

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Crop specific nutrient solution examples
(major macronutrients, EC, and pH are shown as examples)

Nutrient	Tomato[Z] (stage 3)	Cucumber[Y]	Strawberry[X]	Lettuce[W]
NO_3-N	190	190	111	154
NH_4-N	0	18	10	0
P	47	39	30	43
K	350	270	156	170
Ca	200	185	86	171
Mg	60	33	22	34
pH	5.5-6.5	5.5-6.5	5.5-6.5	5.5-6.5
EC	2.0-3.0	2.0-2.5	1.0-1.5	2.0

[Z] Univ. of Arizona formula; [Y] Sonneveld and Straver (1992); [X] Tochigi formula; [W] Univ. of Arizona formula (modified to EC = 2.0)

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Hydroponic nutrient solution example: tomato

Nutrient	Stage 1 (ppm)	Stage 2 (ppm)	Stage 3 (ppm)	Micro (ppm)	
	Up to 2nd truss	2nd to 5th	After 5th truss	All stages	
N	90	120	190	B	0.34
P	47	47	47	Mn	0.55
K	144	350	350	Cu	0.05
Ca	144	160	200	Mo	0.05
Mg	60	60	60	Zn	0.33
S	116*	116*	116*	Fe	2.00
Cl	89*	89*	89*		

*Not critical requirements (much lower levels are acceptable)

1 ppm = 1 mg/L

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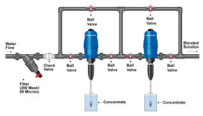
Stock solution formula for
Stage 3 tomato nutrient solution (an example with 2-3 injectors)

Tank 1		
Macronutrients	g/l	g/l for 100x
KNO_3	0.521	52.1
KH_2PO_4	0.204	20.4
$MgSO_4$-$7H_2O$	0.6	60
K_2SO_4	0.211	21.1
Micronutrients	**mg/l**	g/l for 100x
$Na_2B_4O_7$-$10H_2O$	3.09	0.309
$MnSO_4$	1.69	0.169
$CuSO_4$-$5H_2O$	0.195	0.0195
Na_2MoO_4-$2H_2O$	0.125	0.0125
$ZnSO_4$-$7H_2O$	1.45	0.145

Tank 2		
Macro/Micronutrients	g/l	g/l for 100x
$Ca(NO_3)_2$	0.79	79
$CaCl_2$	0.167	16.7
Fe 330 Sprint	0.02	2

Additional injector (Tank 3) is for adding diluted acid (Nitric acid etc.) for pH adjustment



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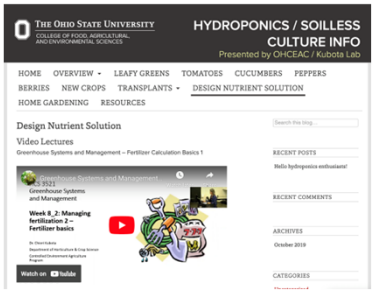
Useful resources: https://u.osu.edu/hydroponics

"Design Nutrient Solution" in OSU Hydronic Information Website



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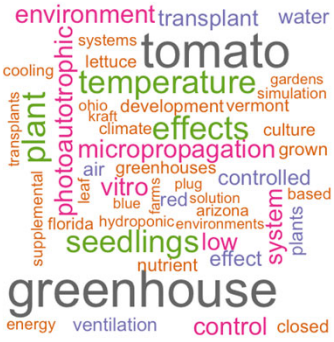
KUBOTA LAB
Controlled Environment Agriculture

OHCEAC

Email: Kubota.10@osu.edu

Thank you!



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