Environmental Control in PFAL
Nutrients & Water

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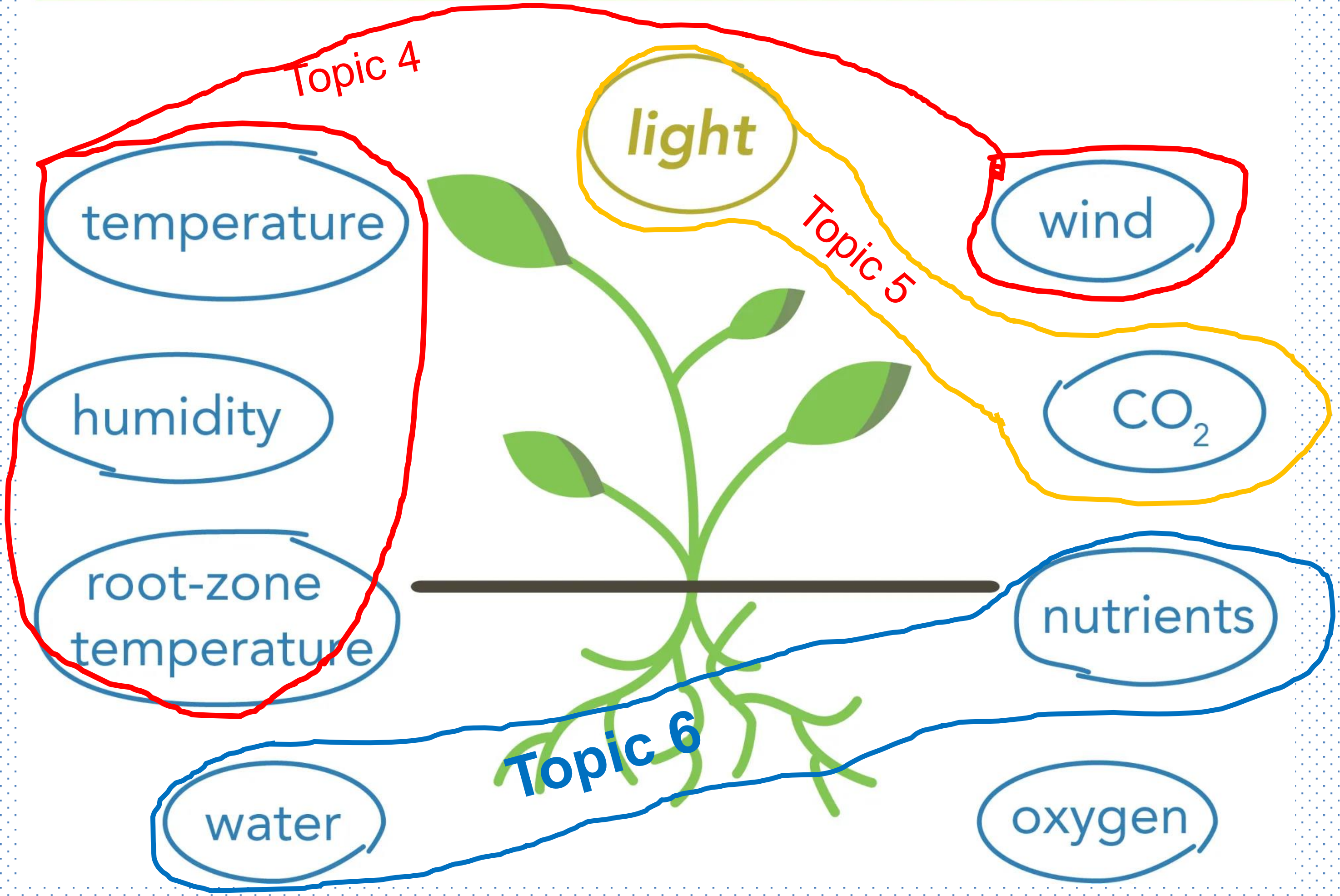
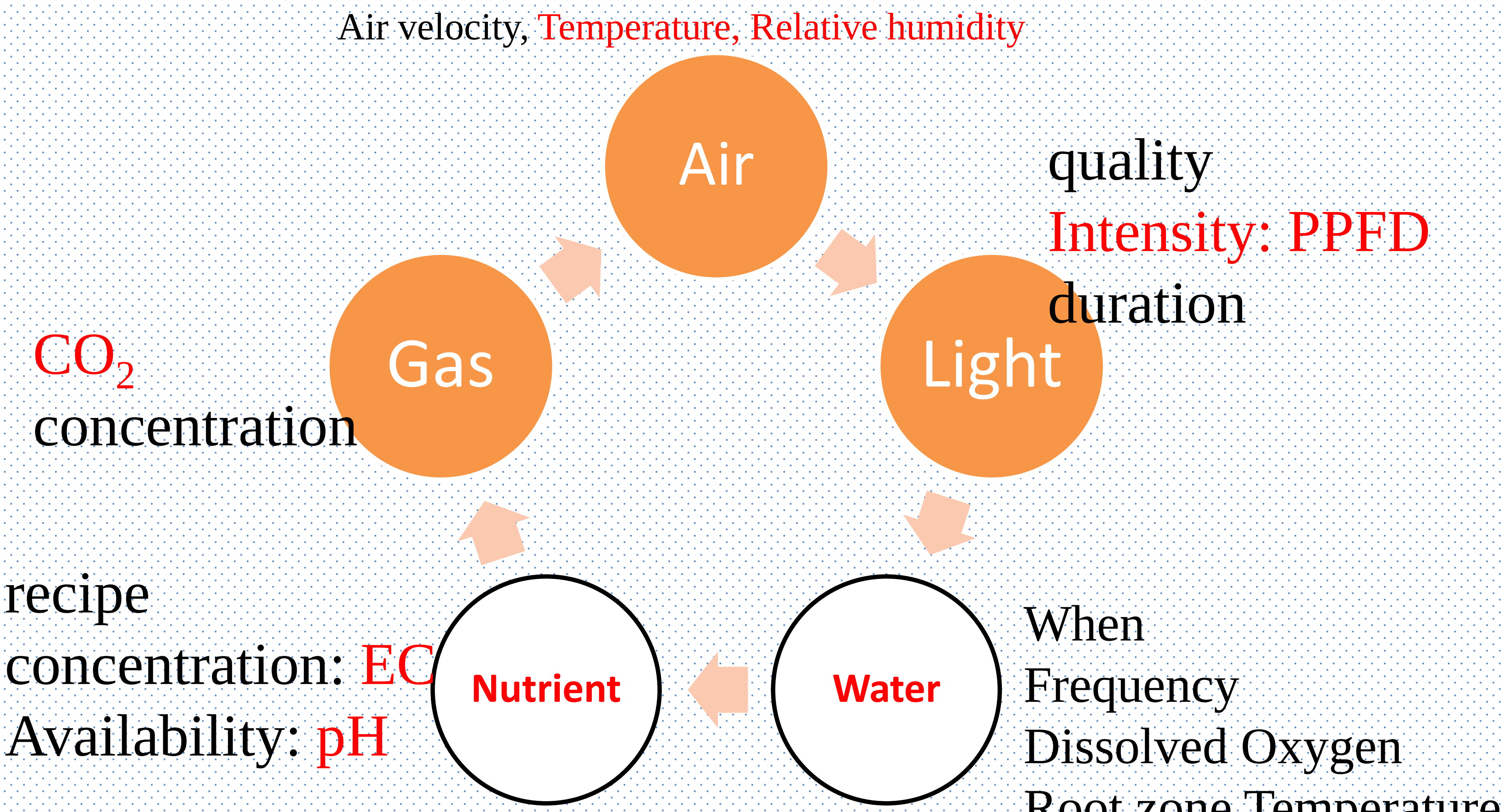
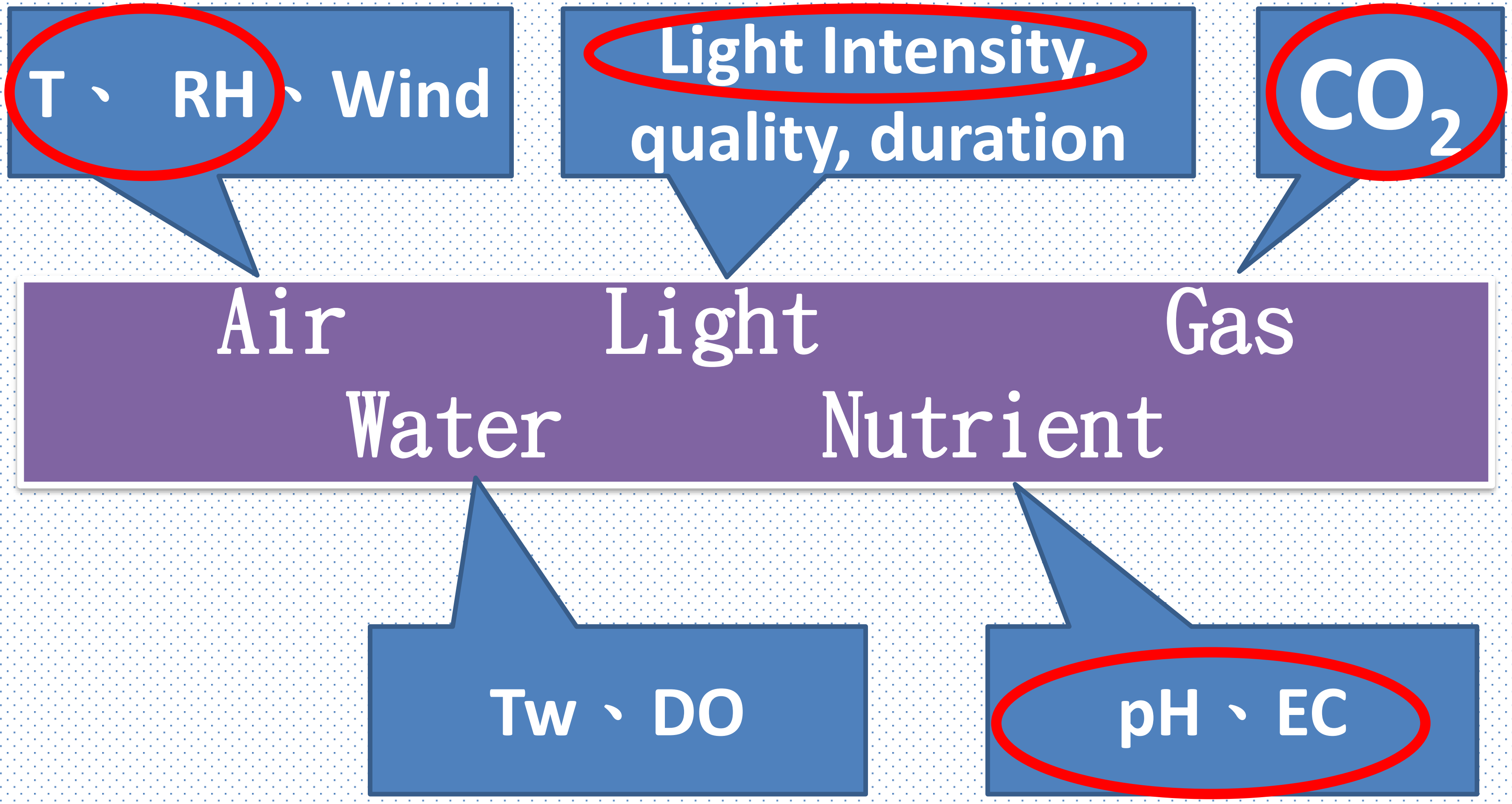
9 KEY VARIABLES FOR CROP PRODUCTION



Five governing factors in PFAL



Must have monitoring items in PFAL

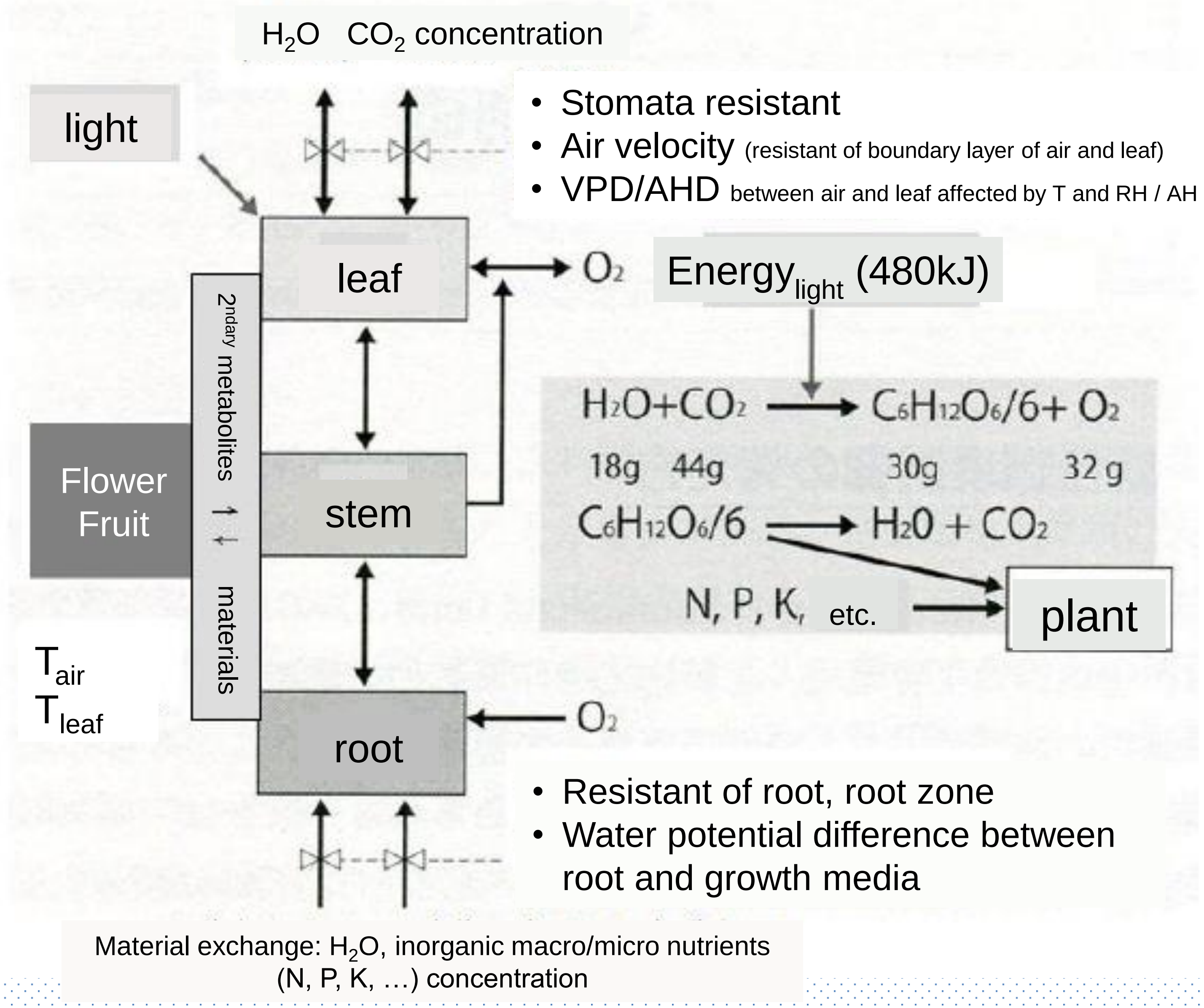


Factors affecting plant growth and development

	Temperature	Light	Humidity	CO_2	Nutrient+H_2O
photosynthesis	+	+++	+	+++	
respiration	+++				
Absorb. of nutrient+H_2O	+	+++	+++	+	+++
Transpiration	+	+++	+++	+	++
Development (leaf,flower formation)	+++				
booming	++	++		+	
fruiting	++	++	++	+	
Distribution of sugar	+++	++			
Formation of organ	++		+		++
Extension of cell/organ	+++	++	+		+
Mature of fruit	+++	++			

(Houter, 2006)
Modified by Fang, 2018

Degree of influence: +++ large, ++ medium, + small
Suitable range in between 15 ~ 30 ^{o}C



H2O CO2 concentration
light
Stomata resistant
Air velocity (resistant of boundary layer of air and leaf)
VPD/AHD between air and leaf affected by T and RH / AH
leaf
O2
Energylight (480kJ)
2ndary metabolites
materials
Flower
Fruit
stem
H2O+CO2 → C6H12O6/6+ O2
18g 44g 30g 32 g
C6H12O6/6 → H20 + CO2
N, P, K, etc.
plant
Tair
Tleaf
root
O2
Resistant of root, root zone
Water potential difference between root and growth media
Material exchange: H2O, inorganic macro/micro nutrients
(N, P, K, …) concentration

Outline

What is hydroponics and how does it works?

Preparation of nutrient solution

- Materials / Device
- Recipes
- Unit conversion

pH, EC

Management

pH

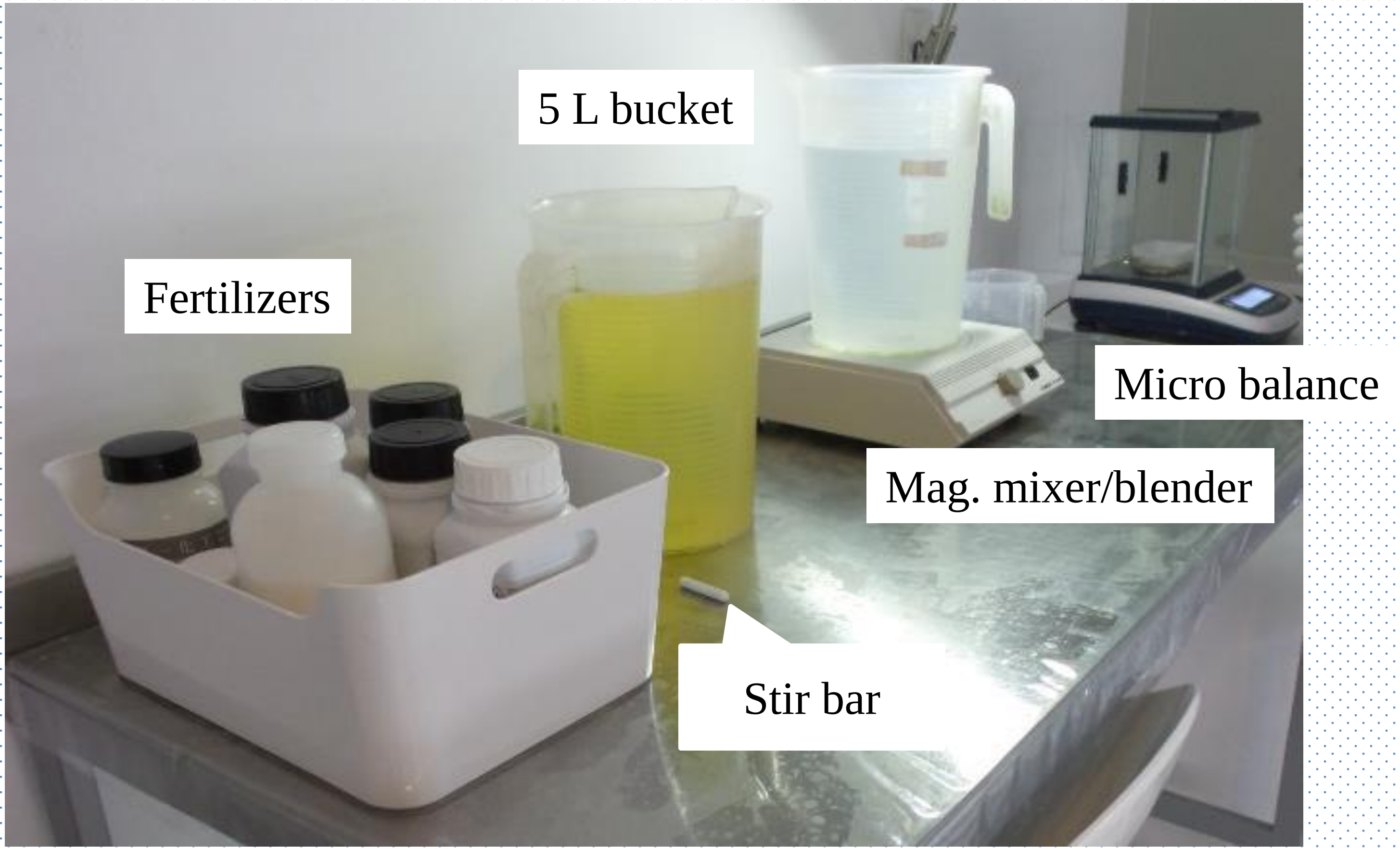
Adjustment

Hydroponic systems

Literature Review

All about hydroponics

Materials and Device



Related Equipment

Balance:

- Micro-elements: 0.001 g grade (precise scale)
- Macro-elements: 0.1 g grade

- blender

Macro elements of Yamazaki formula for various crops

1000 L nutrient solution

養液配方 (g)	KNO_3	$Ca(NO_3)_2$ $4H_2O$	$MgSO_4$ · $7H_2O$	NH_4 H_2PO_4	Fe · EDTA	成分濃度 (mL/L)					EC (mS/cm)
						NO_3-N	K	Ca	P	Mg	
胡瓜	610	830	500	120	20	13.0	6.0	7.0	3.0	4.0	2.0
洋香瓜	610	830	380	155	20	13.0	6.0	7.0	4.0	3.0	2.0
西瓜	610	830	185	60	20	13.0	6.0	7.0	1.5	1.5	1.6
菠菜	300	470	250	80	20	7.0	3.0	4.0	2.0	2.0	1.1
番茄	400	360	250	80	20	7.0	4.0	3.0	2.0	2.0	1.1
草莓	310	240	125	60	20	5.0	3.0	2.0	1.5	1.0	0.7
甜椒	610	360	250	100	20	9.0	6.0	3.0	2.5	2.0	1.3
茄	710	360	250	120	20	10.0	7.0	3.0	3.0	2.0	1.5
Lettuce	400	240	125	60	20	6.0	4.0	2.0	1.5	1.0	0.8
茼蒿	810	470	500	155	20	12.0	8.0	4.0	4.0	4.0	2.0
蕪菁	510	240	125	60	20	7.0	5.0	2.0	1.5	1.0	0.9
鴨兒芹	710	240	250	190	20	9.0	7.0	2.0	5.0	2.0	1.6
柑桔	200	470	185	60	20	6.0	2.0	4.0	1.5	1.5	0.9
蕹菜	707	354	246	152	20	10.0	7.0	3.0	4.0	2.0	1.6

Stock solution for micro elements

dilute 10,000 times to use

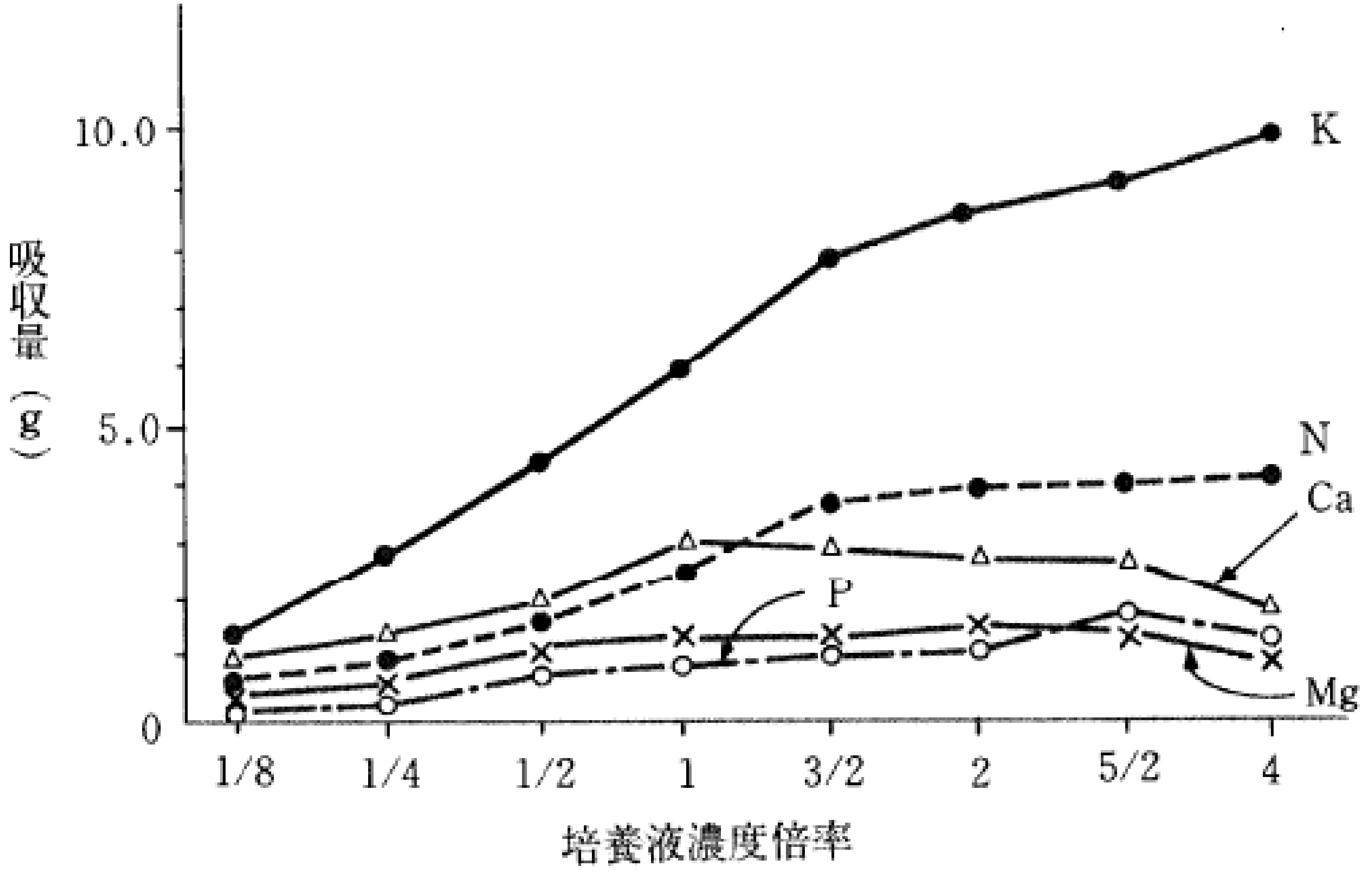
	concentration ppm	Fertilizer	concentration (mg/L)	Amount required in 10 L of stock solution（g）
B	0.5	硼酸 (H_3BO_3)	2.86	286
Mn	0.5	氯化錳 ($MnCl_2 \cdot 4H_2O$) or 硫酸錳（$MnSO_4 \cdot 4H_2O$）	1.81 or 2.13	181 or 213
Zn	0.05	硫酸鋅 ($ZnSO_4 \cdot 7H_2O$)	0.22	22
Cu	0.02	硫酸銅 ($CuSo_4 \cdot 5H_2O$)	0.08	8
Mo	0.01	鉬酸鈉 ($Na_2MoO_4 \cdot 2H_2O$)	0.025	2.5
Fe	3	EDTA-Fe		226

add 0.1 L (100 ml) of stock solution in 1 ton (1000 L) of nutrient solution

Concentration of recipe

- 1 S: 1 Strength
- ½ S: Half Strength
- ¾ S: 3 quarter Strength
- ½ or ¾ only represents concentration of macro elements. Concentration of micro elements should remain the same.
- Assuming using Yamazaki lettuce formula at $^3/_2$ S, means all the macro elements are $^3/_2$ times of 1 S， EC should be 0.8 x $^3/_2$ = 1.2 $mS.cm^{-1}$

Absorption of macro elements of Tomato under various strength of recipe concentration

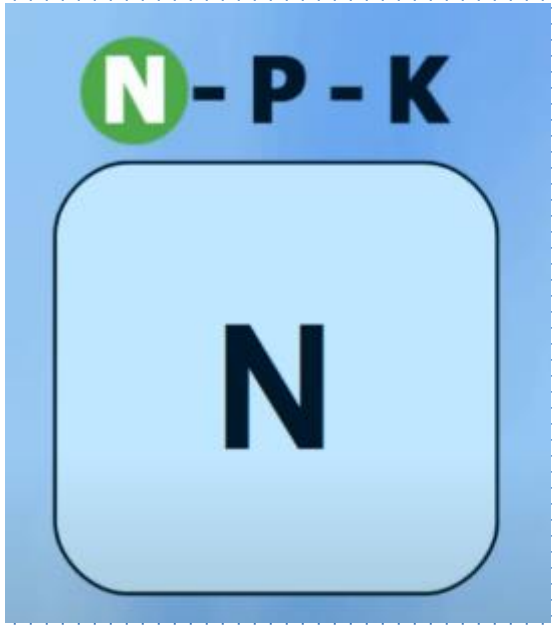


1 S：N 200, P 31, K 274, Ca 160, Mg 48 ppm

Tomato enjoy K and N

Too much K^+ inhibit absorption of Ca^{+2} and Mg^{+2}

Vegetative
Growth
Stage

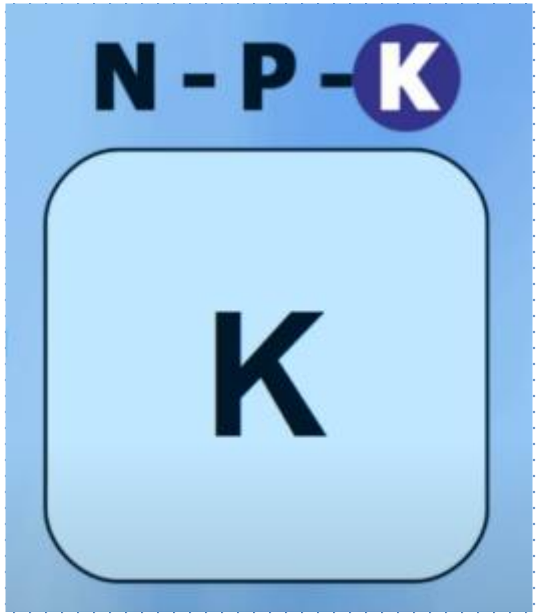


NO_3
Nitrate

NH_4
Ammonium

GROWTH ELEMENT

Heavy Fruiting
and
Flowering



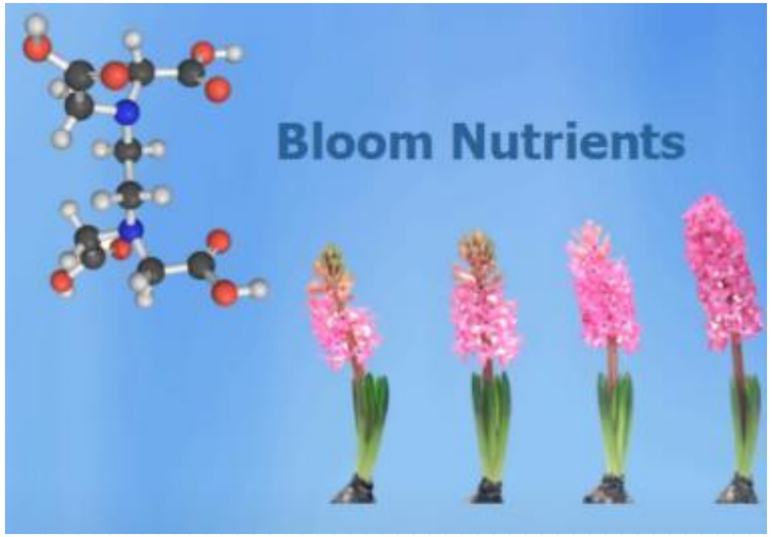
Add with
Bloom
Stimulants

HEALTH ELEMENT

Tomato Recipe

Table 6. Recipe for tomatoes in winter according to crop growth stage (units are ppm).	Weeks 0-6 Higher N, Ca and Mg for vegetative growth	Weeks 6-12 Lower N, higher K for reproductive growth	Week 12+ Maintain balance of vegetative / reproductive growth
Nitrogen (N)	224	189	189
Phosphorus (P)	47	47	39
Potassium (K)	281	351	341
Calcium (Ca)	212	190	170
Magnesium (Mg)	65	60	48
Iron (Fe)	2.00	2.00	2.00
Manganese (Mn)	0.55	0.55	0.55
Zinc (Zn)	0.33	0.33	0.33
Boron (B)	0.28	0.28	0.28
Copper (Cu)	0.05	0.05	0.05
Molydenum (Mo)	0.05	0.05	0.05

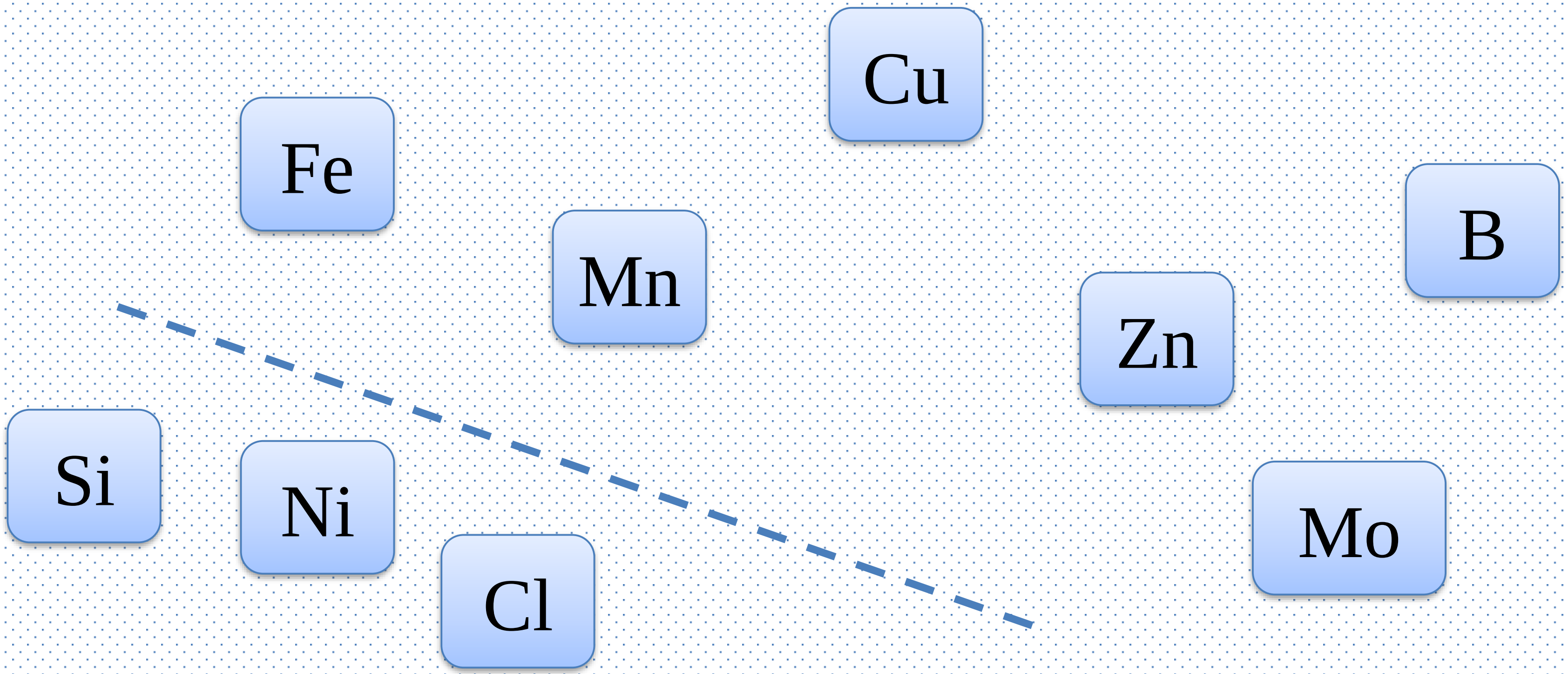
Source: Sunco, Ltd., and University of Arizona, Controlled Environment Agriculture Center, http://tinyurl.com/ljlj785/



N P K Ca Mg S

BASE NUTRIENTS

Macro nutrients
Macro elements

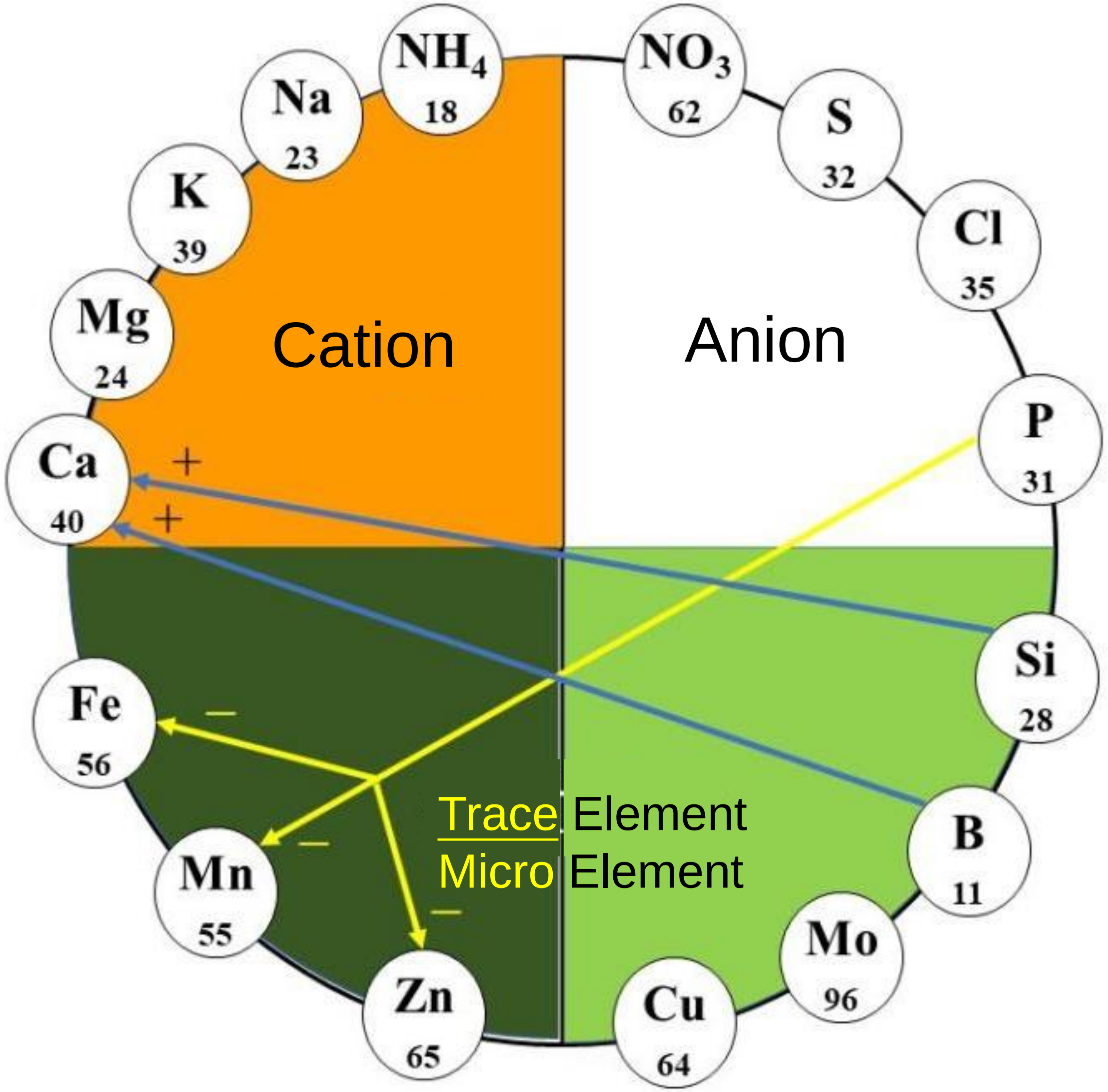


Other important trace elements
Micro nutrients
Micro elements

19 elements for plants

類別	element	Atomic weight	Available form	
Macro 3	碳 C	12.01	CO_2	1mM 44 mg
	氫 H	1.01	H_2O	1mM 18 mg
	氧 O	16	O_2	1mM 32 mg
Macro 6	氮 N	14.01	NO_3^-, NH_4^+	1 me = 14.0 mg
	磷 P	30.98	$H_2PO_4^-$, HPO_4^{-2}	10.3
	鉀 K	39.1	K^+	39.1
	鈣 Ca	40.08	Ca^{+2}	20
	鎂 Mg	24.32	Mg^{+2}	12.1
	硫 S	32.07	SO_4^{-2}	16
Micro 7	鐵 Fe	55.85	Fe^{+3}, Fe^{+2}	27.9
	錳 Mn	54.94	Mn^{+2}	27.5
	硼 B	10.82	BO_3^{-3}, $B_4O_7^-$	3.6
	銅 Cu	63.54	Cu^{+2}, Cu^+	31.8
	鋅 Zn	65.38	Zn^{+2}	32.7
	鉬 Mo	95.95	MoO_4^{-2}	48
	氯 Cl	35.46	Cl^-	35.4
Special 3	矽 Si	28.09	SiO_4^{-4}	7
	鋁 Al	26.98	Al^{+3}	9
	鈉 Na	22.99	Na+	23

Competition/Cooperation among ions



Ions in same quadrant are competing

Plant preferred ions with low atomic weight x valence

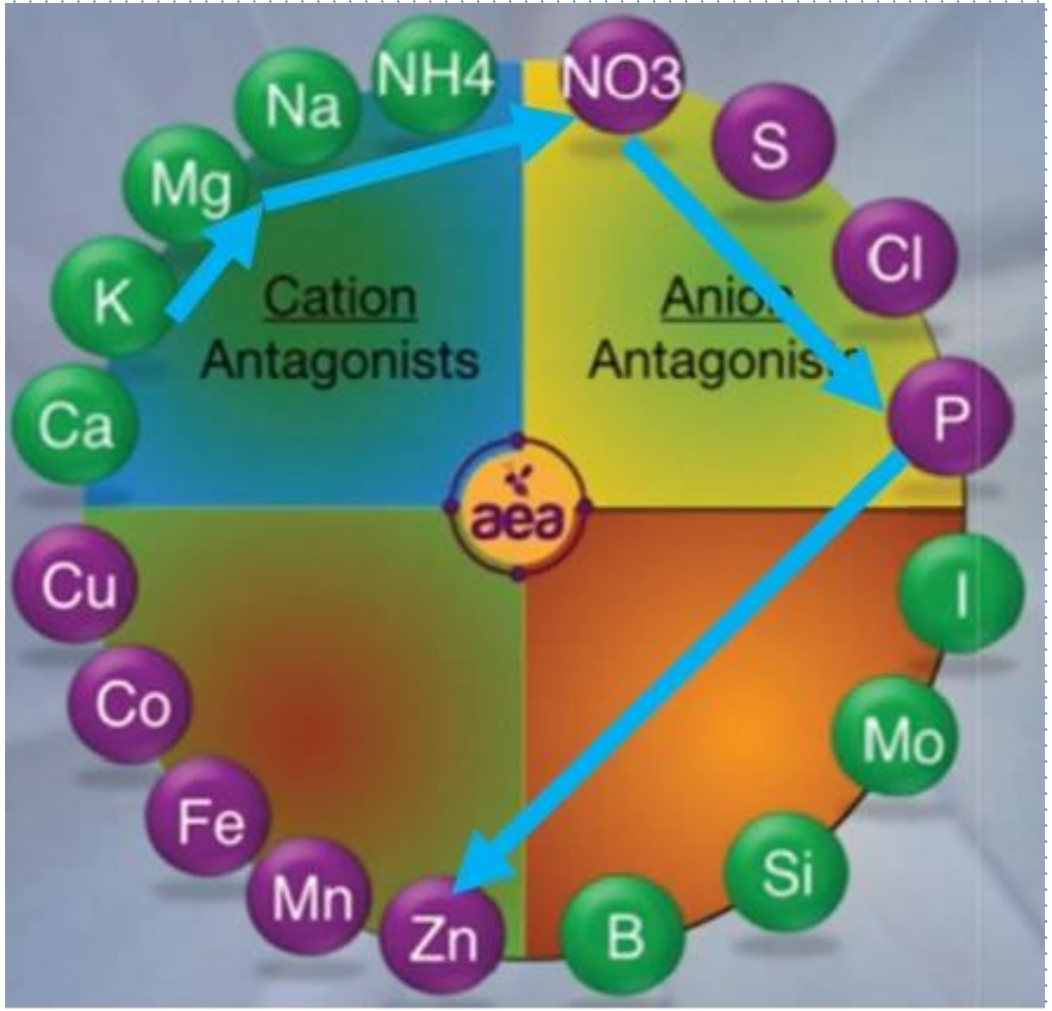
- $NH_4^+ > Na^+ > K^+ > Mg^{+2} > Ca^{+2}$

  18, 23, 39, 24*2, 40*2

ions in different quadrants also affect one another

- Macro affects micro, such as P up, inhibits Fe, Mn, Zn
- Micro affects macro, such as Si, B up, promotes Ca

AEA Antagonistic interactions



Low K →

High Mg →

low NO3 →

high P → low Zn

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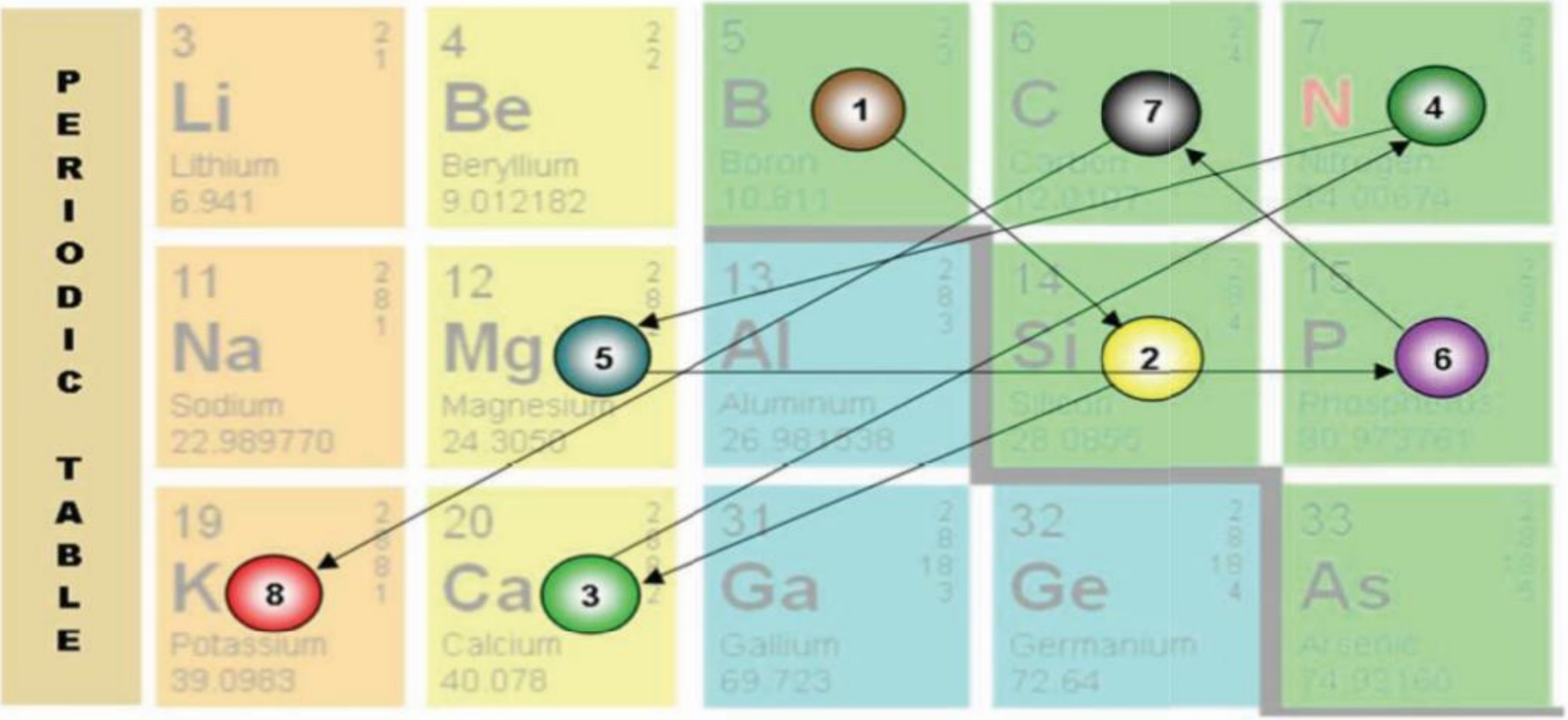
Biochemical sequence of nutrition in plants



Plant biochemical sequences begin with:

1. ***Boron***, which activates →
2. ***Silicon*** which carries all other nutrients starting with →
3. ***Calcium*** which binds →
4. ***Nitrogen*** to form amino acids, DNA and cell division.

Amino acids form proteins such as chlorophyll and tag trace elements, especially →

5. ***Magnesium*** which transfers energy via →
6. ***Phosphorus*** to →
7. ***Carbon*** to form sugars which go where →
8. ***Potassium*** carries them. This is the basis of plant growth.

Frequent used fertilizer

Type of fertilizer	Molecular formula	Molecular weight	ion	solubility 20°C g/l	purity %	Price NT$/kg
硝酸鉀	KNO_3	101	K^+,NO_3^-	315	95	50~60
硝酸鈣	$Ca(NO_3)_2 \cdot 4H_2O$	236	$Ca^{+2},2(NO_3^-)$	1270	70	20~27
磷酸銨	$NH_4H_2PO_4$	115	$NH_4^+,H_2PO_4^-$	365	98	50~64
硫酸鎂	$MgSO_4 \cdot 7H_2O$	246	Mg^{+2},SO_4^{-2}	252	45	44
硝酸銨	NH_4NO_3	80	NH_4^+,NO_3^-	655	98	
硫銨	$(NH_4)_2SO_4$	132	$2(NH_4^+),SO_4^{-2}$	754	94	5.6
氯化銨	NH_4Cl	53	NH_4^+,Cl^-	1630		
尿素	$(NH_2)_2CO$	60	NH_4^+	1000	98	9.8
硫酸鉀	K_2SO_4	174	$2K^+,SO_4^-$	111	90	31
氯化鉀	KCl	74	K^+,Cl^-	265	95	8.4
氯化鈣	$CaCl_2 \cdot 2H_2O$	147	Ca^{+2},Cl^-	536	75	24
磷酸一鉀	KH_2PO_4	136	K^+,H_{2PO4}^-	227	98	70
EDTA鐵	Fe^-EDTA	421	Fe^{+2}	421	12.5	250
硼酸	H_3BO_3	62	B_3^+	46	18	55~60
硫酸錳	$MnSO_4 \cdot 4H_2O$	223	Mn^{+2},SO_4^{-2}	500	99	

Nutrient Concentration
Frequent used units

- Macro elements
  - mM 或 mmol/L
  - me/L
- Micro elements
  - ppm
  - mg/L
  - μM 或 μmol/L

- gram equivalent = atomic weight/valence
(克當量=原子量/原子價)
- Milligram equivalent, me = e/1000 毫克當量

me/L to ppm

ppm: parts per million

1 mg in in 1 L of water, 1 g in 1000 L of water

1 g in 1 ton of water is 1 ppm

Element	Atomic weight	Valence	1 me/L
K	39.1	1	39.1 mg/L
Ca	40	2	20 mg/L
Mg	24.3	2	12.15 mg/L

me/L x atomic weight/valence = ppm

Example

fertilizer	N		P	K	Ca	Mg	EC	Amount
	NO_3-N	NH_4-N						
unit	me/L	me/L	me/L	me/L	me/L	me/L	mS/cm	g
Target concentration	**7**	**0.67**	**2**	**4**	**3**	**2**	0.24	
Source water	0	0	0	0.02	1.6	0.45		
Required	7	0.67	2	3.98	1.4	1.55		
KNO_3	3.98			3.98				402
$Ca(NO_3)_2 \cdot 4H_2O$	1.4				1.4			165
$MgSO_4 \cdot 7H_2O$						1.55		191
$NH_4H_2PO_4$		0.67	2					76
(NH_4NO_3)	(1.62)	(1.62)						(64.8)
(KNO_3)	(1.62)			(1.62)				(163.6)
合計	**5.38**	**0.67**	**2**	**4**	**3**	**2**		

3.98 me/L N → 3.98 x (39+62) / 1 = 401.98 g KNO_3 (KNO_3 molecular weight 39+62)
1.4 me/L Ca → 1.4 x (40+62x2+4x18) / 2 = 330/2 = 165

Yamazaki formula for Lettuce

Chemical composition of nutrient solution.	purity (%)	lettuce (mg/L)	Stock solution (100X) (g/500 mL)	Stock solution (100X) (g/500 mL)
硝酸鈣 $Ca(NO_3)_2 \cdot 4H_2O$	70	240	12	12/0.7 = 17.14
硝酸鉀 KNO_3	99.8	400	20	20.04
硫酸鎂 $MgSO_4 \cdot 7H_2O$	49	125	6.25	12.76
磷酸一銨 $NH_4H_2PO_4$	98.5	60	3	3.05
鉗形鐵 Fe · EDTA	99.9	20	1	1.00
硼酸 H_3BO_3	99.9	1.2	0.6 (1000X；500 mL)	0.6006
硫酸銅 $CuSO_4 \cdot 5H_2O$	99.9	0.09	0.045 (1000X；500 mL)	0.0450
硫酸鋅 $ZnSO_4 \cdot 7H_2O$	98	0.04	0.02 (1000X；500 mL)	0.0204
硫酸錳 $MnSO_4 \cdot H_2O$	97.5	1.82	0.813 (1000X；500 mL)	0.8339
鉬酸鈉 $NaMoO_4 \cdot 2H_2O$	99.9	0.01	0.005 (1000X；500 mL)	0.0050

2 versions of Yamazaki Recipe

			施用量, g/1000L(山崎)	施用量, g/1000L(修正山崎)
名稱	**Compound**	Molecular weight	g/5L for stock solution, diluted 200 times, EC = 800 μS/cm = 0.8 mS/cm	
硝酸鉀	KNO_3	101.1	404.04	350.55
硝酸鈣(4水)	$Ca(NO_3)_2 \cdot 4H_2O$	236.088	242.42	242.42
硝酸鈣(3水)	Ca(NO3)2・3H2O	218.088	or 223.94	or 223.94
FE-EDTA	$C_{10}H_{12}N_2NaFeO_8$	367.05	25.26	25.26
硫酸鎂	$MgSO_4$	120.34	61.68	61.68
硫酸鎂(7水)	$MgSO_4 \cdot 7H_2O$	246.34	or 126.26	or 126.26
磷酸一銨	$NH_4H_2PO_4$	115.03	60.91	0
磷酸二氫鉀	KH_2PO_4	136.09	0	72.02
硝酸銨	NH_4NO_3	80.052	0	42.34
硼酸	H_3BO_3	62	3.03	3.03
氯化錳(4水)	$MnCl_2 \cdot 4H_2O$	198	0	0
硫酸錳(1水)	MnSO4・H2O	169	1.53	1.53
硫酸錳(4水)	$MnSO_4$・4H2O	223	or 2.02	or 2.02
硫酸銅(5水)	$CuSO_4 \cdot 5H_2O$	250	0.09	0.09
硫酸鋅(7水)	$ZnSO_4 \cdot 7H_2O$	288	0.224	0.224
鉬酸鈉(2水)	$Na_2MoO_4 \cdot 2H_2O$	241.92	0.025	0.025

Table 1. Three hydroponic nutrient solution recipes to prepare 100 gal. of fertilizer suitable for hydroponic production of lettuce, herbs and leafy greens. If preparing to dilute in a 100-gal. reservoir, all the components within a recipe can be mixed into the water. If using stock tanks (i.e., a 100X concentration), then the calculations represent the amount to use per 1 gal. of stock. Where indicated, the Tank A and Tank B components MUST be prepared separately so a precipitate does not occur. If using stocks, dilute using 1:100 injector(s) (two injectors connected in series for Tank A and Tank B mixes). This will make 100 gal. of dilute fertilizer.

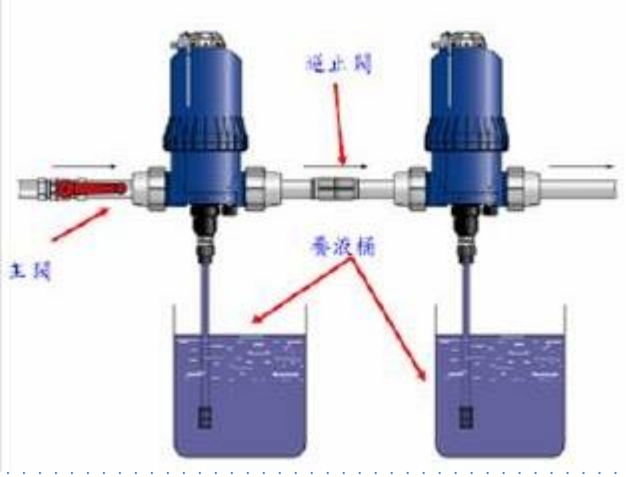
Jack's Hydro-FeEd (16-4-17)
This is a 1-bag solution; use 355 g in 100 gal. water (dilute) or for each 1 gal. in a stock tank (using a 1:100 injector)

Jack's Hydroponic (5-12-26) + Calcium nitrate	
Tank A	**Tank B**
284 g Calcium nitrate (15-0-0)	284 g 5-12-26

Modified Sonneveld's solution for lettuce	
Tank A	**Tank B**
184.0 g $Ca(NO_3)_2 \cdot 3H_2O$	51.5 g KH_2PO_4
14.4 g NH_4NO_3	93.1 g $MgSO_4 \cdot 7H_20$
167.3 g KNO_3	*0.290g $MnSO_4 \cdot H_2O$
*3.8 g 10% Iron-DTPA Sprint 330 or Sequestrene 330	*0.352g H_3BO_3
	*0.023g $Na_2MoO_4 \cdot 2H_2O$
	*0.217g $ZnSO_4 \cdot 7H_2O$
	*0.035g $CuSO_4 \cdot 5H_2O$

*A precise scale is needed to weigh the micronutrients

diluter



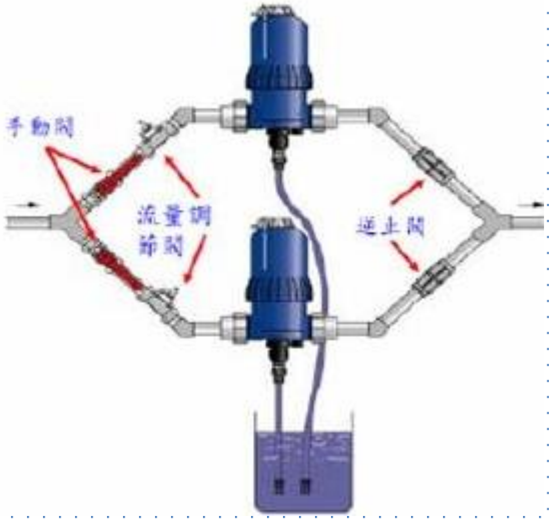


Table 2. Comparison of the nutrients (in ppm) supplied by the three different recipes for lettuce, herbs and leafy greens.

	Jack's Hydro-FeED (16-4-17)	Jack's Hydroponic (5-12-26) + Calcium nitrate	Modified Sonneveld's solution
Nitrogen (N)	150	150	150
Phosphorus (P)	16	39	31
Potassium (K)	132	162	210
Calcium (Ca)	38	139	90
Magnesium (Mg)	14	47	24
Iron (Fe)	2.1	2.3	1.0
Manganese (Mn)	0.47	0.38	0.25
Zinc (Zn)	0.49	0.11	0.13
Boron (B)	0.21	0.38	0.16
Copper (Cu)	0.131	0.113	0.023
Molydenum (Mo)	0.075	0.075	0.024

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

Table 4. Two hydroponic nutrient solution recipes to prepare 100 gal. of fertilizer suitable for hydroponic production of tomatoes, cucumbers and peppers.

Jack's Hydroponic (5-12-26) + Calcium nitrate	
Tank A	**Tank B**
360 g Calcium nitrate (15-0-0)	360 g 5-12-26
UA CEAC Recipe*	
Tank A	**Tank B**
347.8 g $Ca(NO_3)_2{\cdot}3H_2O$	64.9 g KH_2PO_4
152.5 g KNO_3	184.3 g $MgSO_4{\cdot}7H_20$
*7.6 g 10% Iron-DTPA Sprint 330 or Sequestrene 330	114.7 g K_2SO_4
	*0.641g $MnSO_4{\cdot}H_2O$
	*0.606g H_3BO_3
	*0.048g $Na_2MoO_4{\cdot}2H_2O$
	*0.549g $ZnSO_4{\cdot}7H_2O$
	*0.074g $CuSO_4{\cdot}5H_2O$

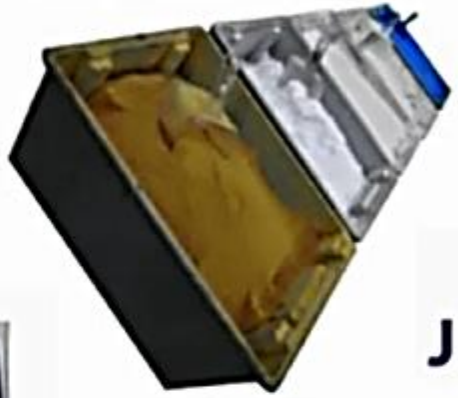
*A precise scale is needed to weigh the micronutrients
Adapted from University of Arizona, Controlled Environment Agriculture Center, http://tinyurl.com/ljlj785/

Table 5. Comparison of the nutrients (in ppm) supplied by the three different recipes for lettuce, herbs and leafy greens.

	Jack's Hydroponic (5-12-26) + Calcium nitrate	UA CEAC Recipe
Nitrogen (N)	190	189
Phosphorus (P)	50	39
Potassium (K)	205	341
Calcium (Ca)	176	170
Magnesium (Mg)	60	48
Iron (Fe)	2.85	2.00
Manganese (Mn)	0.48	0.55
Zinc (Zn)	0.14	0.33
Boron (B)	0.48	0.28
Copper (Cu)	0.14	0.05
Molydenum (Mo)	0.10	0.05

Commercially available fertilizers for hydroponic systems

- Single-element mixes
- Water-soluble concentrates
- Complete one-bag formula



Haifa

JR PETERS INC

Hyponex

various size

Medium: 500 g

Large: 2 kg, 800 NT$

	N:P:K	
No. 1	07-06-19	Leafy vegetable
No. 2	20-20-20	General usage
No. 3	10-30-20	Promote flowering
No. 4	25-05-20	Leafy Ornamental plants
No. 5	30-10-10	Fast growth of Seedling

Hyponex No.1 (N-P-K: 7-6-19)

Hyponex NO.1			
氮			7%
銨態氮	Ammoniacal Nitrogen	NH_4-N	1.2%
硝酸態氮	Nitrate Nitrogen	NO_3-N	5.8%
可利用磷	Available Phosphate	P_2O_5	6%
水溶性鉀	Soluble Potassium	K_2O	19%

來源	Sources
硝酸鉀	Potassium Nitrate
重過磷酸鈣	Triple SuperPhosphate
硫酸銨	Ammonium Sulfate

More recipes

in ppm

Elements	US Hoagland and Arnon / Modified Hogland	UK Cooper	Netherlands Modified Steiner	US Wilcox 1	US Wilcox 2	Canada Resh	Japan
N	210 / 224	200	171	132	162	175	132
P	31 / 62	60	48	58	58	65	42
K	234 / 235	300	304	200	284	400	314
Ca	160 / 160	170	180	136	136	197	162
Mg	48 / 24	50	48	47	47	44	50
Fe	50 / 1~3	12	3	4	4	2	3
Mn	0.5 / 0.11	2	1	0.5	0.5	0.5	0.5
B	0.5 / 0.27	1.5	0.3	1.5	1.5	0.5	0.5
Zn	0.05 / 0.13	0.1	0.4	0.3	0.3	0.05	0.05
Cu	0.02 / 0.03	0.1	0.2	0.1	0.1	0.05	0.02
Mo	0.01 / 0.05	0.2	0.1	0.1	0.1	0.02	0.01
S	/ 32						
Cl, Ni, Si	/ 1.77, 0.03, 28						

Modified Hoagland

TABLE 5.3
Composition of a modified Hoagland nutrient solution for growing plants *(Part 1)*

Compound	Molecular weight	Concentration of stock solution	Concentration of stock solution	Volume of stock solution per liter of final solution	Element	Final concentration of element	
	g mol^{-1}	m*M*	g L^{-1}	mL		µ*M*	ppm
Macronutrients							
KNO_3	101.10	1,000	101.10	6.0	N	16,000	224
$Ca(NO_3)_2 \cdot 4H_2O$	236.16	1,000	236.16	4.0	K	6,000	235
$NH_4H_2PO_4$	115.08	1,000	115.08	2.0	Ca	4,000	160
$MgSO_4 \cdot 7H_2O$	246.48	1,000	246.49	1.0	P	2,000	62
					S	1,000	32
					Mg	1,000	24

Source: After Epstein 1972.

Note: The macronutrients are added separately from stock solutions to prevent precipitation during preparation of the nutrient solution. A combined stock solution is made up containing all micronutrients except iron. Iron is added as sodium ferric diethylenetriaminepentaacetate (NaFeDTPA, trade name Ciba-Geigy Sequestrene 330 Fe; see Figure 5.2); some plants, such as maize, require the higher level of iron shown in the table.

[a]Nickel is usually present as a contaminant of the other chemicals, so it may not need to be added explicitly. Silicon, if included, should be added first and the pH adjusted with HCl to prevent precipitation of the other nutrients.

PLANT PHYSIOLOGY, Fourth Edition, Table 5.3 (Part 1)

TABLE 5.3
Composition of a modified Hoagland nutrient solution for growing plants *(Part 2)*

Compound	Molecular weight	Concentration of stock solution	Concentration of stock solution	Volume of stock solution per liter of final solution	Element	Final concentration of element	
	g mol^{-1}	m*M*	g L^{-1}	mL		µ*M*	ppm
Micronutrients							
KCl	74.55	25	1.864	2.0	Cl	50	1.77
H_3BO_3	61.83	12.5	0.773	2.0	B	25	0.27
$MnSO_4 \cdot H_2O$	169.01	1.0	0.169	2.0	Mn	2.0	0.11
$ZnSO_4 \cdot 7H_2O$	287.54	1.0	0.288	2.0	Zn	2.0	0.13
$CuSO_4 \cdot 5H_2O$	249.68	0.25	0.062	2.0	Cu	0.5	0.03
H_2MoO_4 (85% MoO_3)	161.97	0.25	0.040	2.0	Mo	0.5	0.05
NaFeDTPA (10% Fe)	468.20	64	30.0	0.3–1.0	Fe	16.1–53.7	1.00–3.00

Source: After Epstein 1972.

Note: The macronutrients are added separately from stock solutions to prevent precipitation during preparation of the nutrient solution. A combined stock solution is made up containing all micronutrients except iron. Iron is added as sodium ferric diethylenetriaminepentaacetate (NaFeDTPA, trade name Ciba-Geigy Sequestrene 330 Fe; see Figure 5.2); some plants, such as maize, require the higher level of iron shown in the table.

[a]Nickel is usually present as a contaminant of the other chemicals, so it may not need to be added explicitly. Silicon, if included, should be added first and the pH adjusted with HCl to prevent precipitation of the other nutrients.

TABLE 5.3
Composition of a modified Hoagland nutrient solution for growing plants *(Part 3)*

Compound	Molecular weight	Concentration of stock solution	Concentration of stock solution	Volume of stock solution per liter of final solution	Element	Final concentration of element	
	g mol^{-1}	m*M*	g L^{-1}	mL		μ*M*	ppm
Optional[a]							
$NiSO_4 \cdot 6H_2O$	262.86	0.25	0.066	2.0	Ni	0.5	0.03
$Na_2SiO_3 \cdot 9H_2O$	284.20	1,000	284.20	1.0	Si	1,000	28

Source: After Epstein 1972.

Note: The macronutrients are added separately from stock solutions to prevent precipitation during preparation of the nutrient solution. A combined stock solution is made up containing all micronutrients except iron. Iron is added as sodium ferric diethylenetriaminepentaacetate (NaFeDTPA, trade name Ciba-Geigy Sequestrene 330 Fe; see Figure 5.2); some plants, such as maize, require the higher level of iron shown in the table.

[a]Nickel is usually present as a contaminant of the other chemicals, so it may not need to be added explicitly. Silicon, if included, should be added first and the pH adjusted with HCl to prevent precipitation of the other nutrients.

Radish and Lettuce
JFK Space Center

TABLE 1 Initial concentration of elements in the nutrient solutions of growth chamber radish and lettuce from the Kennedy Space Center

Element	Starter Concentration	Replenishment Concentration[1]
NO_3-N	7.5 mM	49 mM
PO_4-P	0.5 mM	5 mM
K	3.0 mM	36 mM
Ca	2.5 mM	9 mM
Mg	1.0 mM	8 mM
S	1.0 mM	8 mM
Fe	50.0 µM	135 µM
B	4.75 µM	48 µM
Mn	3.7 µM	37 µM
Zn	0.64 µM	6.4 µM
Cu	0.52 µM	5.2 µM
Mo	0.01 µM	0.1 µM

mM = mmol/L

µM = µmol/L

[1] This solution was added to the working nutrient solution to maintain an electrical conductivity of 0.12 $S \cdot m^{-1}$. Slight adjustments in the concentrations of specific nutrients were made over the course of the studies.

0.12 S/m = 1.2 mS/cm = 1200 µS/cm

表一、菾菜培養液巨量元素之組成

Table 1. Nutrient composition of macro-nutrition for Swiss chard

Macro-nutrition	Concentration of stock solution M		Volumes of stock solution per liter of final solution mL	Concentration in system mM	
NO_3^- : NH_4^+ = 7:1, 5:1	7:1	5:1		7:1	5:1
KNO_3	0.25	0.2	10	2.5	2
$Ca(NO_3)_2 \cdot 4H_2O$	0.4	0.4	10	4	4
$NH_4H_2PO_4$	0.15	0.2	10	1.5	2
H_3PO_4	0.05		10	0.5	
$MgSO_4 \cdot 7H_2O$	0.075	0.075	10	0.75	0.75
K_2SO_4	0.075	0.1	10	0.75	1

偏差 (standard deviation) 表示 (n = 4)。

表二、紫色葉用甘藷培養液巨量元素之組成

Table 2. Nutrient composition of macro-nutrition for Sweet potato

Macro-nutrition	Concentration of stock solution M		Volumes of stock solution per liter of final solution mL	Concentration in system mM	
NO_3^- : NH_4^+ = 7:1, 5:1	7:1	5:1		7:1	5:1
KNO_3	0.25	0.2	10	2.5	2
$Ca(NO_3)_2 \cdot 4H_2O$	0.4	0.4	10	4	4
$NH_4H_2PO_4$	0.15	0.2	10	1.5	2
H_3PO_4	0.05		10	0.5	
$MgSO_4 \cdot 7H_2O$	0.1	0.075	10	1	0.75
K_2SO_4	0.1	0.125	10	1	1.25

表三・恭菜和紫色葉用甘藷培養液微量元素之組成

Table 3. Nutrient s composition of micro-nutrition for Swiss chard and Sweet potato

Micro-nutrient	Concentration of stock solution mM	Volumes of stock solution per liter of final solution mL	Concentration in system μM
H_3BO_3	25	0.75	18.75
$MnSO_4$	10 / 20	0.75	7.5 / 15
$ZnSO_4$	2	0.75	1.5
$CuSO_4 \cdot 5\ H_2O$	0.5	0.75	0.375
$(NH_4)_6Mo_7O_4$	0.5	0.75	0.375
Fe-EDTA	40	0.75	30

(/): Swiss chard/Sweet potato

Home Hydroponic Garden's Recipe

		Compound	g/10L
Stock A	磷酸一銨	$NH_4H_2PO_4$	340
(Macro)	硝酸鈣	$Ca(NO_3)_2 \cdot 4H_2O$	2080
	硝酸鉀	KNO_3	1100
			g/4L
Stock B	硫酸鎂	$MgSO_4.7H_2O$	492
(Micro)	硫酸錳	$MnSO_4 . 4H_2O$	2.48
	硼酸	H_3BO_3	6.2
	硫酸銅	$CuSO_4 \cdot 5H_2O$	0.48
	硫酸鋅	$ZnSO_4 \cdot 7H_2O$	1.2
	鉬酸銨	$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$	0.02
	螯合鐵	$EDTA_2Fe$	8.46

add 5 ml A(Macro) and 2 ml B(micro) in 1 L of water

Bradley, P. And Tabares, C.H.M., 2000, Spreading Simplified Hydroponics：Home Hydroponic Gardens, Global Hydroponics Network, Corvallis, OR.

Generic Hydroponic Recipe

		Compound	g/100L
A	硝酸鈣	$Ca(NO_3)_2 \cdot 4H_2O$	13110
	硝酸鉀	KNO_3	2557
	螯合鐵	$EDTA_2Fe$	500
B	硝酸鉀	KNO_3	2557
	磷酸鉀	KH_2PO_4	3567
	硫酸鎂	$MgSO_4.7H_2O$	6625
	硫酸錳	$MnSO_4 . 4H_2O$	121
	硫酸鋅	$ZnSO_4 \cdot 7H_2O$	11
	硼酸	H_3BO_3	39
	硫酸銅	$CuSO_4 \cdot 5H_2O$	3
	鉬酸銨	$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$	1.02

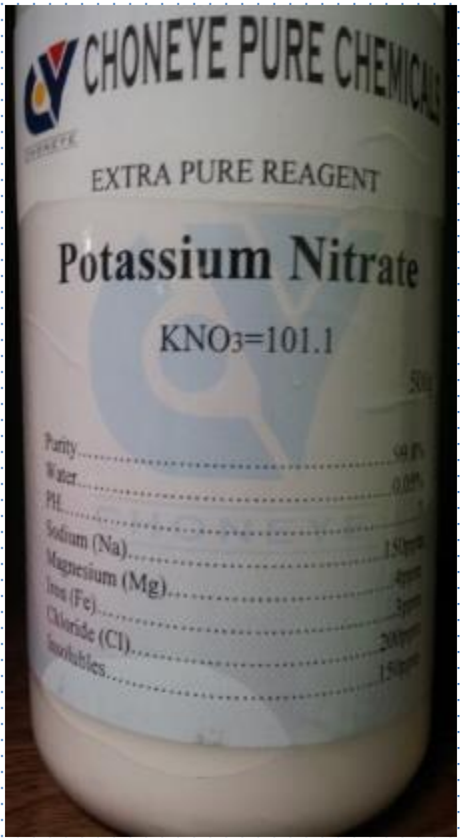
Both dilute 1: 100, EC=2.5, TDS=1806

Morgan, L., 2002e, The Growing Edge 14(1)：11.

4 single element fertilizers for stock solution A

四水硝酸鈣

Calcium Nitrate



硝酸鉀

Potassium Nitrate

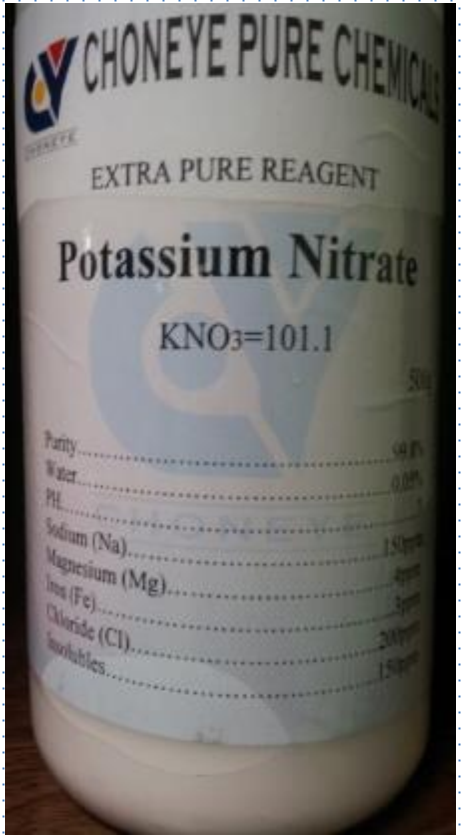
硝酸銨

Ammonium Nitrate

螯合鐵

Sprint 330 Iron - DTPA (10% Iron)

4 out of 9 single element fertilizers for stock solution B



KNO_3
硝酸鉀
Potassium Nitrate

KH_2PO_4
磷酸一鉀
Monopotassium Phosphate

K_2SO_4
硫酸鉀
Potassium Sulfate

$MgSO_4.7H_2O$
七水硫酸鎂
Magnesium Sulfate

5 out of 9 single element fertilizers for stock solution B

一水硫酸亞錳　　硼酸　　五水硫酸銅　二水鉬酸鈉　七水硫酸鋅

Manganese Sulfate*H_2O (25% Mn)

Boric Acid (17.5% B

Copper Sulfate*5H_2O (25% Cu)

Sodium Molybdate*2H_2O (39% Mo)

Zinc Sulfate*7H2O (??%Zn)

2015 Cornell Recipe：DFT

For 100 gallon (378.5 L) RO water = Dilute 100 times in 1 gallon RO water to make stock solution

Modified Sonneveld's solution for lettuce

Tank A	Tank B
184.0 g $Ca(NO_3)_2 \cdot 3H_2O$	51.5 g KH_2PO_4
14.4 g NH_4NO_3	93.1 g $MgSO_4 \cdot 7H_20$
167.3 g KNO_3	*0.290g $MnSO_4 \cdot H_2O$
*3.8 g 10% Iron-DTPA	*0.352g H_3BO_3
Sprint 330 or	*0.023g $Na_2MoO_4 \cdot 2H_2O$
Sequestrene 330	*0.217g $ZnSO_4 \cdot 7H_2O$
	*0.035g $CuSO_4 \cdot 5H_2O$

	Tank A	Tank B
New recipe	4	7
Old recipe	4	9

Comparison on new/old Cornell Recipes

		2015 Cornell Lettuce recipe	g/100 gal = 濃縮100 倍，g/1 gal	g/1000L = 濃縮200 倍，g/5L	old recipe, g/5 L		
4	A液	硝酸鈣 $Ca(NO_3)_2*3H_2O$	184	486.13		486	4
		硝酸鉀 KNO_3	167.3	442.01		102.2	
		硝酸銨 NH_4NO_3	14.4	38.04		14.0	
		螯合鐵 10% Iron-DTPA	3.8	10.04		9.4	
7	B液				KNO3	339.6	9
					K2SO4	10.9	
		硫酸鎂 MgSO4*7H2O	93.1	245.97	MgSO4	123	
		磷酸二氫鉀 KH_2PO_4	51.5	136.06		136	
		硫酸錳 $MnSO_4*H_2O$	0.29	0.77		0.43	
		硫酸鋅 $ZnSO_4*7H_2O$	0.217	0.57		0.57	
		硫酸銅 $CuSO_4*5H_2O$	0.035	0.09		0.09	
		硼酸 H_3BO_3	0.352	0.93		0.93	
		鉬酸鈉 $Na_2MoO_4*2H_2O$	0.023	0.06		0.06	

2015 Cornell

Recipe adjustment due to compounds with various hydrate

Magnesium sulfate

Magnesium sulfate monohydrate

Magnesium sulfate heptahydrate

			施用量, g/1000L(2015Cornell)
名稱	化學式	分子量	g/5 L 為母液，稀釋 200 倍後EC為 1200 uS/cm
硝酸鉀	KNO_3	101.1	442.01
硝酸鈣(4水)	$Ca(NO_3)_2 \cdot 4H_2O$	236.088	526.25
硝酸鈣(3水)	Ca(NO3)2 • 3H2O	218.088	or 486.13
FE-EDTA	$C_{10}H_{12}N_2NaFeO_8$	367.05	10.04
硫酸鎂	$MgSO_4$	120.34	120.16
硫酸鎂(7水)	$MgSO_4 \cdot 7H_2O$	246.34	or 245.97
磷酸一銨	$NH_4H_2PO_4$	115.03	0
磷酸二氫鉀	KH_2PO_4	136.09	136.06
硝酸銨	NH_4NO_3	80.052	38.04
硼酸	H_3BO_3	62	0.93
氯化錳(4水)	$MnCl_2 \cdot 4H_2O$	198	0
硫酸錳(1水)	MnSO4 • H2O	169	0.77
硫酸錳(4水)	$MnSO_4$ • 4H2O	223	or 1.016
硫酸銅(5水)	$CuSO_4 \cdot 5H_2O$	250	0.09
硫酸鋅(7水)	$ZnSO_4 \cdot 7H_2O$	288	0.57
鉬酸鈉(2水)	$Na_2MoO_4 \cdot 2H_2O$	241.92	0.06

Outline

Preparation of nutrient solution

pH, EC Management

- meters
- Introducing EC & pH
- Maintenance of electrodes
- EC control

pH Adjustment

Hydroponic systems

Literature Review

Desktop device

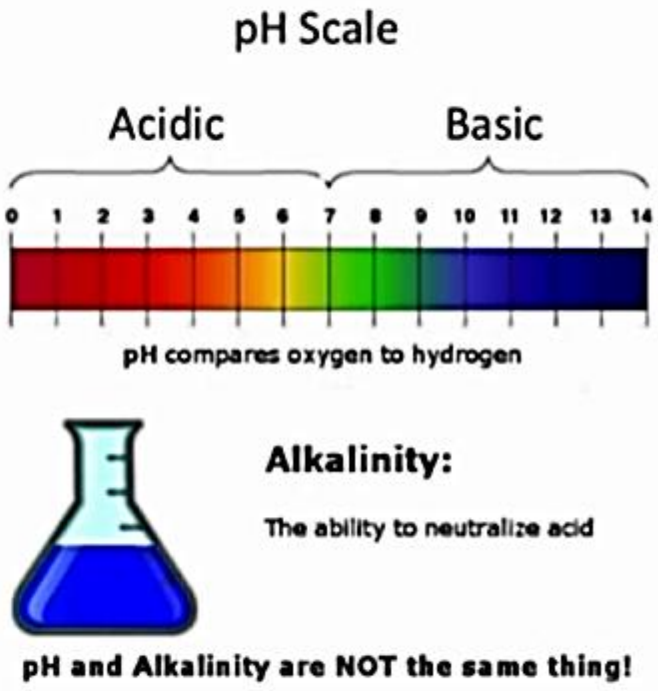
EC meter   pH meter

Portable pH/EC meter

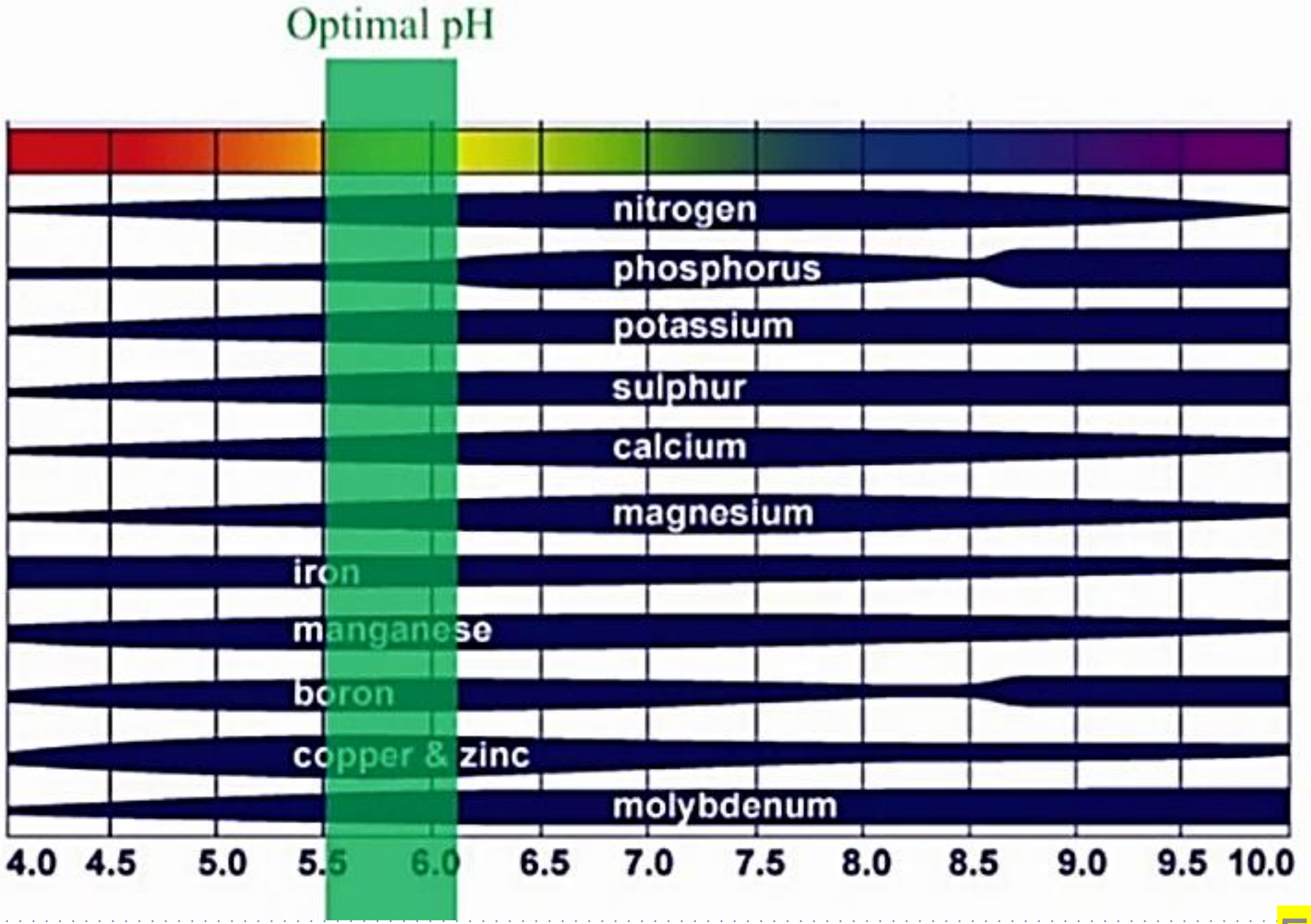
Item 2182 Economy pH/EC Meter
Item 2183 Replacement pH/EC Probe
Item 2110 Refill Solutions - pH 4 and 7, (2) 30mL ea.
Item 2251 Conductivity Standard, 1.41 mS/cm, 230mL

pH and Alkalinity

- pH is a one-time snapshot of how acid or basic your water source is
- Alkalinity measures its long-lasting pH effect



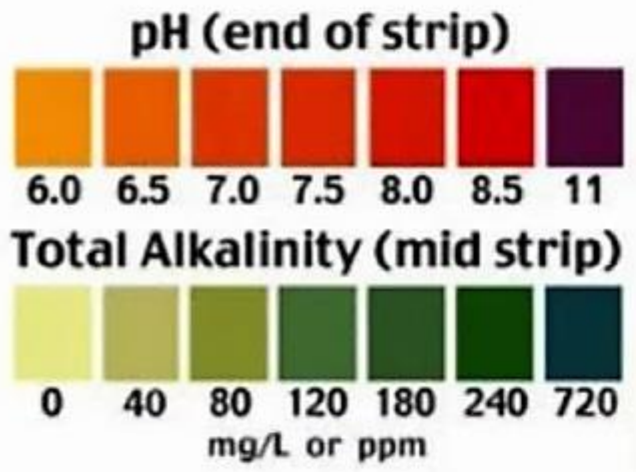
pH affects the plant nutrient availability and uptake!



Alkalinity

- Alkalinity: Determine the sensitivity / durability of water to pH variation.
- Low alkalinity: very sensitive
- High alkalinity: low sensitive, required more acid to reduce pH and more alkali liquid to increase pH

- Alkalinity high, pH also high
- Knowing alkalinity of source water is vital.
- Alkalinity test strip



Proper range for alkalinity

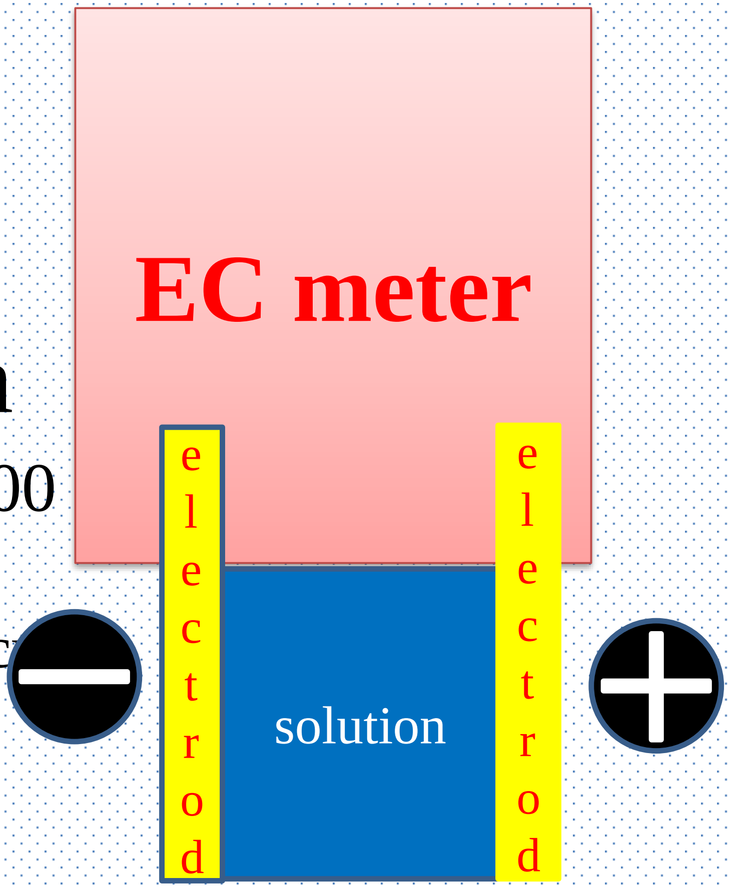
Reported in units of ppm of calcium carbonate equivalents ($CaCO_3$)

Milliequivalents = ppm total alkalinity expressed as mg $CaCO_3$/ liter divided by 50

WATER SOURCE	RECOMMENDED RANGE		LEVEL OF CONCERN	
JR PETERS Laboratory	ppm=mg $CaCO_3$/L	Milliequivalents $CaCO_3$	ppm=mg $CaCO_3$/L	Milliequivalents $CaCO_3$
Ideal Targets	60 - 100	1.2 - 2.0	< 40 low >120 high	<0.8 low >2.4 high

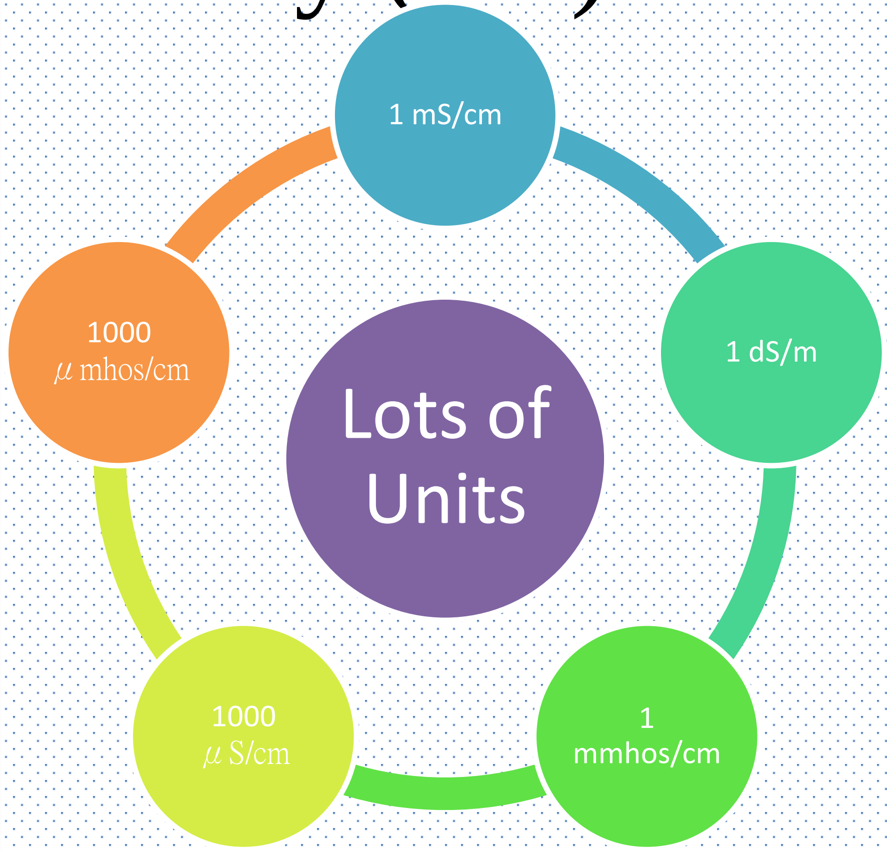
Electrical Conductivity (EC)

- Positively proportion to concentration of ionized nutrients
- EC in mS/cm= mmhos/cm
  - 1.0 mS/cm = 0.1 S/m = 1000 μS/cm
  - 1 dS/m = 0.1 S/m = 100 mS/100 c = 1 mS/cm
- An overall index, not able to know details of each elements



Electrical Conductivity (EC)

- A measure of the total dissolved solids
- Considers both essential nutrients and contaminants
- Gives you a rough estimate of your water's purity
- The electrical conductivity is very commonly used for measuring the strength of the fertilizer solution



Target EC for Source Water:	Ideal ?	High
Recirculating Systems (Water is captured & reused)	< 0.25 mmhos/cm	> 0.5 mmhos/cm

RO water is a must better source water

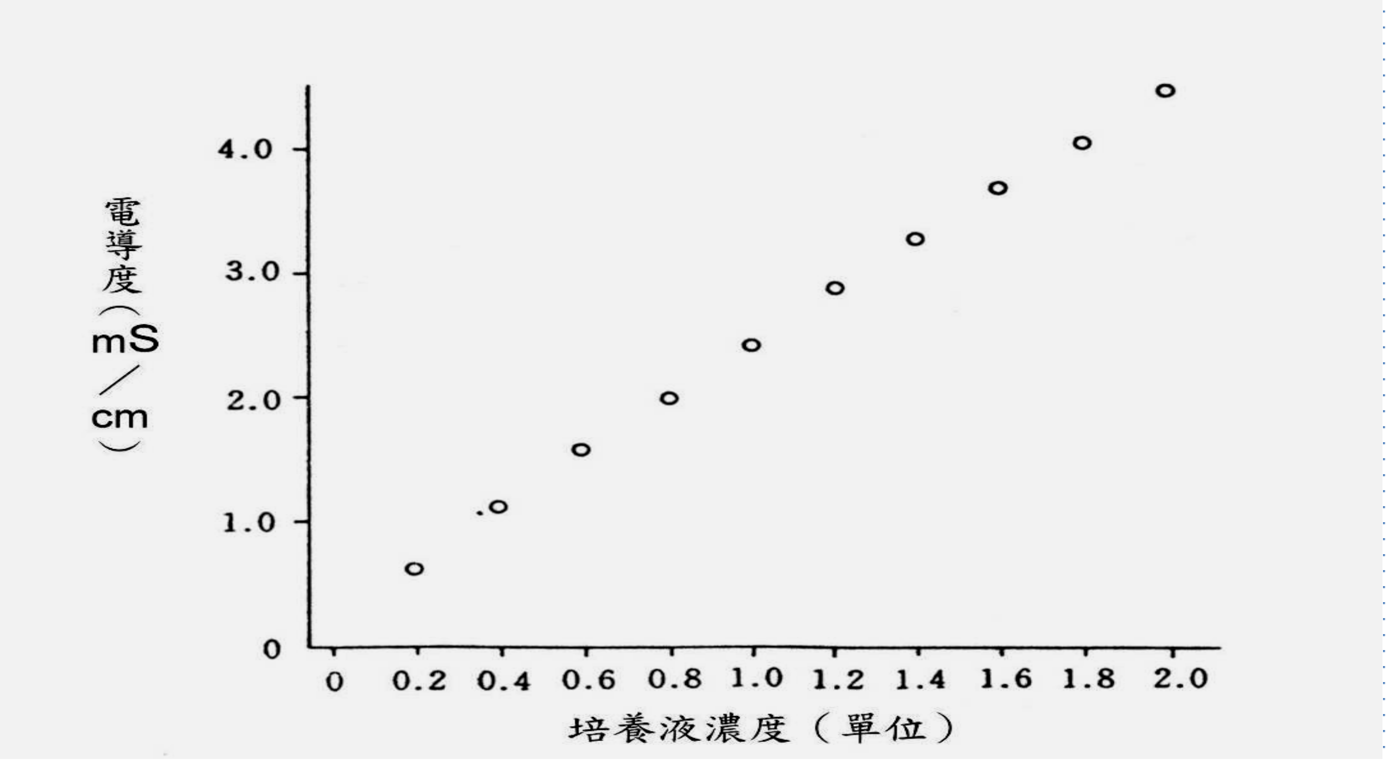
Assuming Target EC for nutrient solution is 1.2 mS/cm

Water	EC mS/cm	Unknown risk	
Tap water	0.2	16.67%	20
Tap water	0.1	8.3%	10
RO water	0.01	0.83%	1

Upper limit of source water

PARAMETERS		HIGH
	Soluble Salts (mmhos/cm)	> 1.3
MACROS	Nitrate Nitrogen (NO3-N)	> 10
	Ammonium Nitrogen (NH4-N)	> 10
	Phosphorus (P)	> 10
	Potassium (K)	> 10
	Calcium (Ca)	> 100
	Magnesium (Mg)	> 50
	Sulfur (S)	> 80
TRACES	Manganese (Mn)	> 1.50
	Iron (Fe)	> 2.00
	Copper (Cu)	> 0.20
	Boron (B)*	> 0.50
	Zinc (Zn)	> 0.40
	Molybdenum (Mo)	> 0.20
OTHER	Sodium (Na)	> 50
	Chlorides (Cl)	> 70
	Fluorides (F)	> 1.0
	Aluminum (Al)	> 1.0

EC vs. Nutrient concentration of a Japanese hydroponic recipe



EC, CF, TDS

- More ions in the water leads to higher Electrical Conductivity.
- Three commonly used terms for measuring concentration of the solution：
  - EC (in mS/cm or μS/cm)、 Conductivity Factor (CF, in CF) and Total Dissolved Solid (TDS, in ppm)
    - Convert EC to CF: 1 mS/cm = 10 CF
    - Convert EC to TDS: There exists different standard, leads to different conversion constant. 1 mS/cm = 500, 640 and 700 ppm for US、ERUO and Australia, respectively.

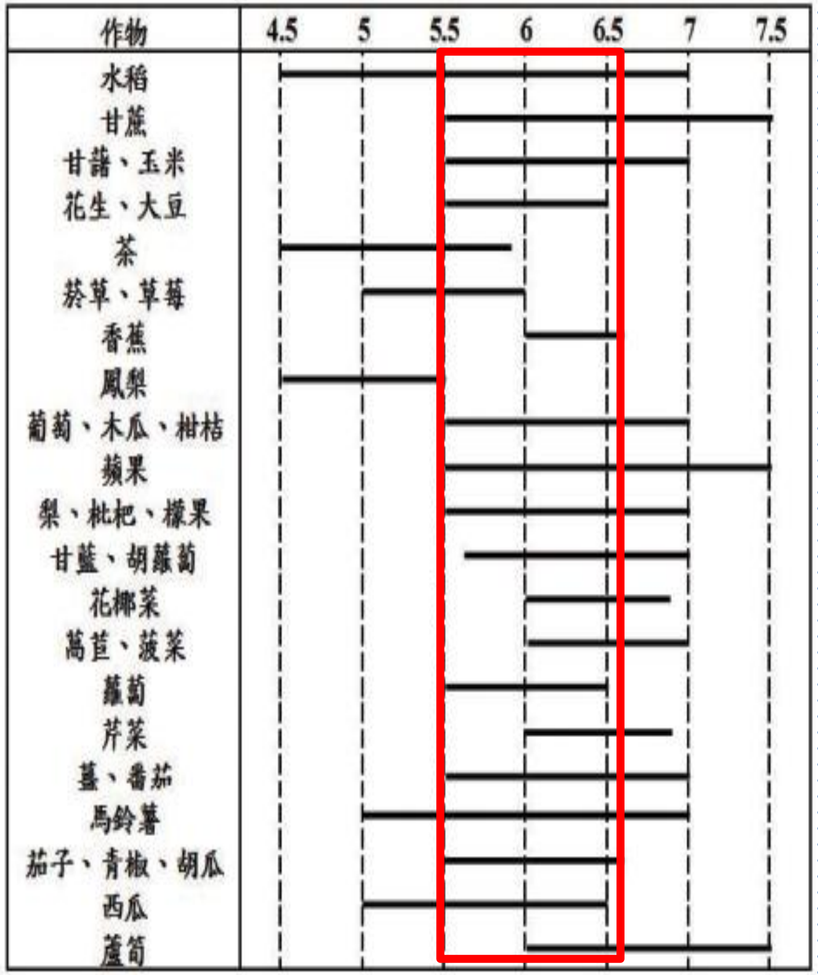
Conversion Tables for devices from different countries for EC measurement

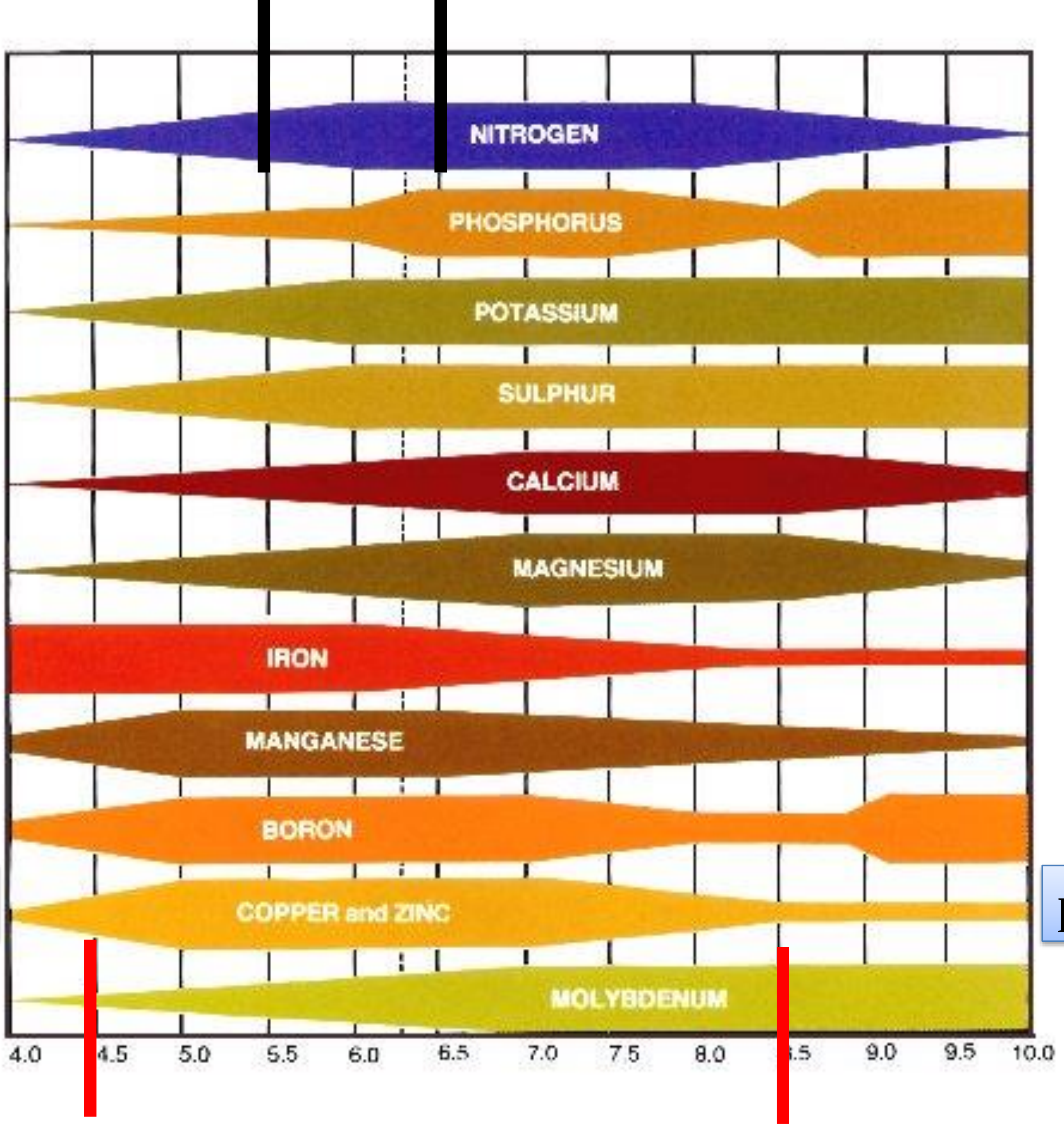
EC	Hanna 美	Eutech 歐	Truncheon 澳	CF
mS/cm	0.5 ppm	0.64 ppm	0.70 ppm	0
0.1	50 ppm	64 ppm	70 ppm	1
0.2	100 ppm	128 ppm	140 ppm	2
0.3	150 ppm	192 ppm	210 ppm	3
0.4	200 ppm	256 ppm	280 ppm	4
0.5	250 ppm	320 ppm	350 ppm	5
0.6	300 ppm	384 ppm	420 ppm	6
0.7	350 ppm	448 ppm	490 ppm	7
0.8	400 ppm	512 ppm	560 ppm	8
0.9	450 ppm	576 ppm	630 ppm	9
1.0	**500 ppm**	**640 ppm**	**700 ppm**	**10**
1.1	550 ppm	704 ppm	770 ppm	11
1.2	600 ppm	768 ppm	840 ppm	12
1.3	650 ppm	832 ppm	910 ppm	13
1.4	700 ppm	896 ppm	980 ppm	14
1.5	750 ppm	960 ppm	1050 ppm	15
1.6	800 ppm	1024 ppm	1120 ppm	16
1.7	850 ppm	1088 ppm	1190 ppm	17
1.8	900 ppm	1152 ppm	1260 ppm	18
1.9	950 ppm	1216 ppm	1330 ppm	19
2.0	1000 ppm	1280 ppm	1400 ppm	20
2.1	1050 ppm	1334 ppm	1470 ppm	21
2.2	1100 ppm	1408 ppm	1540 ppm	22
2.3	1150 ppm	1472 ppm	1610 ppm	23
2.4	1200 ppm	1536 ppm	1680 ppm	24
2.5	1250 ppm	1600 ppm	1750 ppm	25
2.6	1300 ppm	1664 ppm	1820 ppm	26
2.7	1350 ppm	1728 ppm	1890 ppm	27
2.8	1400 ppm	1792 ppm	1960 ppm	28
2.9	1450 ppm	1856 ppm	2030 ppm	29
3.0	1500 ppm	1920 ppm	2100 ppm	30

pH

- Range of pH varied for different crops

- pH range for hydroponics:
  5.5~6.5




NITROGEN
PHOSPHORUS
POTASSIUM
SULPHUR
CALCIUM
MAGNESIUM
IRON
MANGANESE
BORON
COPPER and ZINC
MOLYBDENUM
4.0
4.5
5.0
5.5
6.0
6.5
7.0
7.5
8.0
9.0
9.5
10.0

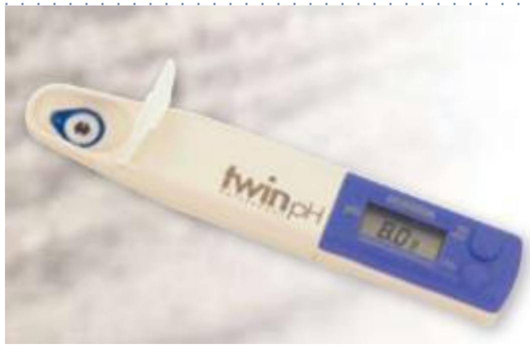
pH < 4.5

pH > 8

pH Adjustment for RO/Tap water

RO water	
pH	5.0~5.3~5.5
EC	< 0.01 mS/cm
Tap water in Taipei	
pH	6.4~6.5~6.6
EC	0.1 mS/cm
Target pH for hydroponics 5.5~6.5	
RO water need to add NaOH or KOH Tap water need to add H_3PO_4 or HCl or H_2SO_4	

portable pH meter



Maintenance of electrodes

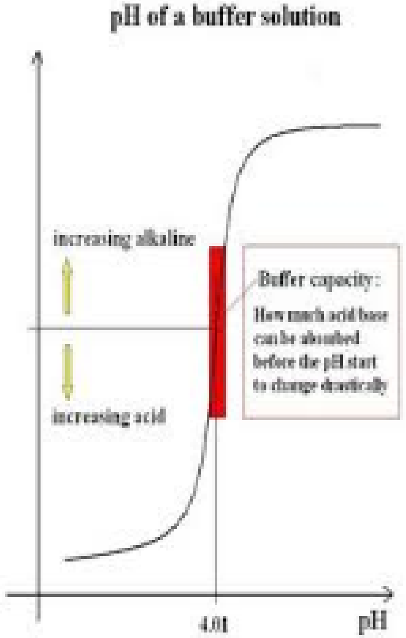
- pH & EC electrodes are consumable materials
  - Both required calibration at least once per month.
  - EC electrode has min maintenance requirement
  - pH electrode
    - has short usable lifespan (6 ~ 12 months)
    - need to be submerged in saturated KCl solution when not in use.

EC calibration solution

- If provided is powder type, need to be soak in pure water or at least de-ionized water to make the calibration solution
- EC calibration solution has sever standards (upper photo)
- Commonly used is under 25 ^{o}C, EC values of 1413 and 12880 μS/cm
- Solution at different temperature will have different EC value ever for same standard solution. (as shown in the bottom photo)

pH buffer solution

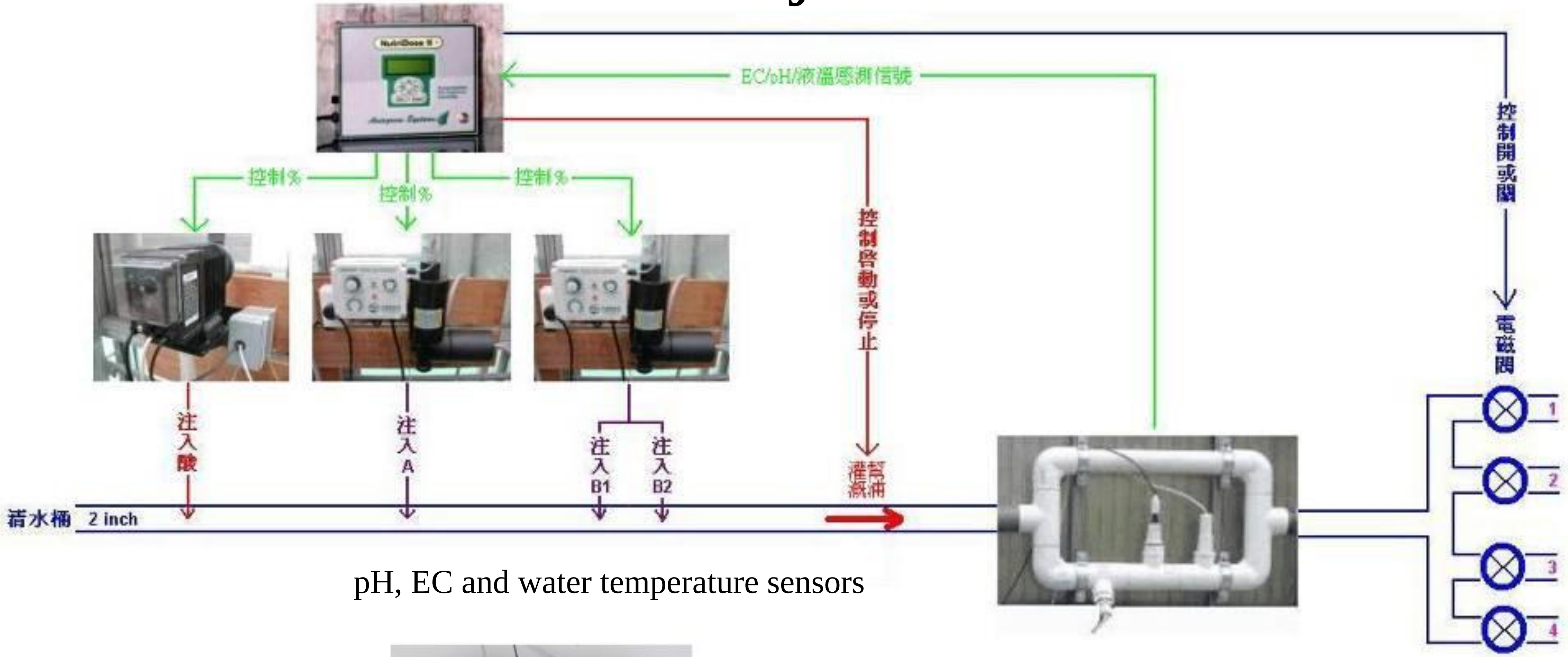
- pH buffer solution is in liquid form
  - normally pH = 4, 7, 10
  - Temperature also affects pH values, as shown below pH = 10.01
- For hydroponic applications, only pH=4, 7 are needed for calibration.



EC control

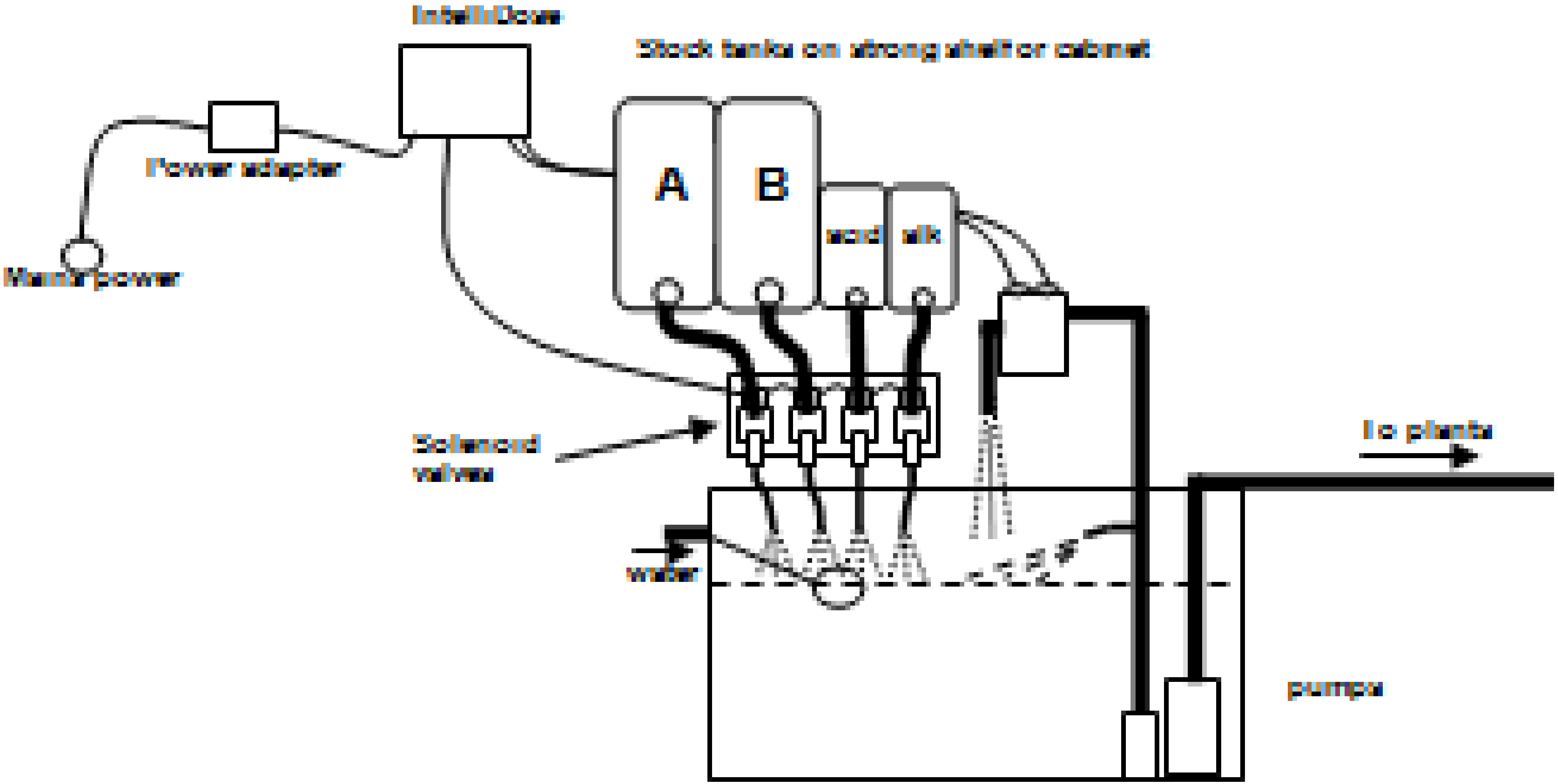
- EC low, provide with rich solution
  - Manually
  - Direct injection
  - Using Solenoid Valves
  - Using peristaltic pump
- EC high, add in RO water
  - Manually
  - Automatically (water level valve)

Direct injection

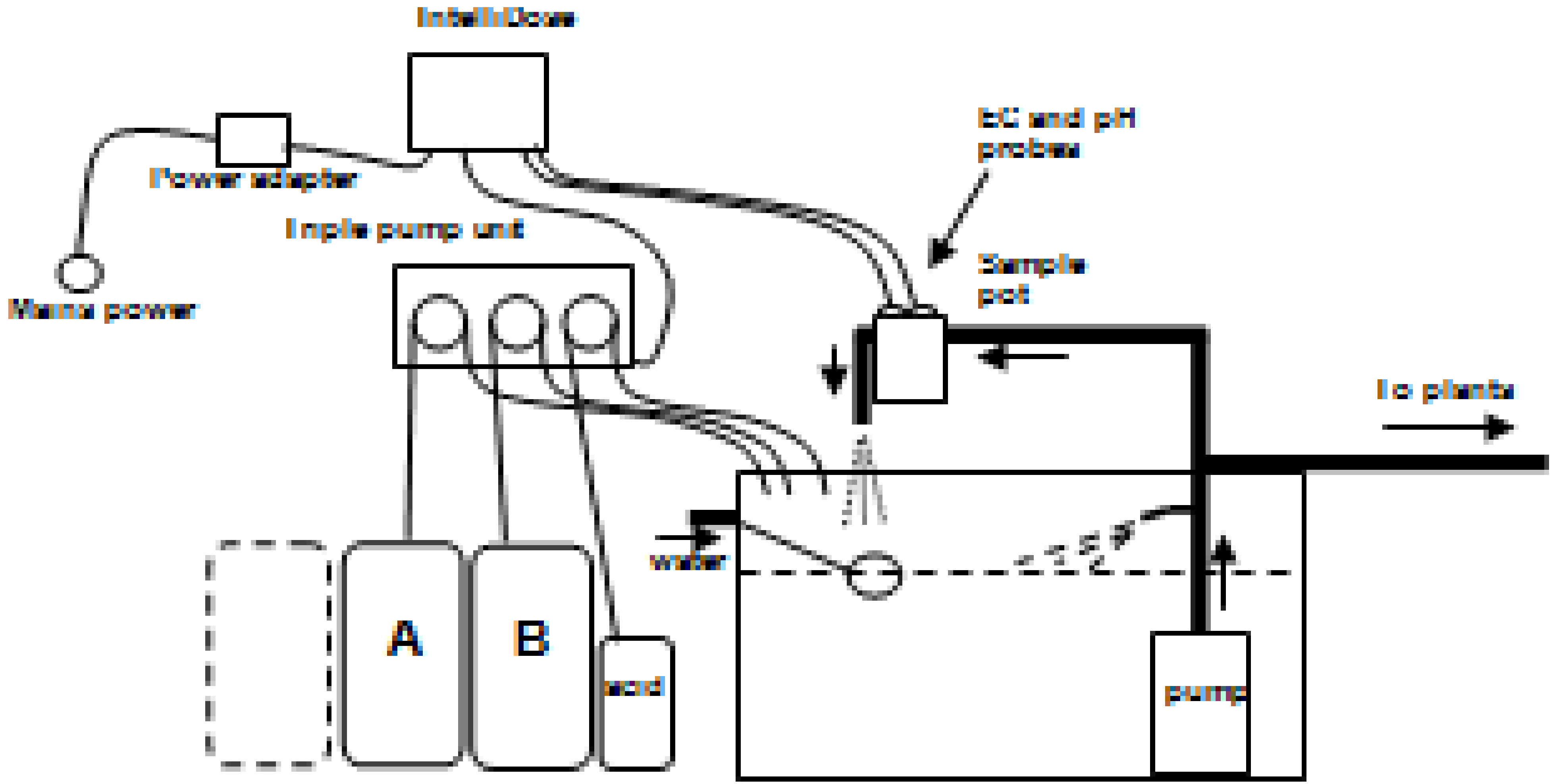


pH, EC and water temperature sensors

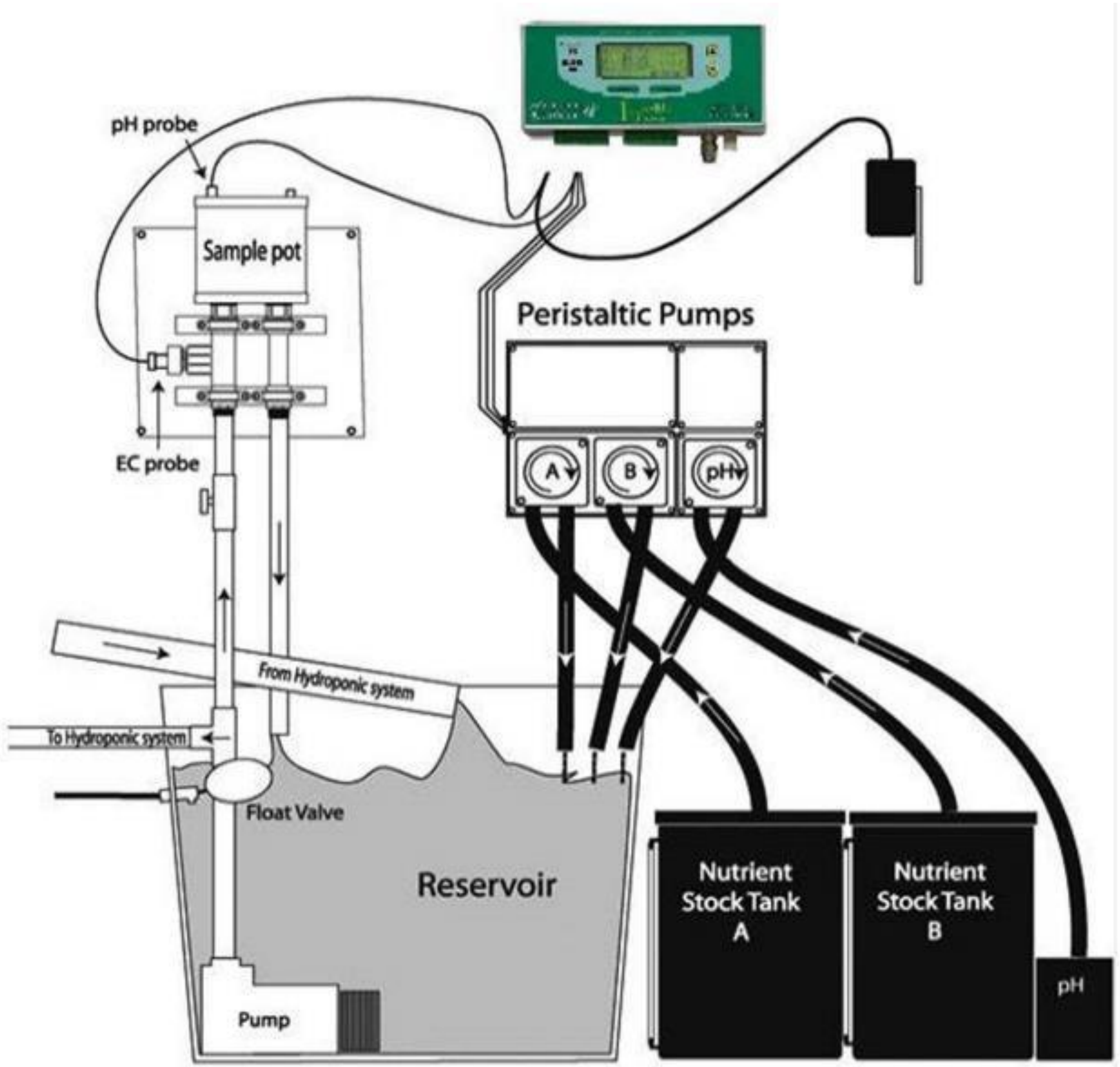
Solenoid Valves



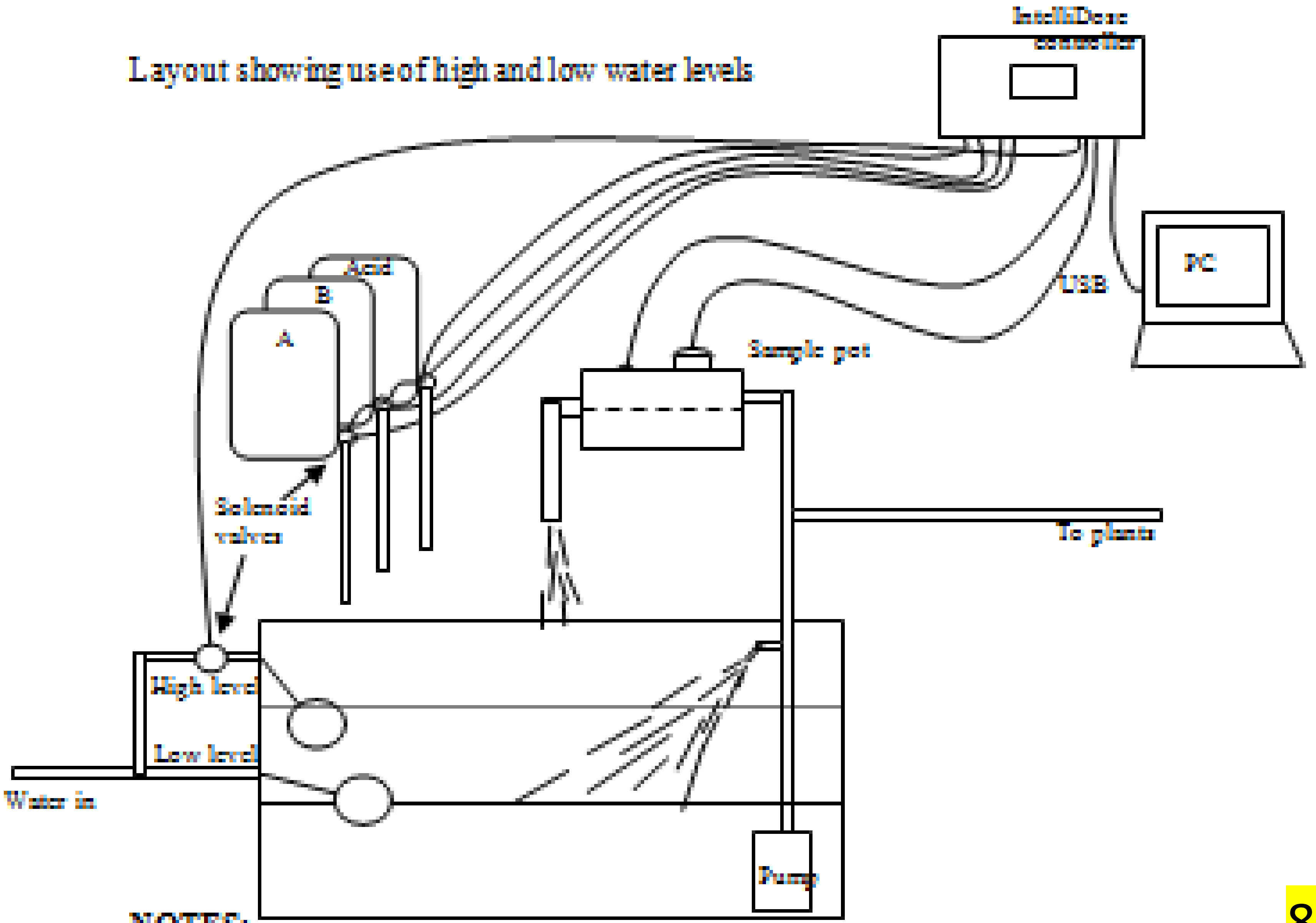
peristaltic pump



Design 2：Sensors not in the buffering tank

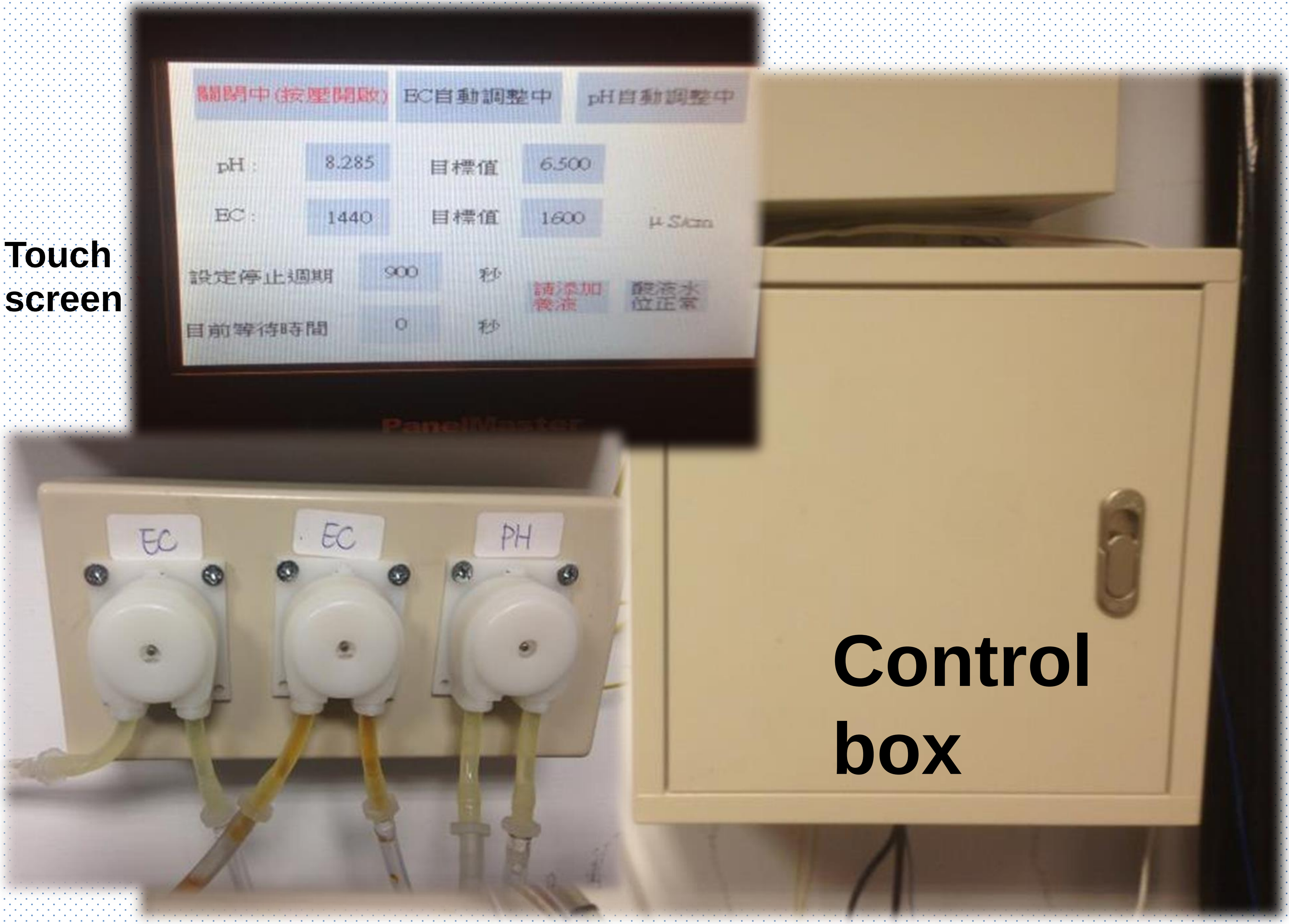


Two water levels to control EC



NOTES:

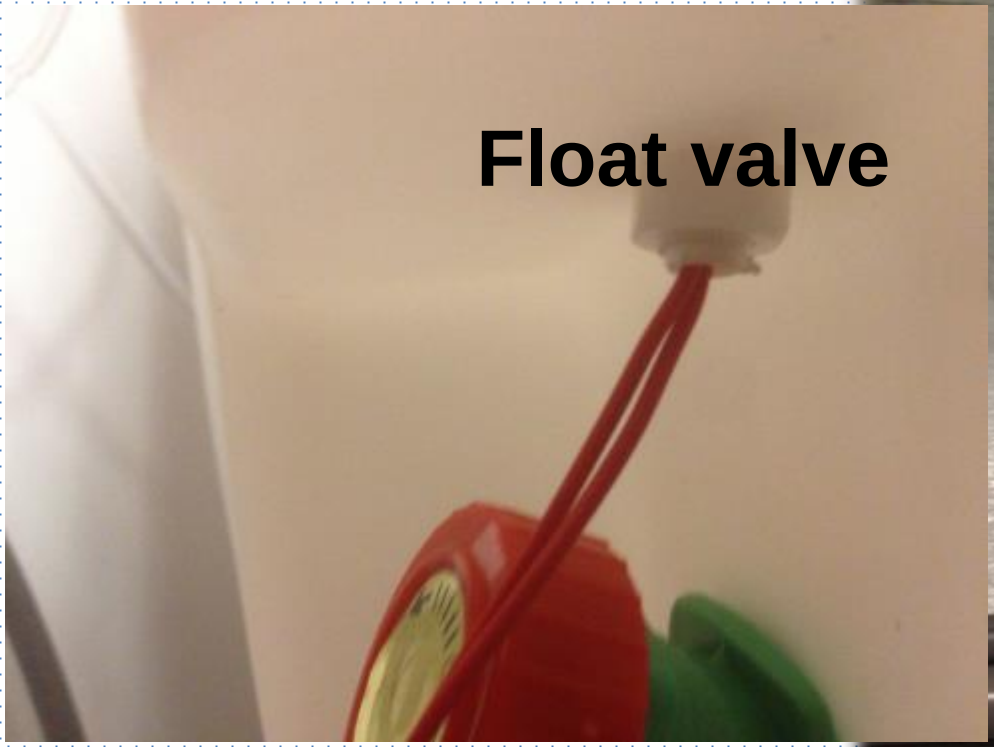
Touch screen



Example of a pH, EC control Box

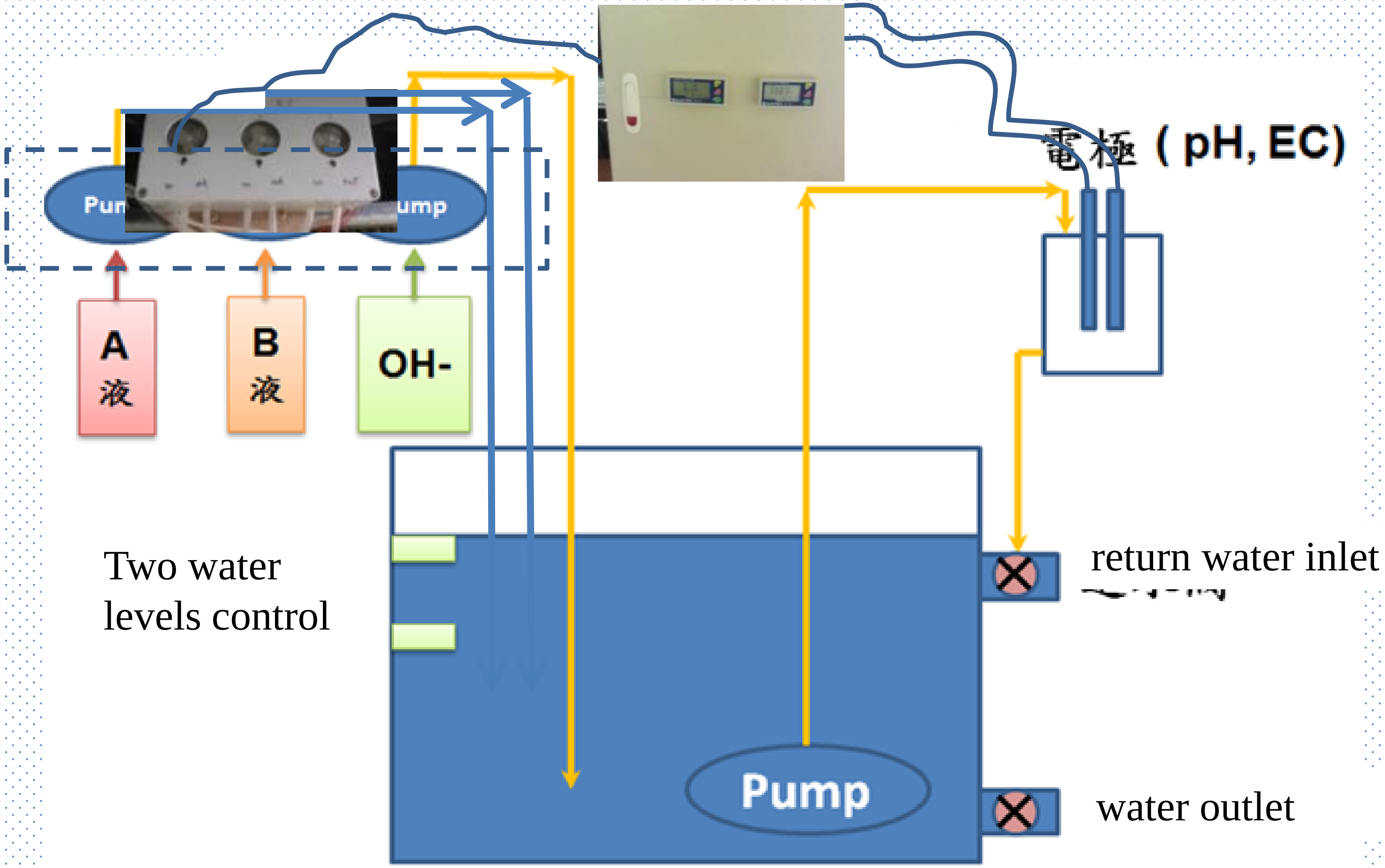
Concentrated Tanks

30 L PE buckets/tanks for concentrated A, B solutions



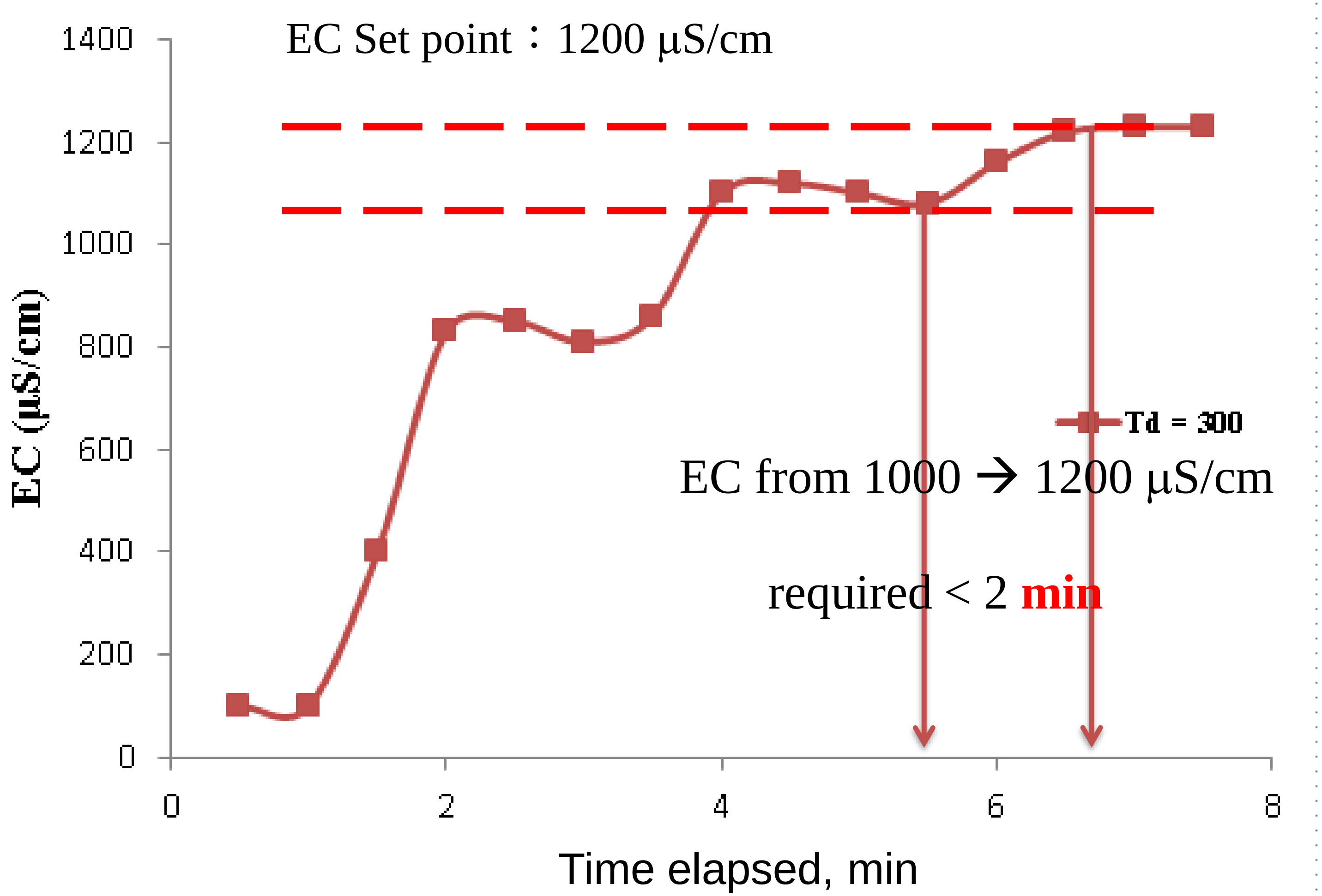
Mixing tank

Nutrient control

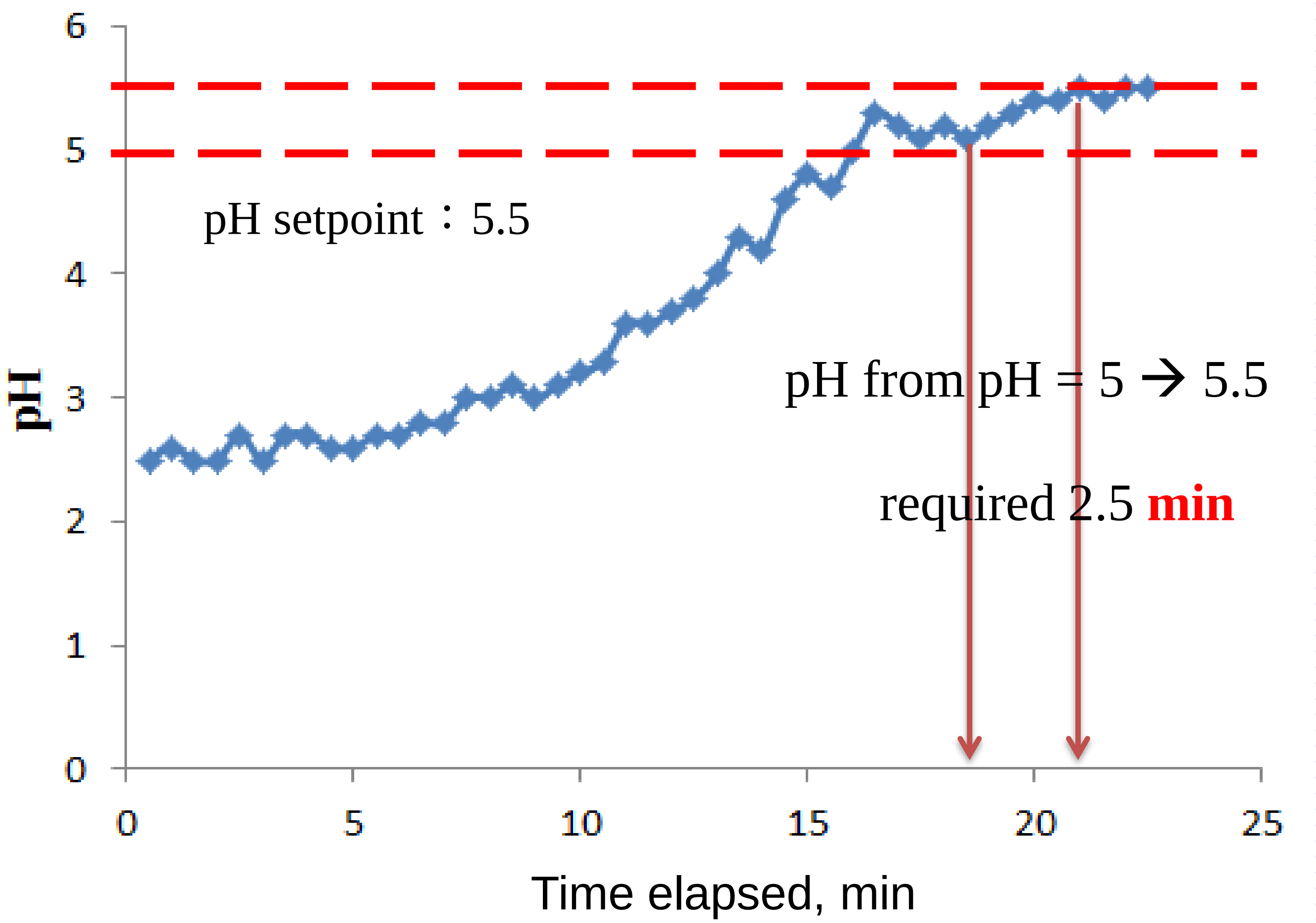


Kong and Fang, 2012

EC control (60 L water)



pH control (60 L water)



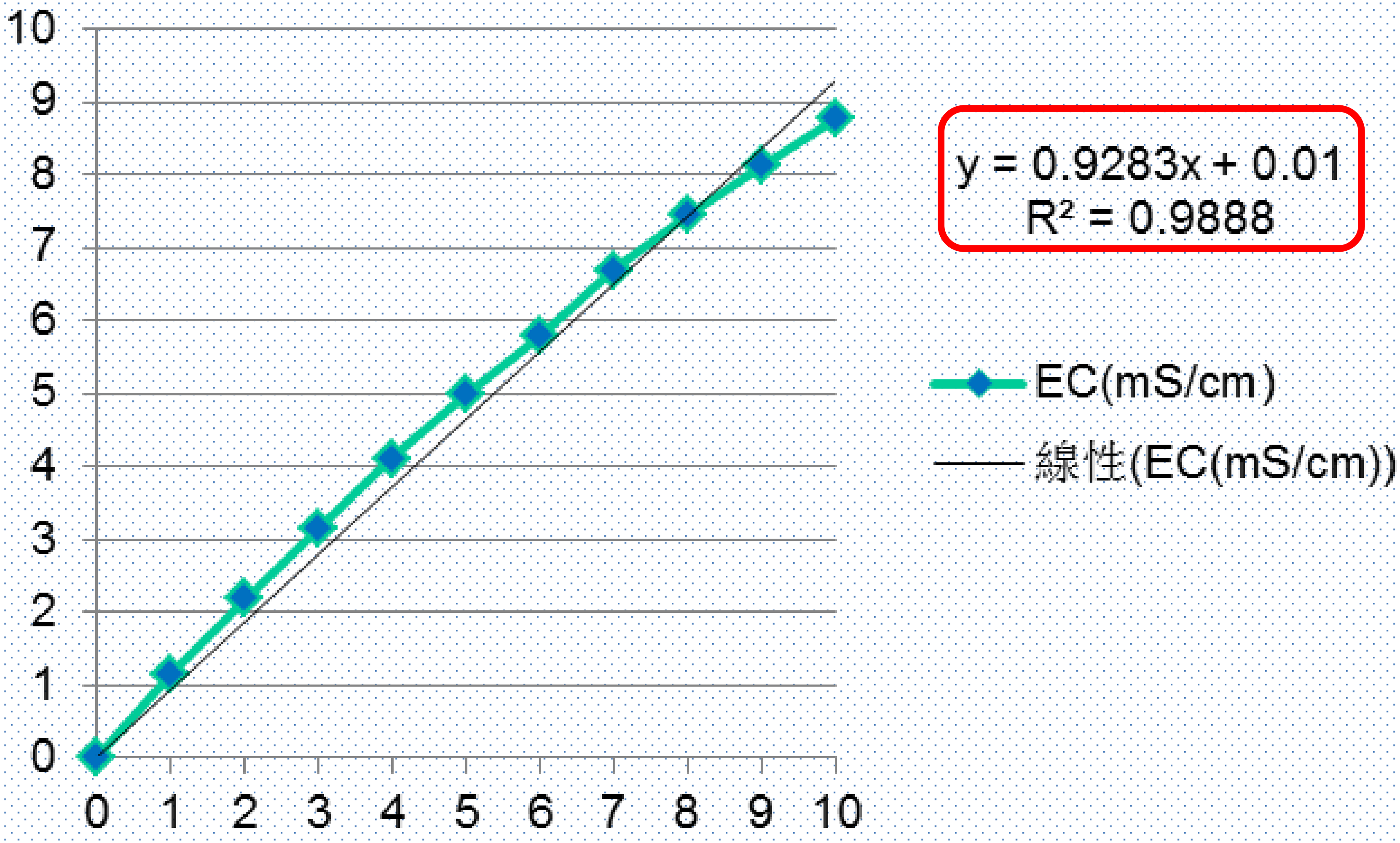
Apply this system to 6 ton of water

- EC from 1000 → 1200 μS/cm
  - ➢required 2 x (6000/60) = **200 min (1 μS/cm / min)**
- pH from pH = 5 → 5.5
  - ➢required 2.5 x 100= **250 min (0.01 / 5 min)**

Capability of the control > dynamic change of the culturing system

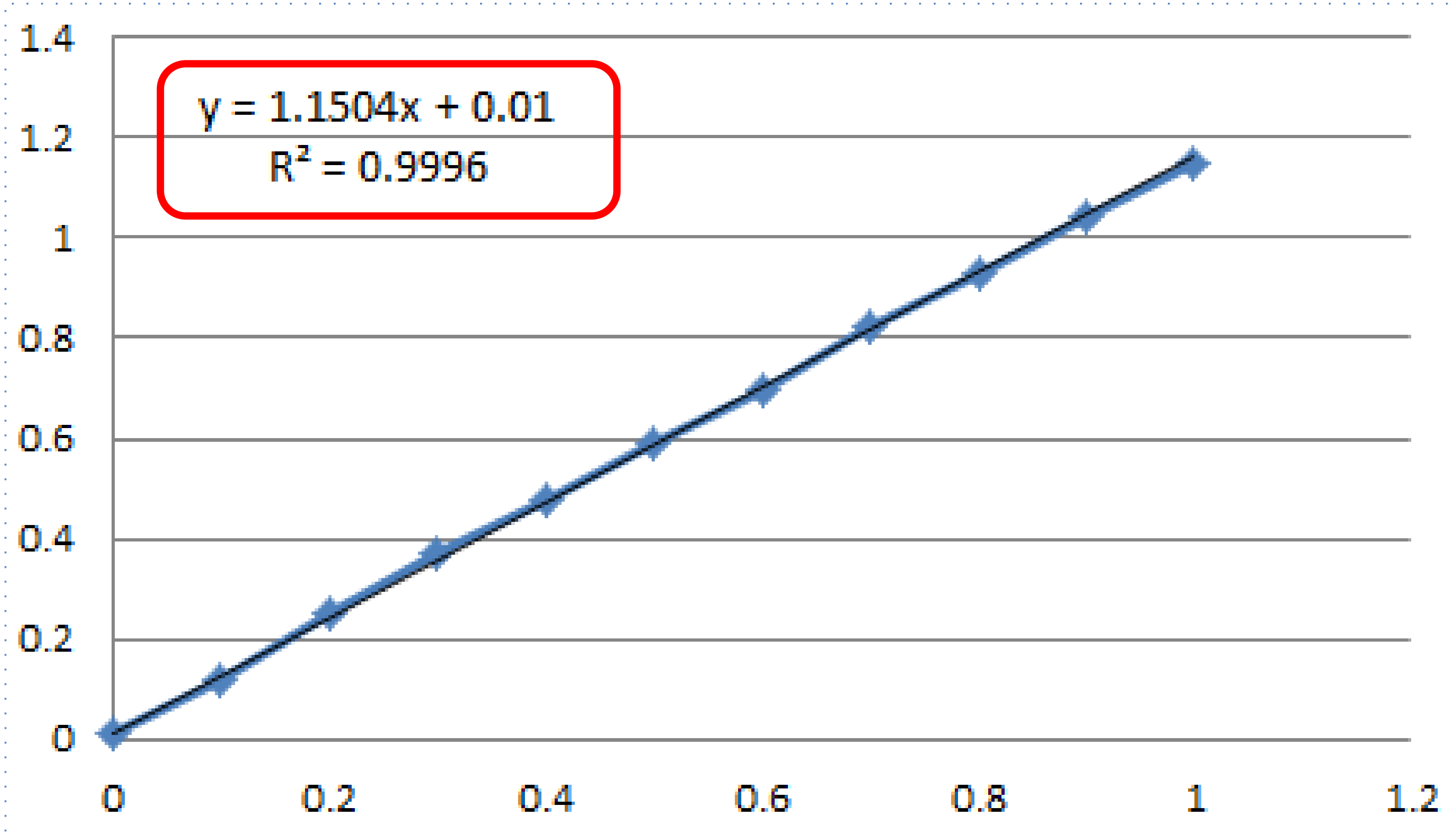
Variation of EC

0 ~ 10 g/L of Hyponex No.1

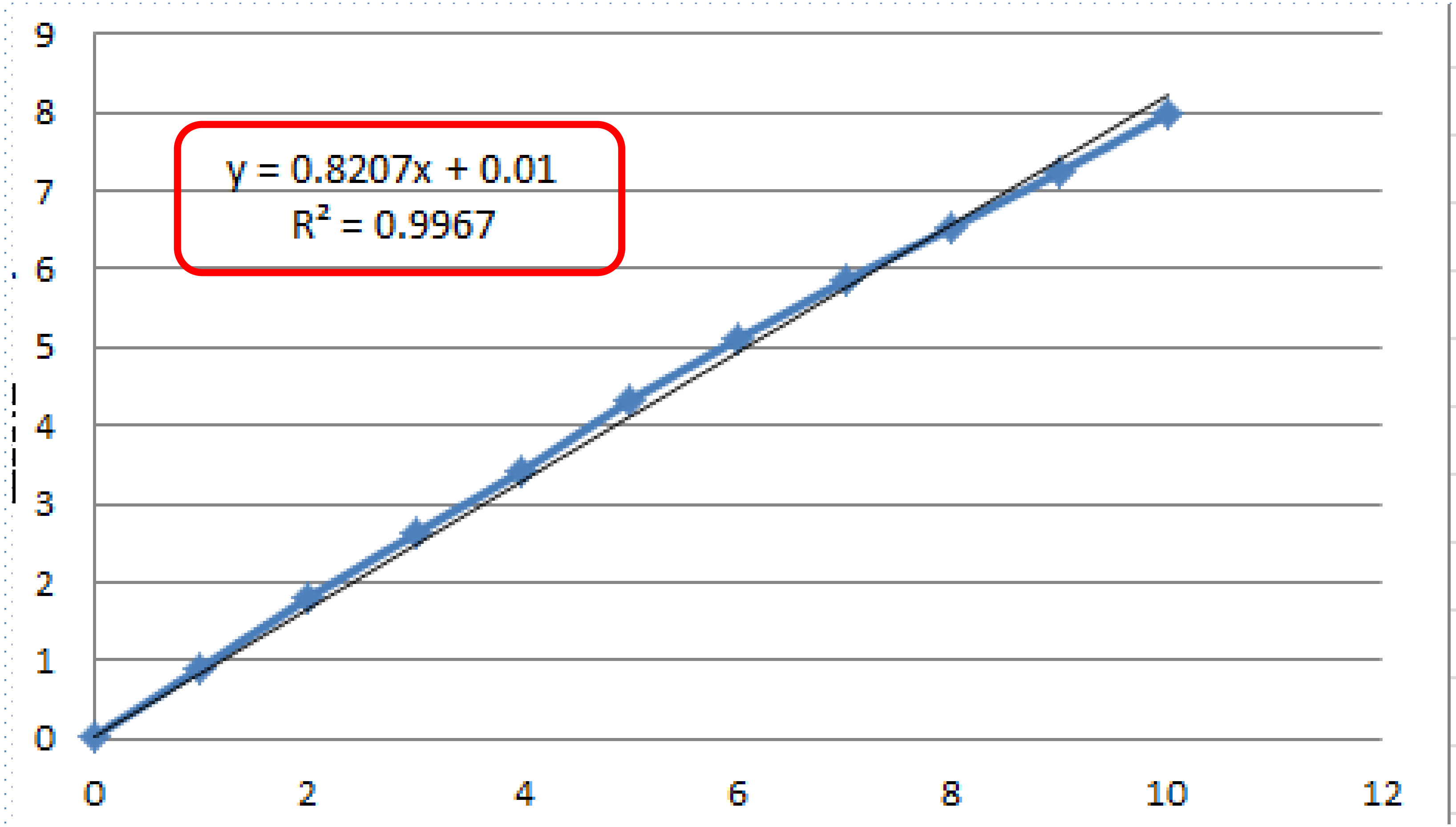


Variation of EC

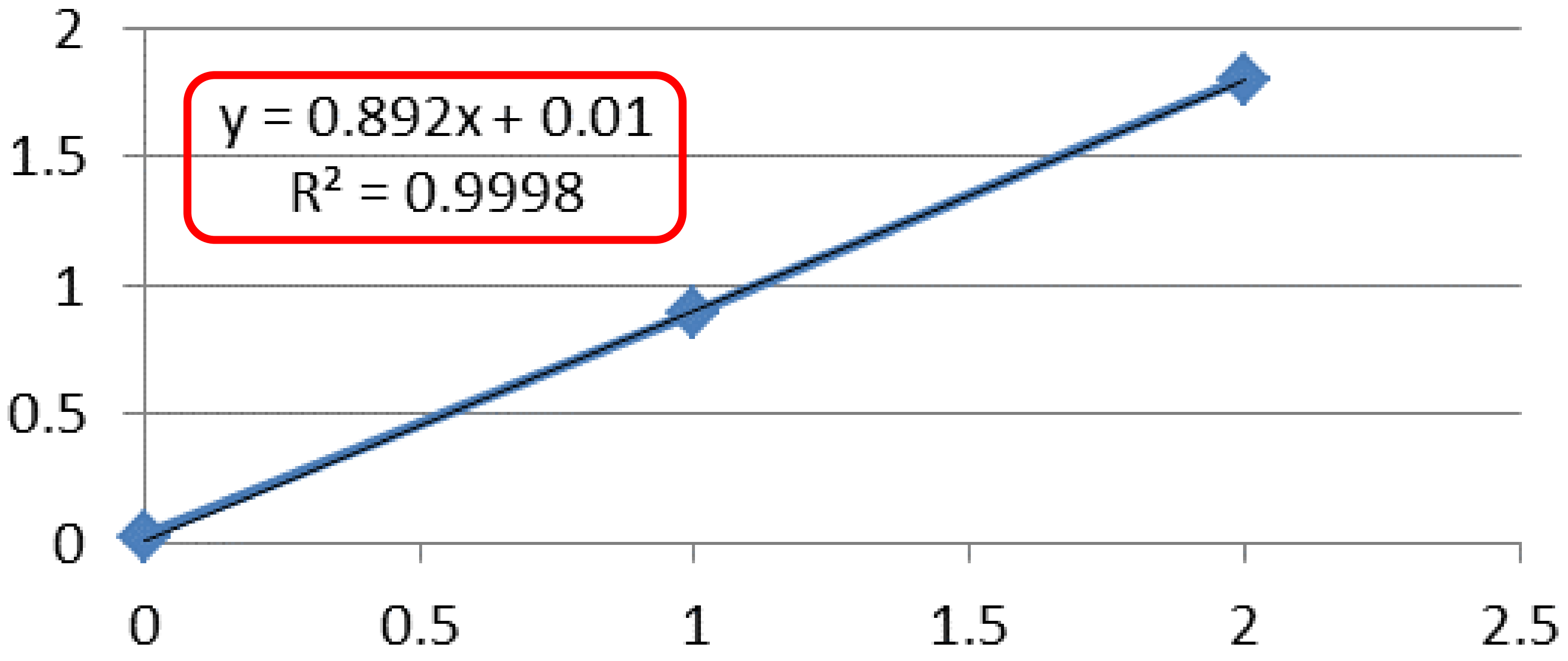
0 ~ 1 g/L of Hyponex No.1



Variation of EC
0 ~ 10 g/L of Hyponex No.2



Variation of EC
0 ~ 2 g/L of Hyponex No.2



Hyponex No.1 vs. No.2

EC of RO =	0.01	
	Slope of EC line	g/L
No.1	1.1504	1.0344
No.2	0.892	1.334

= (1.2 – 0.01)/1.152

= (1.2 – 0.01)/0.892

Required quantity, no. of 2 kg boxes and total price
for 1 ton of nutrient solution@ EC=1.2 mS/cm

	g	boxes	total NT$
No.1	1034.423	0.52	413.8
No.2	1334.081	0.67	533.6

Assuming 800 NT$ per 2 kg pack

Outline

Preparation of nutrient solution

pH, EC

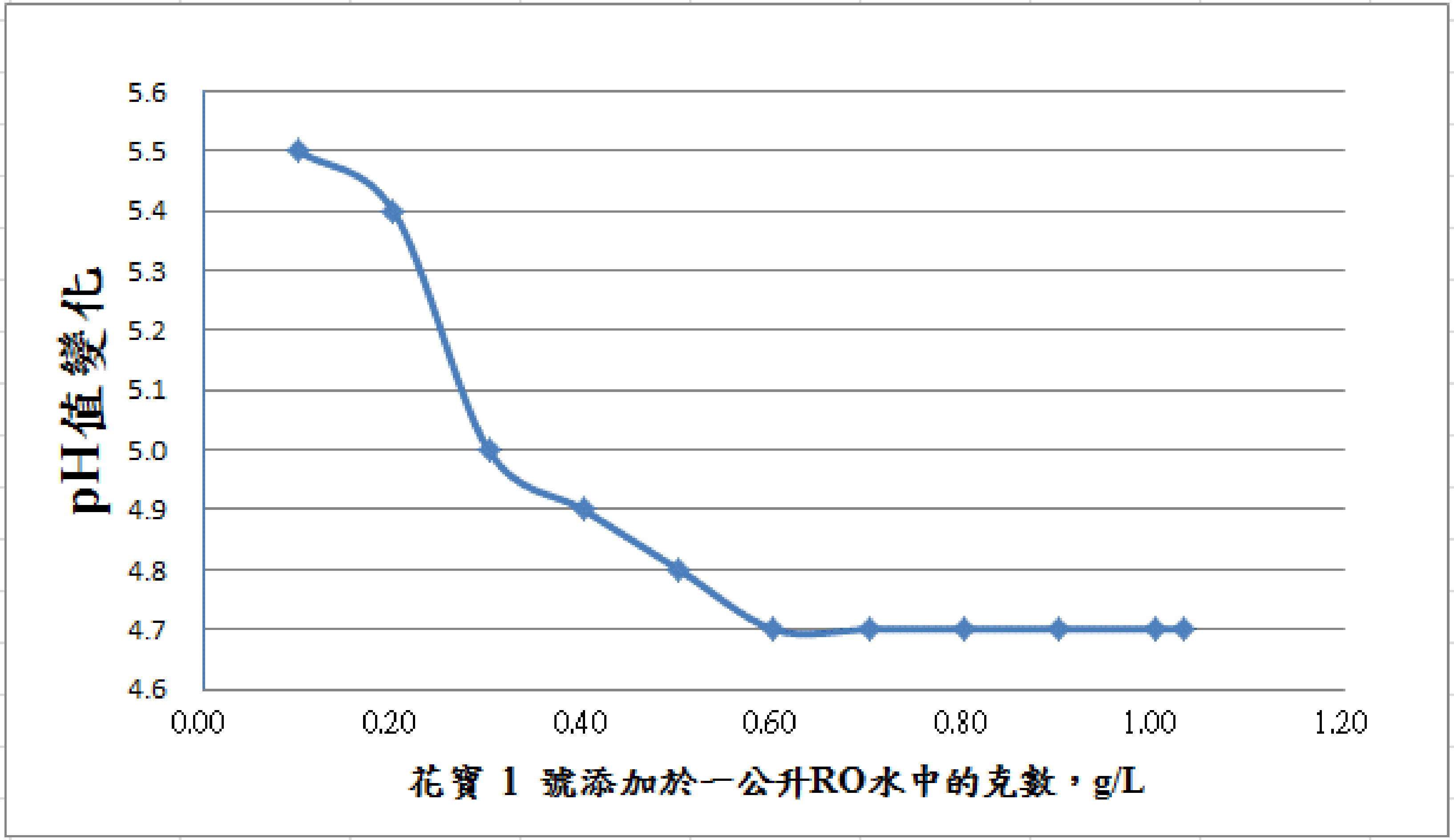
Management

pH Adjustment

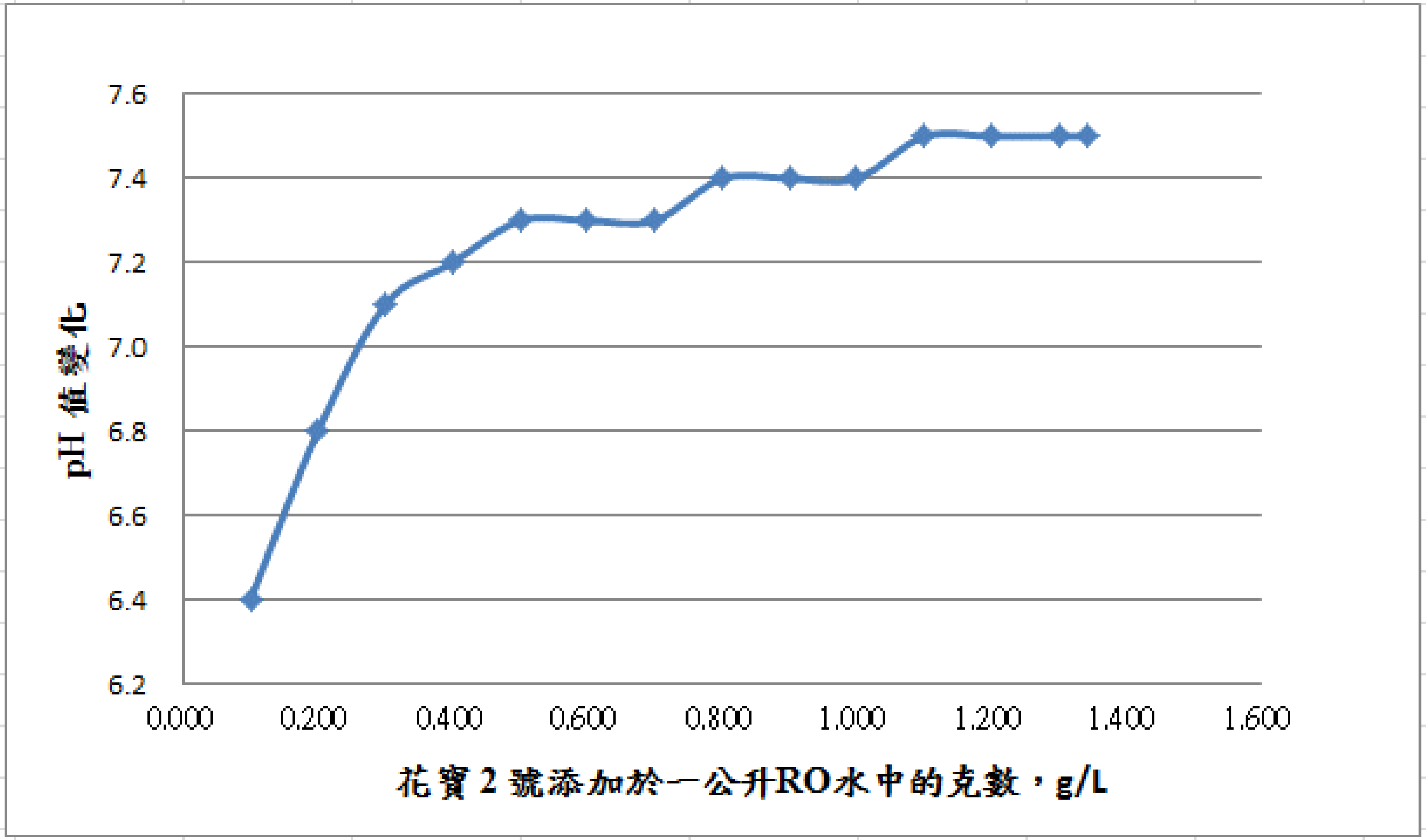
Hydroponic systems

Literature Review

Variation of **pH**
0 ~ 1 g/L of Hyponex No.1



Variation of pH
0 ~ 1 g/L of Hyponex No.2



pH variation in Hyponex No.1, 2

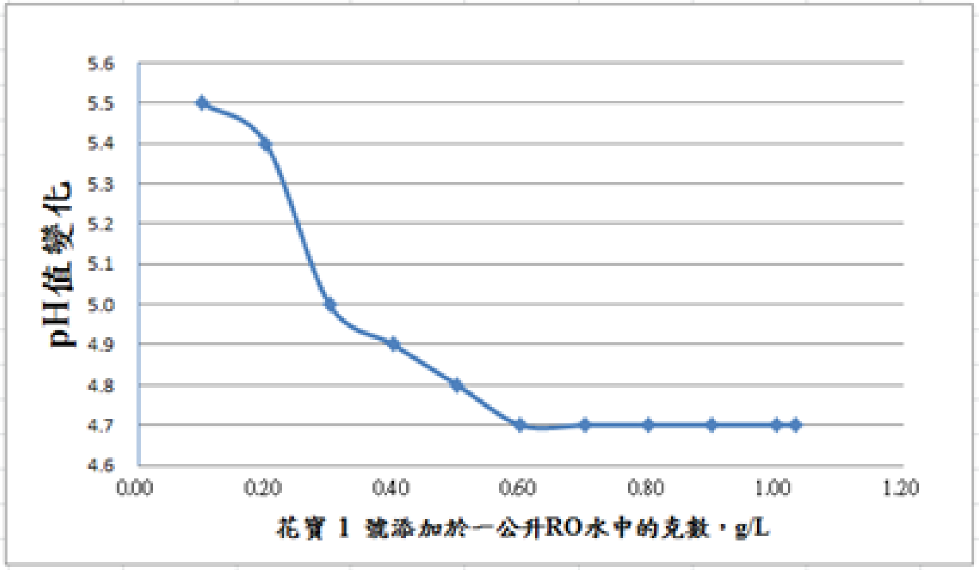
$K^+ \rightarrow H^+$

N:P:K
07-06-19

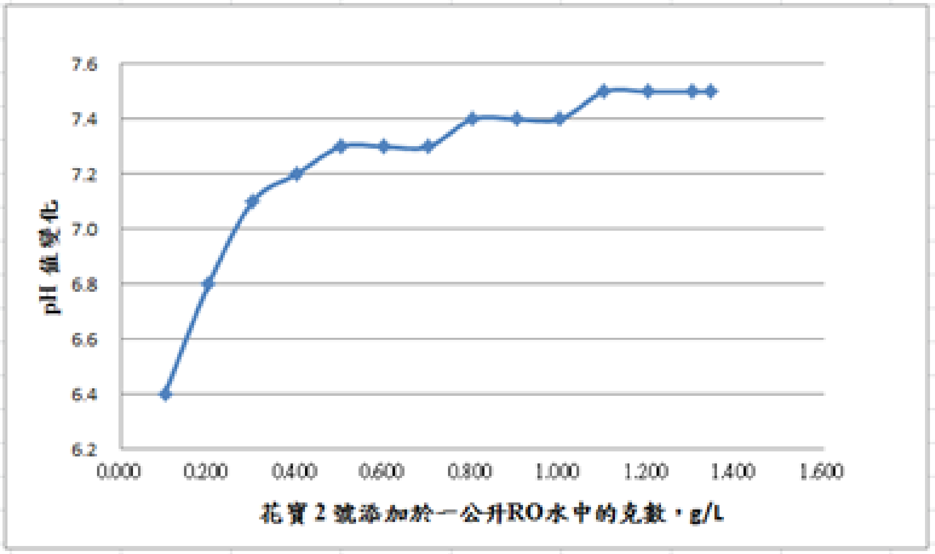
N:P:K
20-20-20

$NO_3^- \rightarrow OH^-$

Hyponex No.1

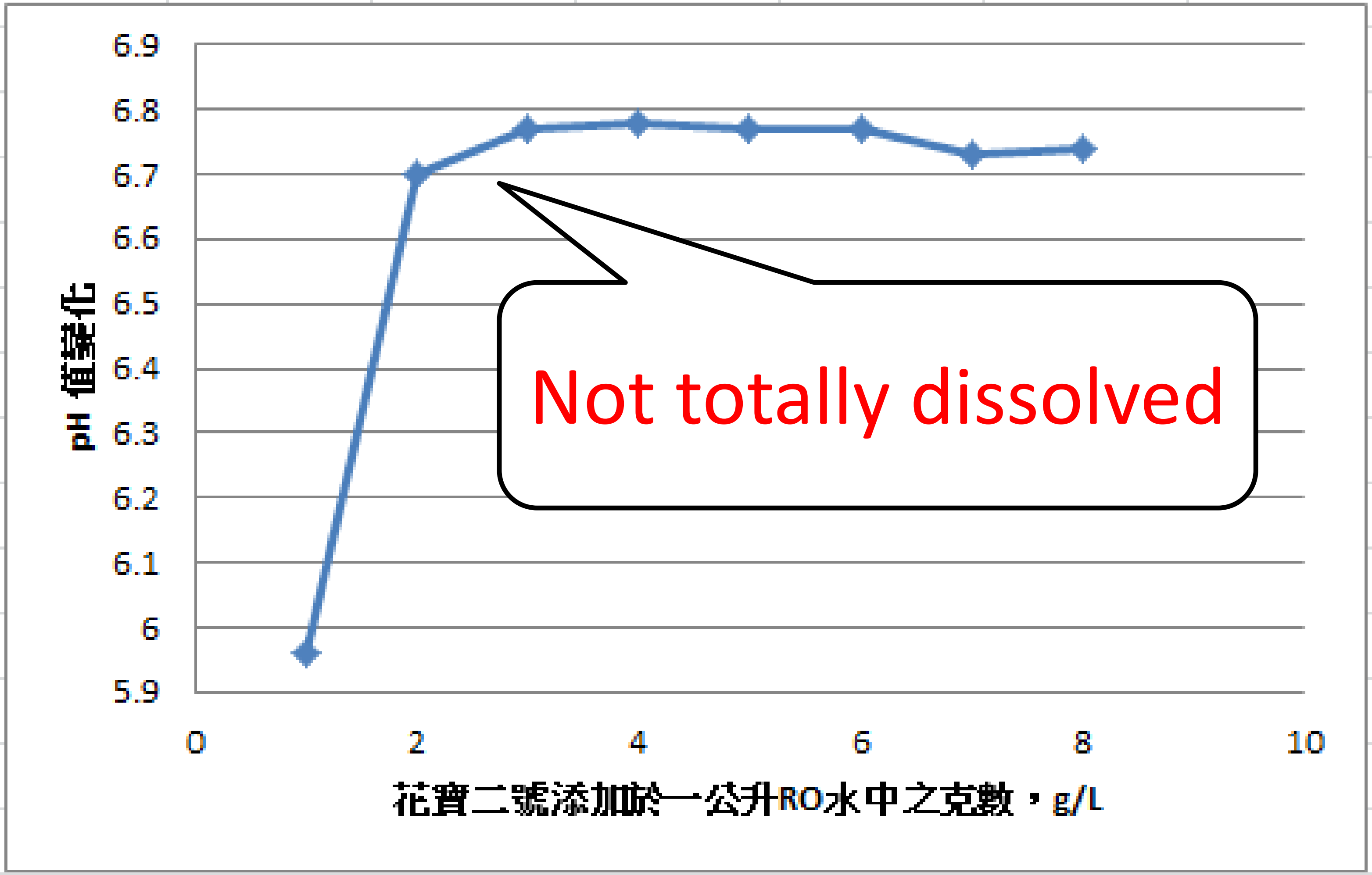


Hyponex No. 2



pH variation of 0 ~ 30 g/L Hyponex No.2

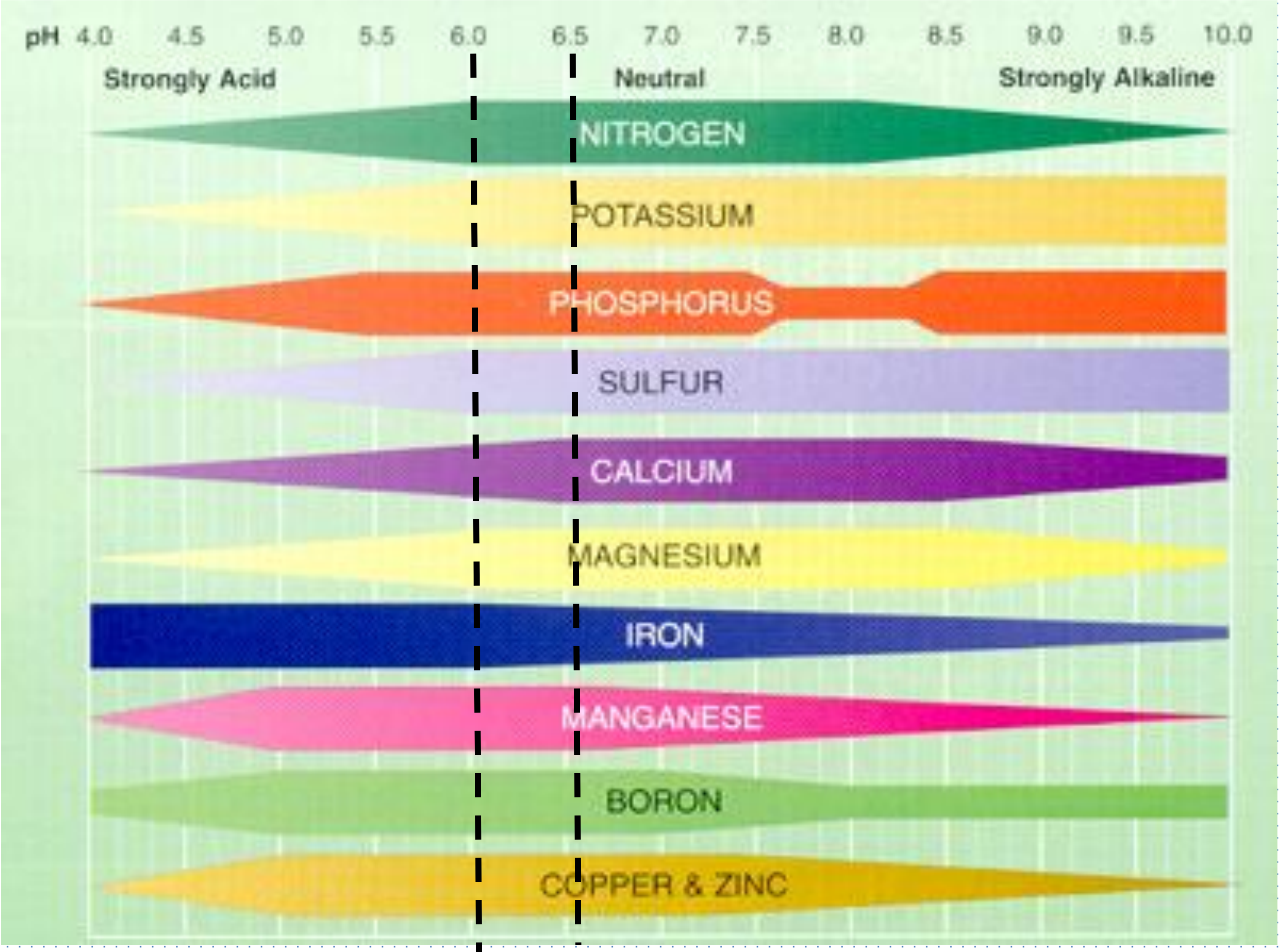
pH variation of 0 ~ 8 g/L Hyponex No.2



Range of pH for hydroponic system

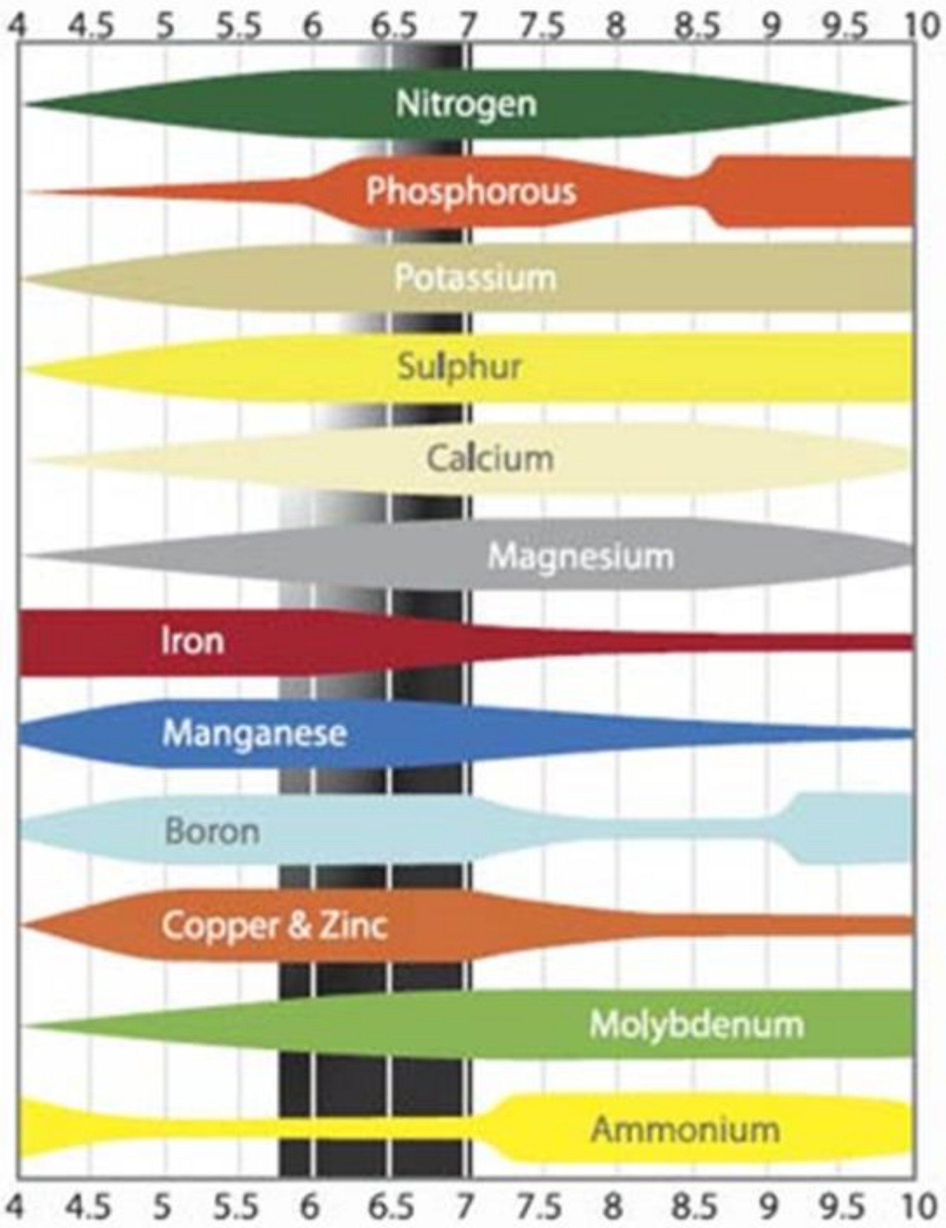
- pH range
  - Best: 6.0~6.2
  - Proper: 6.0-6.5
  - OK: 5.5-6.5
  - pH > 8, Fe, Mn, P deficit
  - pH < **4.5**, Ca, Mg, K precipitation and more

pH affects availability



A different diagram

proper range: 6.5~7 for soil



pH adjustment

1000 L target pH6.0 **H_3PO_4** (mL)		1000 L target pH6.0 **KOH** (mL)	
pH	8.5% H_3PO_4	pH	4.0% KOH
7.0	940.7	5	707.9
6.9	891.7	5.1	666.8
6.8	832.7	5.2	619.2
6.7	763.7	5.3	564.9
6.6	684.6	5.4	504
6.5	595.6	5.5	436.5
6.4	496.5	5.6	362.5
6.3	387.4	5.7	281.8
6.2	268.3	5.8	194.4
6.1	139.1	5.9	100.5
6.0	–	6	–

pH adjustment

pH DOWN

- T affects pH
- Same amount of acid does not bring down same amount of decrease in pH

pH Down (ml)	pH Value		Difference	Temperature (°C)
	before	after		
0.2	7.13	6.40	0.73	25.40
0.2	6.40	6.20	0.20	25.40
0.2	6.20	6.00	0.20	25.40
0.2	6.00	5.80	0.2	25.50
0.2	5.80	5.67	0.13	26.60
0.2	5.67	5.37	0.3	25.60
0.2	5.37	5.00	0.37	25.8
0.2	5.00	3.69	1.31	25.9
0.2	3.69	3.30	0.39	26.0
0.2	3.30	3.14	0.16	26.1
0.2	3.14	2.97	0.17	26.1
0.2	2.97	2.86	0.11	26.1
0.2	2.86	2.78	0.08	26.1
0.2	2.78	2.72	0.06	26.1
0.2	2.72	2.45	0.27	26.2
Average			0.312	

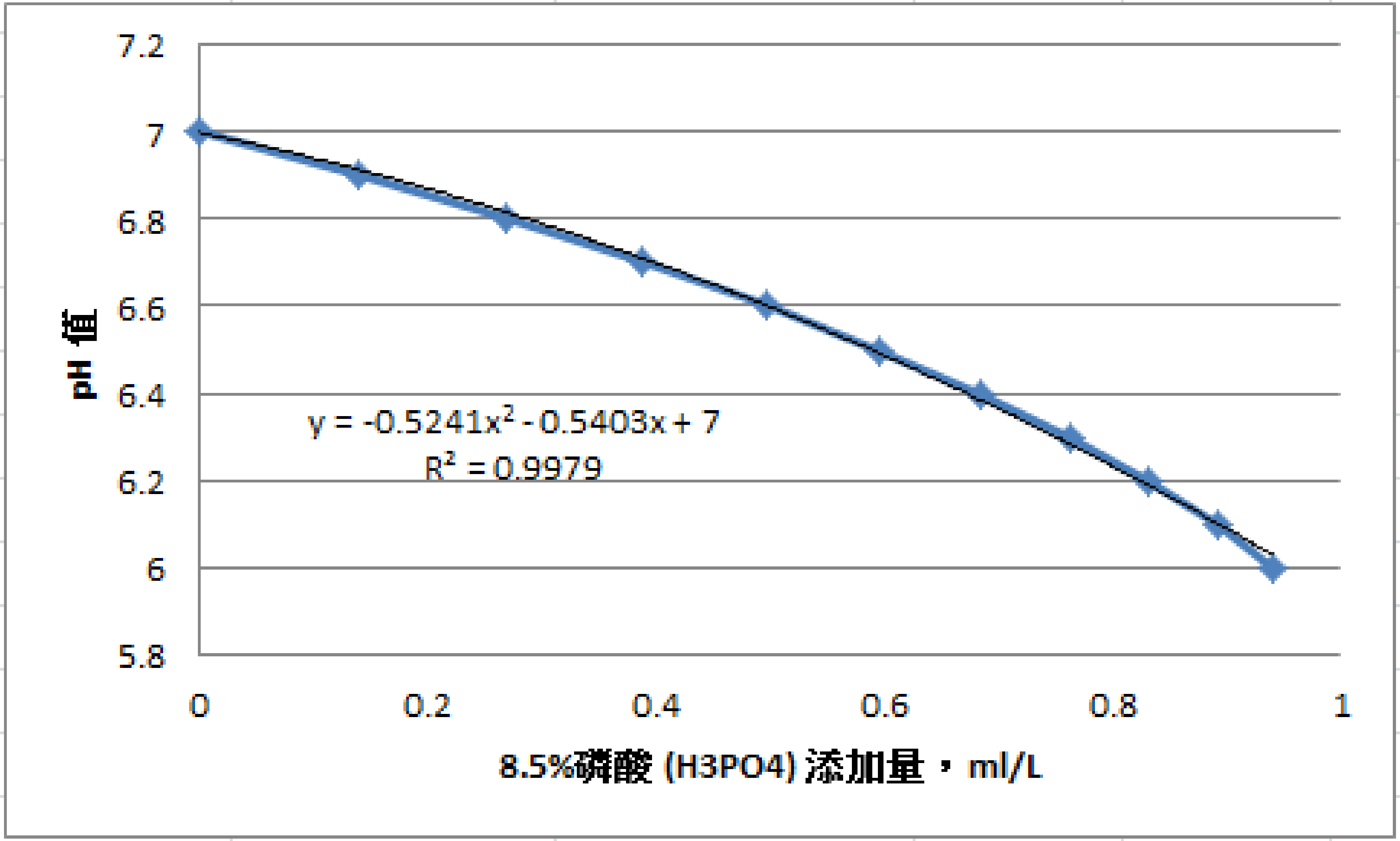
pH adjustment

pH UP

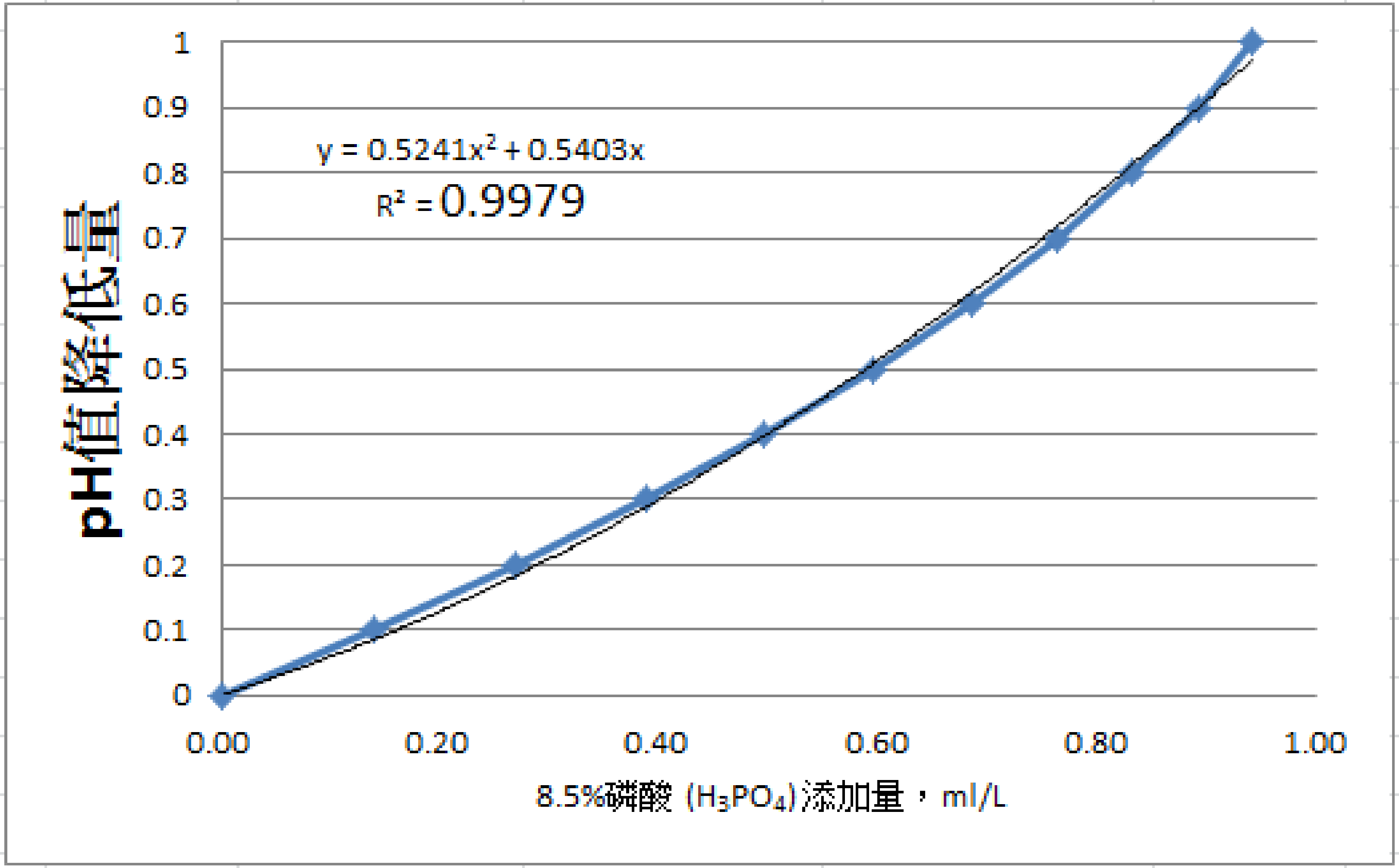
- T affects pH
- Same amount of alkali liquid does not leads to same amount of pH increment
- pH adjustment is more difficult to predict compare with EC adjustment

pH Up (ml)	pH Value		Difference	Temperature (°C)
	before	after		
0.2	2.45	2.54	0.09	26.1
0.2	2.54	2.60	0.06	26.0
0.2	2.60	2.68	0.08	25.9
0.2	2.68	2.78	0.1	25.9
0.2	2.78	2.86	0.08	25.9
0.2	2.86	2.96	0.1	25.9
0.2	2.96	3.09	0.13	25.9
0.2	3.09	3.40	0.31	25.9
0.2	3.40	3.93	0.53	25.9
0.2	3.96	4.89	0.93	25.9
0.2	4.89	5.38	0.49	25.9
0.2	5.38	5.65	0.27	25.9
0.2	5.65	5.84	0.19	26.9
0.2	5.84	5.96	0.12	26.1
0.2	5.96	6.12	0.16	26.1
0.2	6.12	6.23	0.11	26.10
0.2	6.23	6.31	0.08	26.10
0.2	6.31	6.40	0.09	26.2
0.2	6.40	7.06	0.66	26.2
Average			0.244	

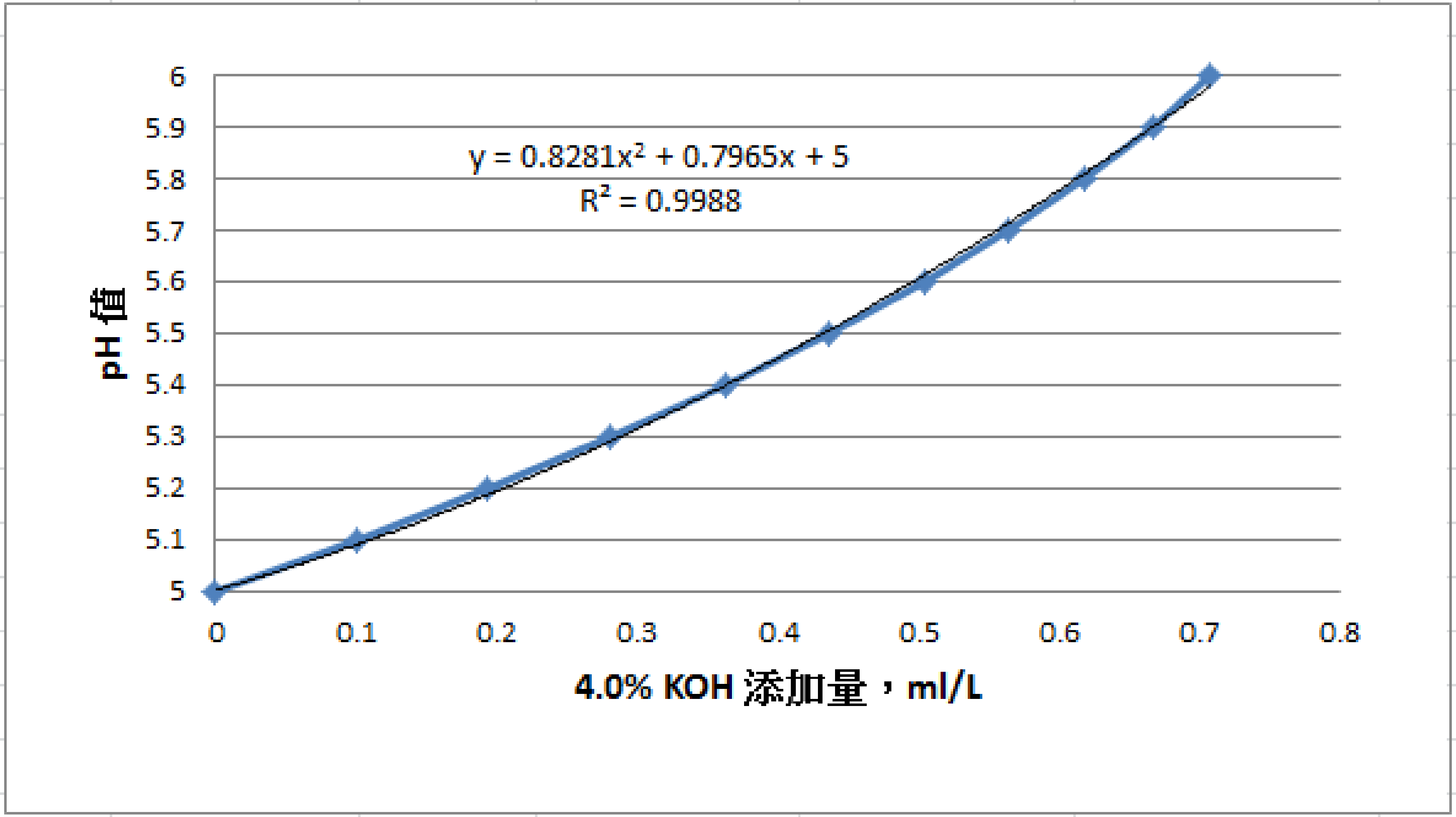
Reduce pH


7.2
7
6.8
6.6
6.4
6.2
6
5.8
pH 值
y = -0.5241x2 - 0.5403x + 7
R2 = 0.9979
0
0.2
0.4
0.6
0.8
1
8.5%磷酸 (H3PO4) 添加量，ml/L

Amount of pH decrement

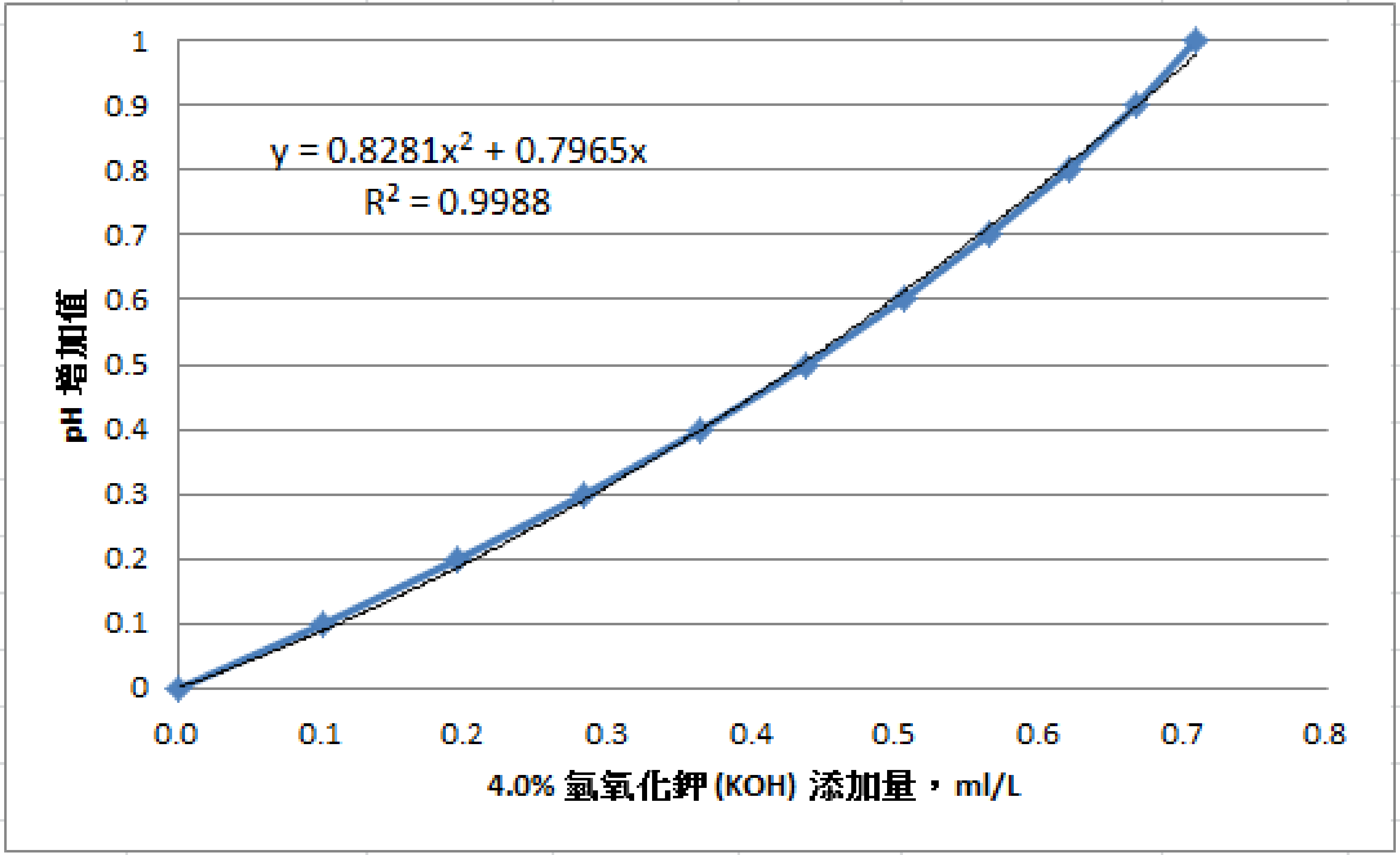


Increase pH



y = 0.8281x² + 0.7965x + 5
R² = 0.9988
pH 值
6
5.9
5.8
5.7
5.6
5.5
5.4
5.3
5.2
5.1
5
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
4.0% KOH 添加量，ml/L

Amount of pH increment



pH adjustment

- To reduce pH by 1, such as pH 7 → pH 6
  - Required 0.9~1 ml/L of 8.5% H_3PO_4
  - Diluted 200 times first then drip in and stirred
- To increase pH by 1, such as pH 5 → pH 6
  - Add 0.7 mL/L of 4 %KOH
  - Diluted 200 times first then drip in and stirred
- The variation of pH is not linear to the amount of H_3PO_4 or KOH added.

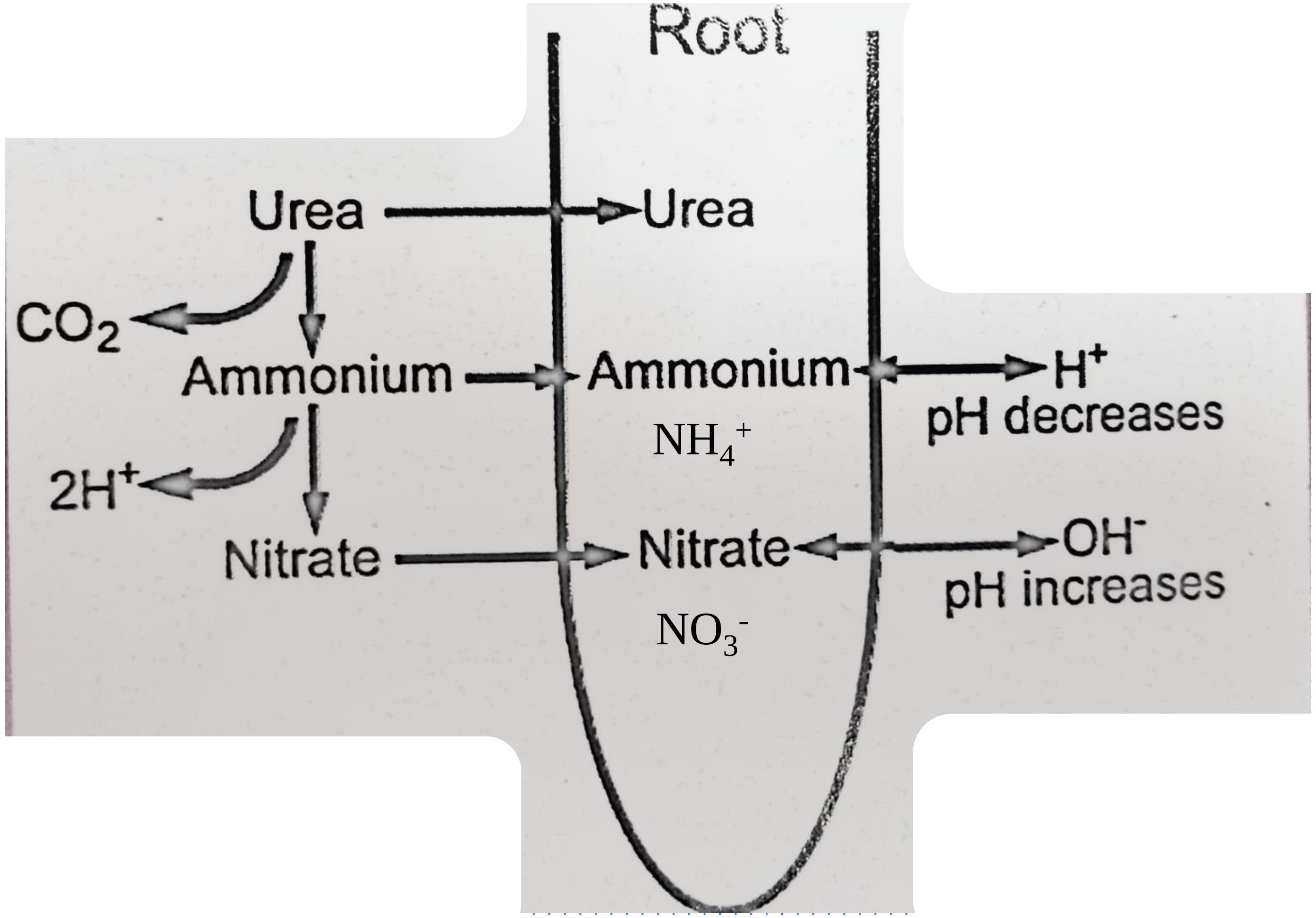
Reasons of pH variation during cultural period

1) Plant absorption differences among elements, such as tomato prefer NO_3^- ， PO_3^{-3} and K^+, melon prefer Ca^{+2} and Mg^{+2}
2) Improper match of recipe and plants
3) Under strong light and high T, plants absorbed more N, P, K, absorbed less Ca, Mg, leads to pH increase
4) Under less light and low T environment, pH tends decrease

Reasons of pH variation during cultural period (cont..)

5) CO_2 in the air dissolved in water to form H_2CO_3 (carbonic acid), leads to pH decrease
6) from respiration of root, CO_2 combined with Ca^{+2}、Mg^{+2} to form $CaCO_3$, $MgCO_3$ precipitation, lead to increase of pH
7) Some plants such as lettuce, strawberry preferred NH_4^+(Ammonium), after absorption, roots excrete **H^+** leads to reduction of pH
8) Some plants such as pak choy, Chinese cabbage preferred NO_3^- (Nitrate), after absorption, roots excrete **OH^-** leads to increase of pH

pH variation after root absorbed NH_4^+/NO_3^-



Outline

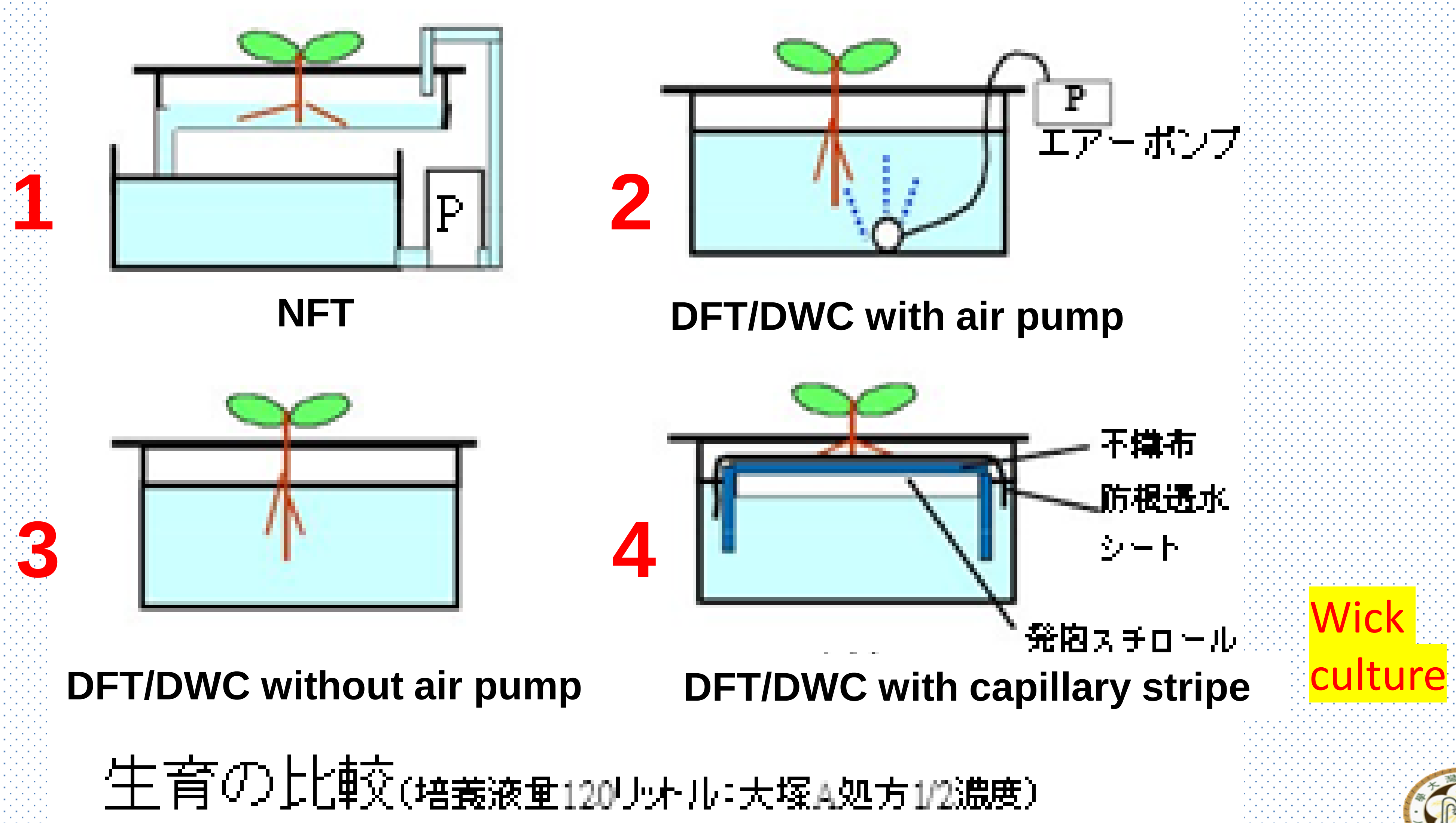
Preparation of nutrient solution

pH, EC Management

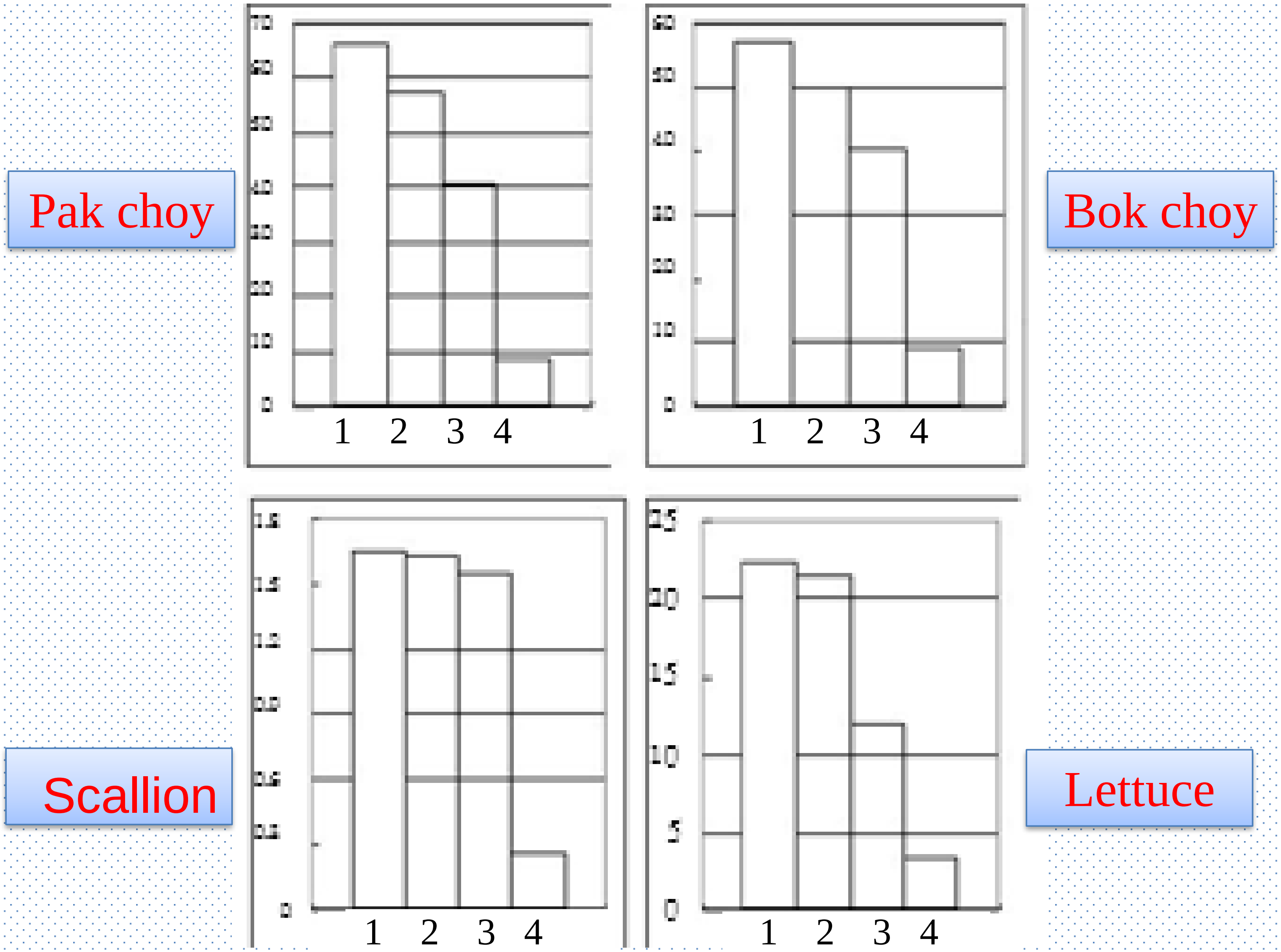
pH adjustment

Hydroponic systems

Comparison on 4 hydroponic systems



Comparison on 4 hydroponic systems



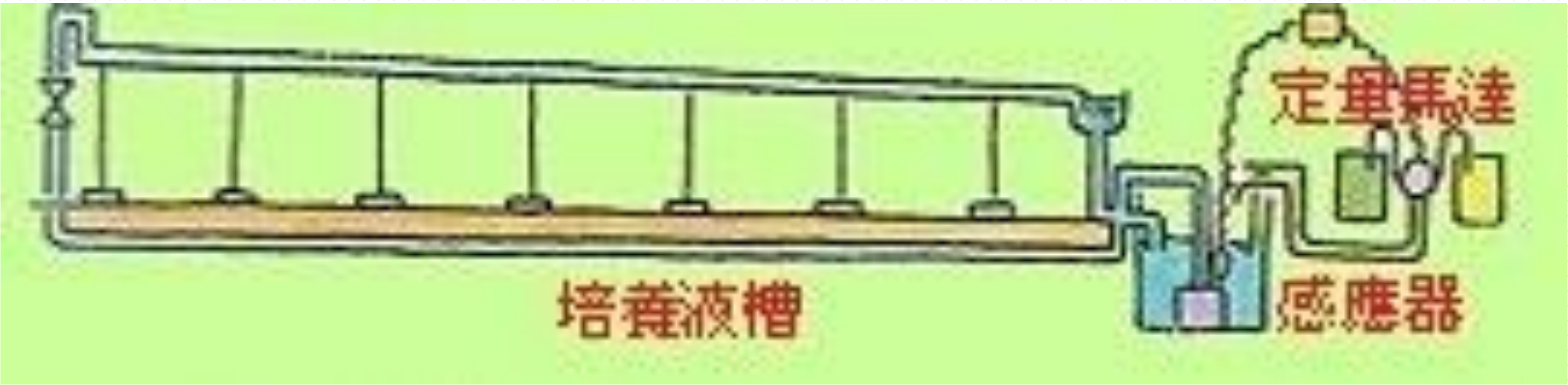
Popular Hydroponic Systems

1. Nutrient Film Technique, NFT
   Leafy vegetable (UK)
2. Deep Flow Technique, DFT
   Deep Water Culture,   DWC
   Leafy vegetable (Japan)
3. Drip Irrigation (rockwool)
   Vine plants: tomato, melon, pepper, cucumber
   (The Netherlands)
4. Ebb and Flow (E&F)

   all of above, tuber plant

5. Aeroponics (spraying, misting, fogging)
6. Wick culture

NFT



Advantages of NFT

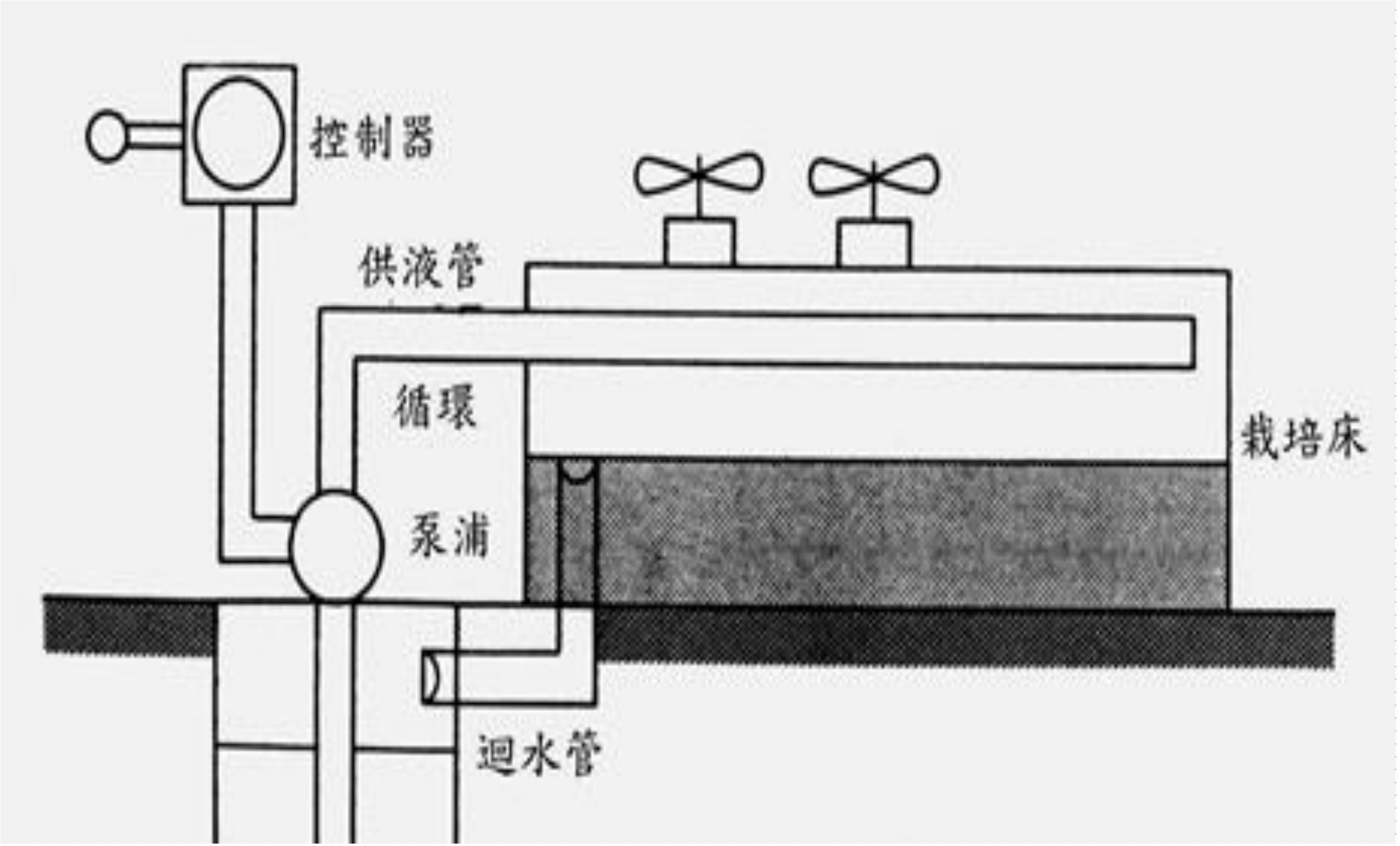
- Easy installation
- Low installation cost
- Continuous flow

NFT trough system

Disadvantages of NFT

- Limited amount of nutrient solution
  - Large influence by the surrounding temperature due to high water T has low saturated dissolved oxygen (DO). only true for GH, not for PFAL
  - Large influence by the plant absorption
- Limited space for root growth: only suitable for plants that did not has lots of roots
- Vigorous growth of root might block the solution flow leads to uneven distribution of nutrient concentration
- Easy to fail in in locations with unstable power supply

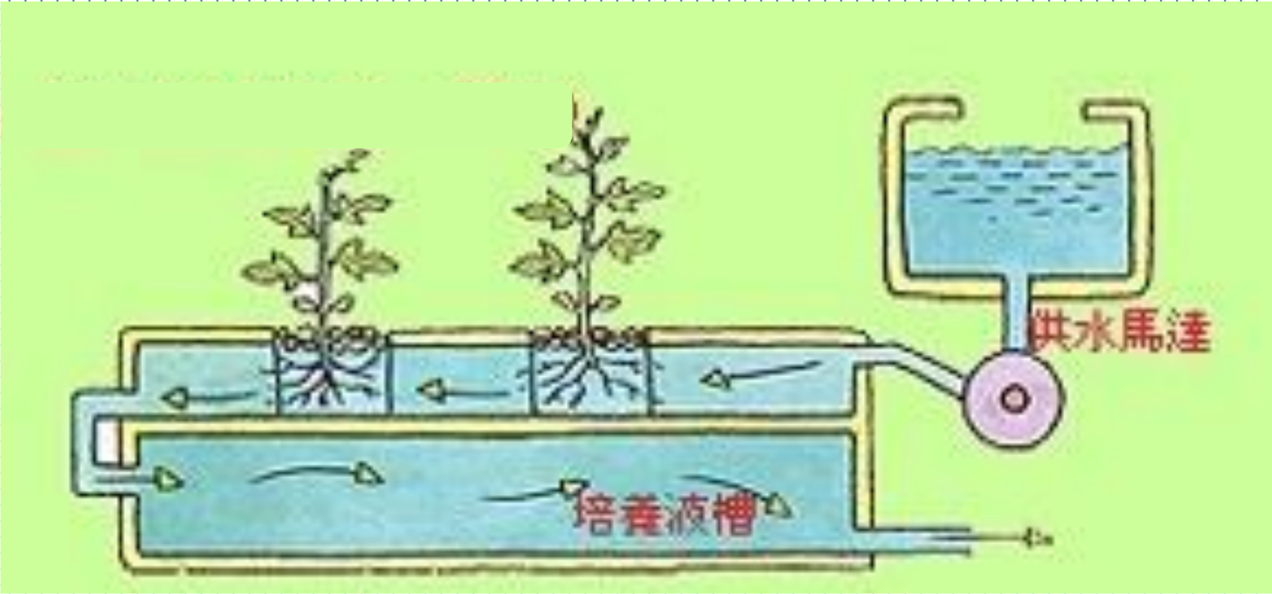
DFT / DWC



DFT: Pipe Culture

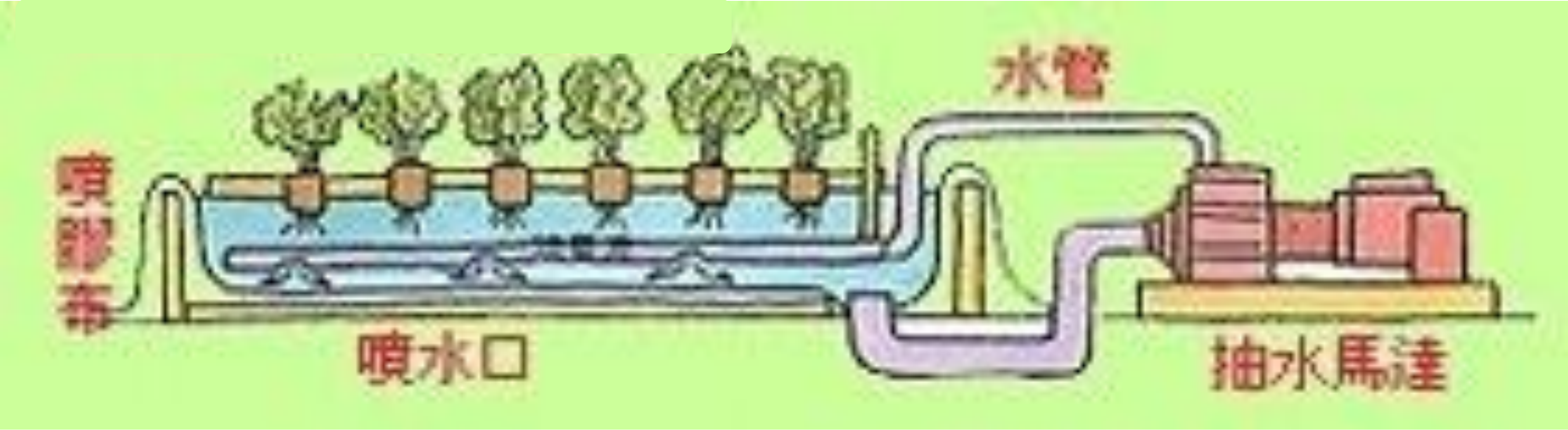



DFT bench system



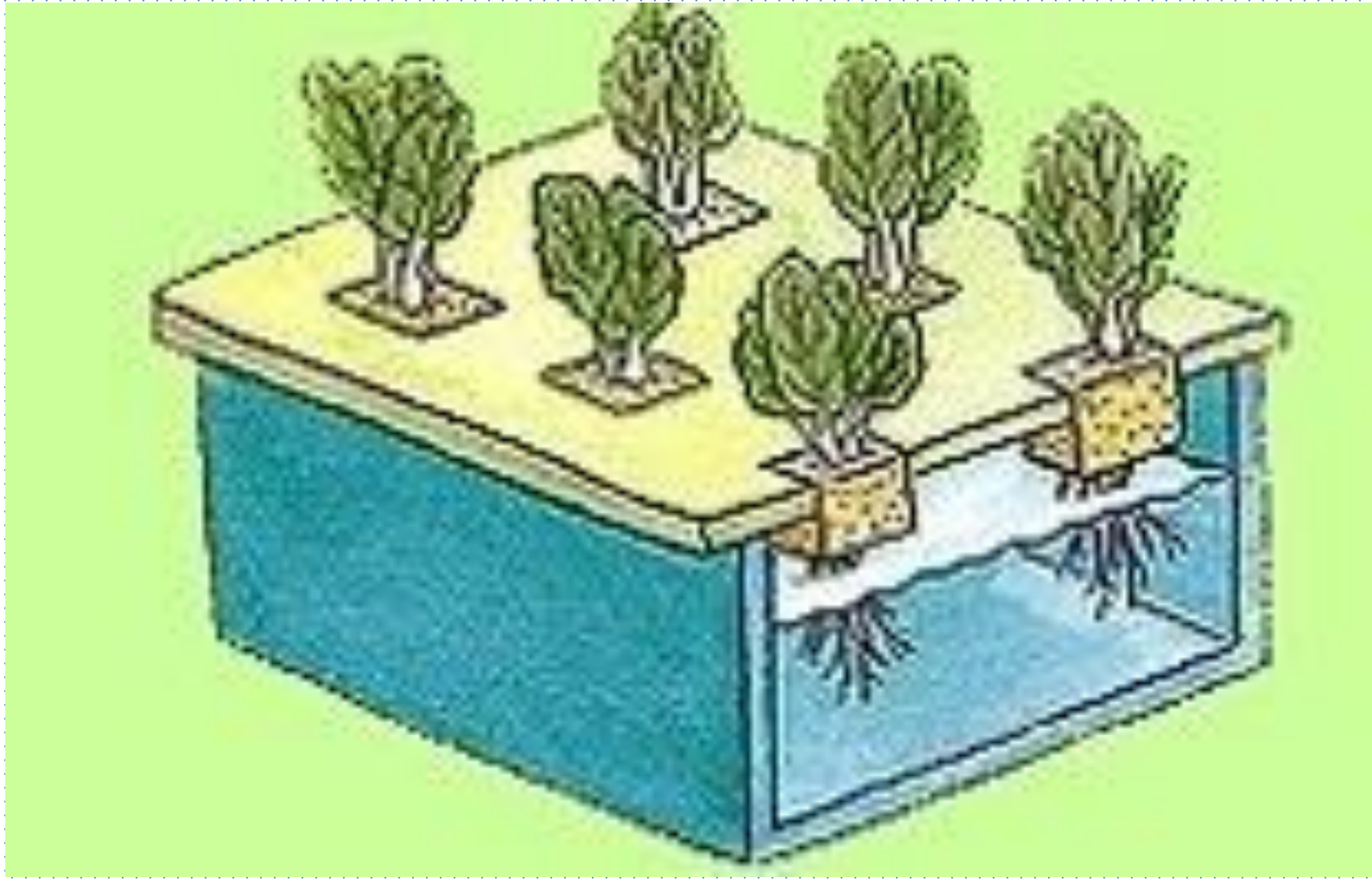
Hyponica style DFT

M style DFT



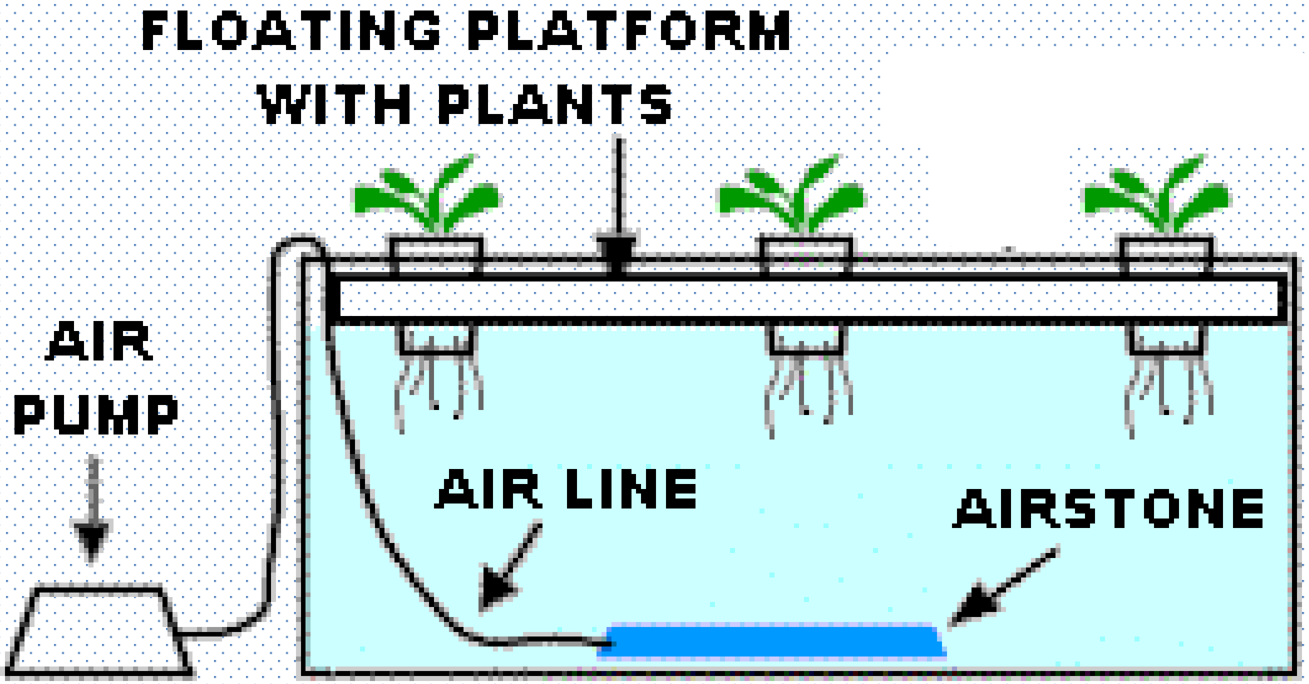
Fixed platform DFT without air pump

Roots are partially soaked in nutrient solution



Floating platform DFT with air pump

Roots are totally soaked in nutrient solution

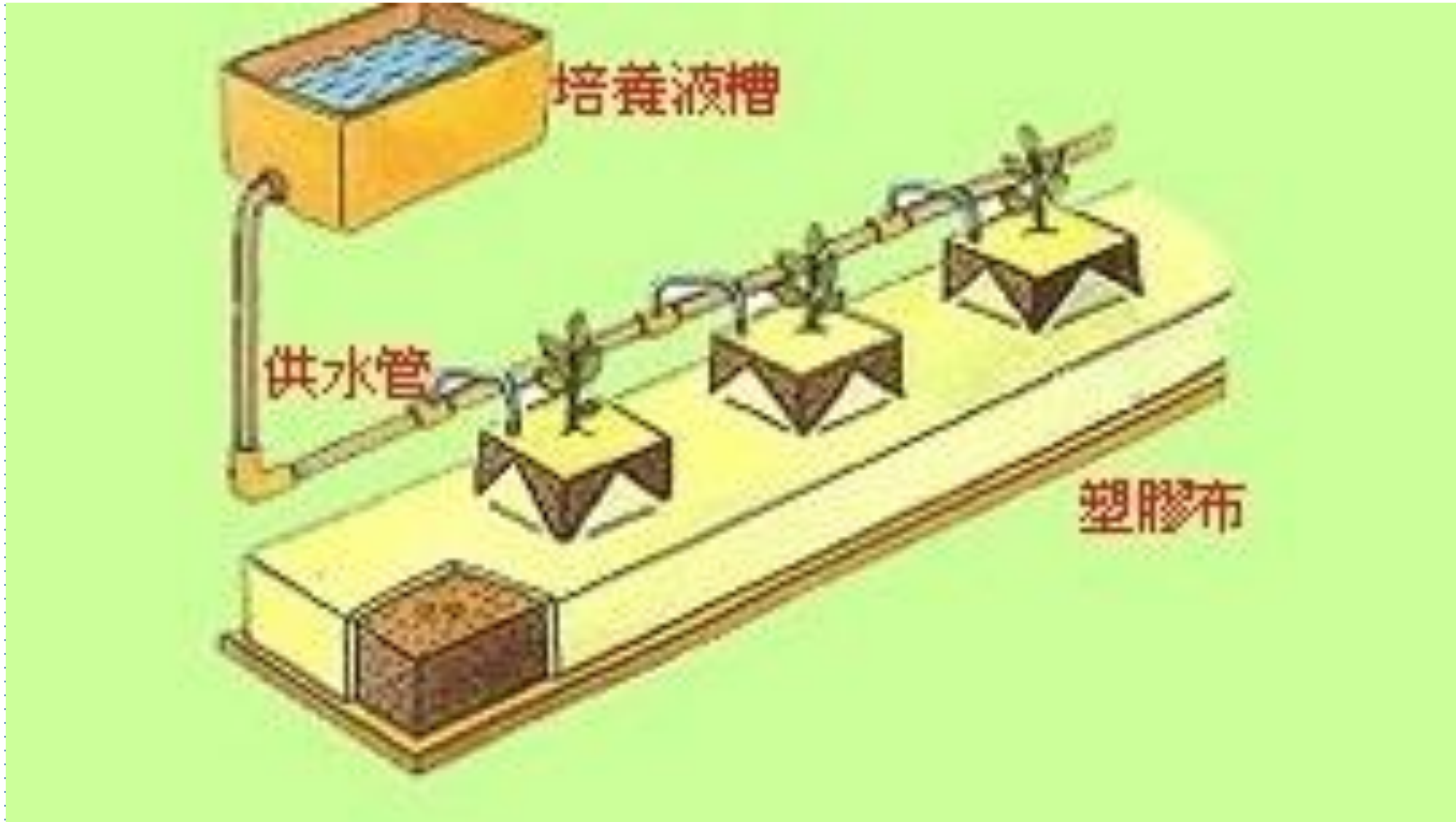


Disadvantages/Advantage of DFT

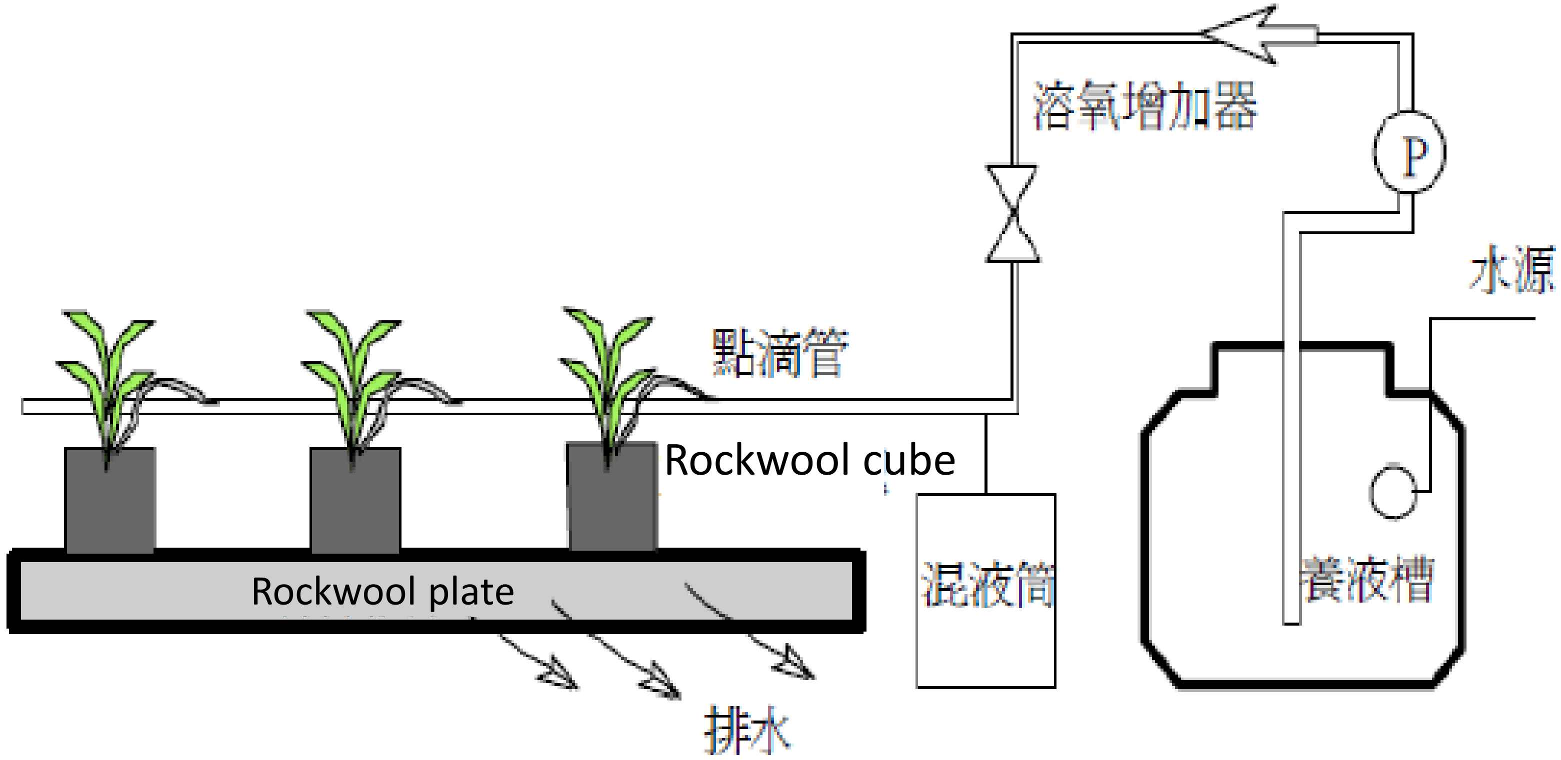
Compare with NFT

1) **More solution required**
2) **More nutrients required**
3) **DO is of great concerned**
4) **More costly to setup and to operate**
5) **Easy to manage, for beginners**
6) **Limited variation on DO due to air T**
7) **Limited variation on nutrients due to plant absorption**

Drip irrigation using rockwool



Rockwool cube and plate



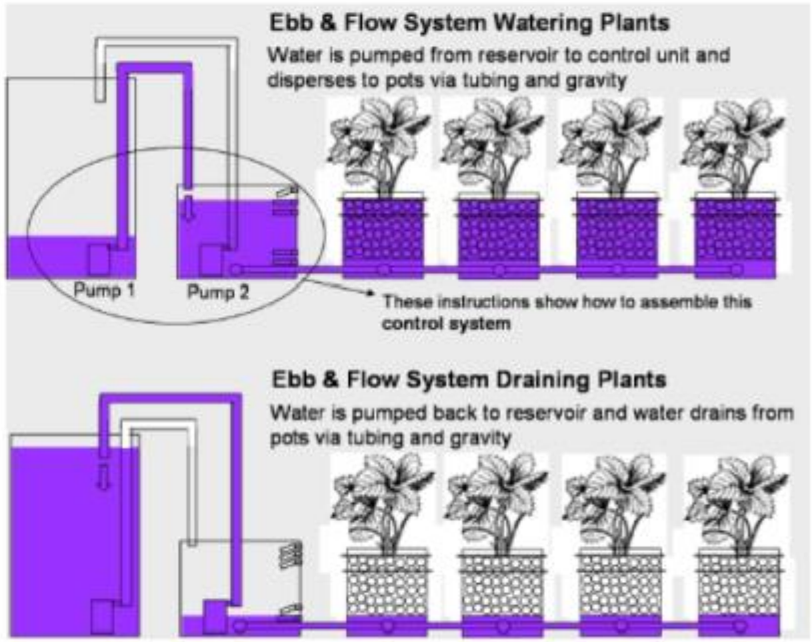
Drip irrigation using rockwool
High wire system

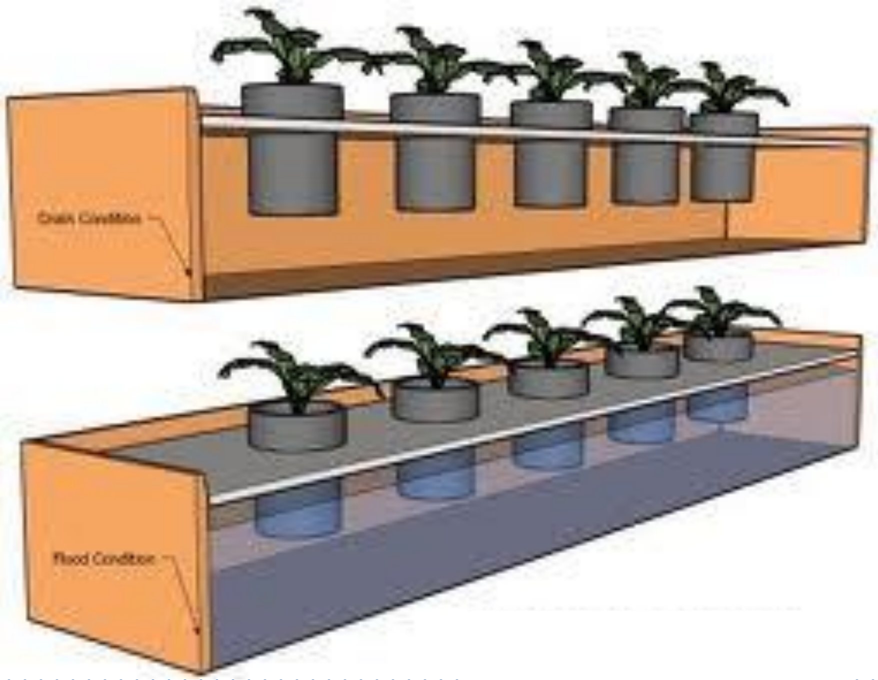
Various Systems using Rockwool

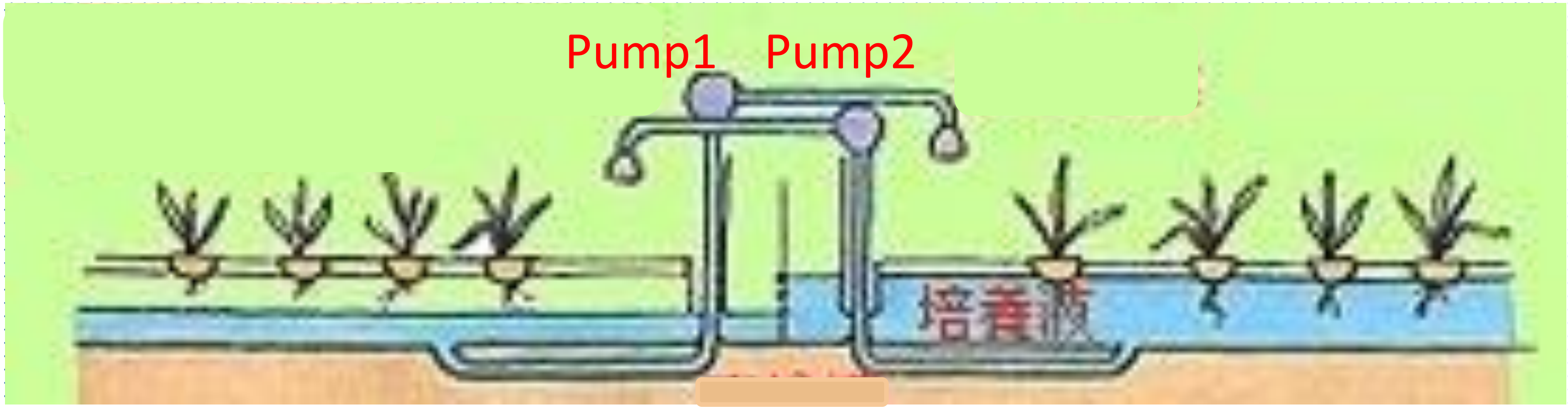
Drip irrigation

Ebb and Flow

Ebb and Flow using double pumps





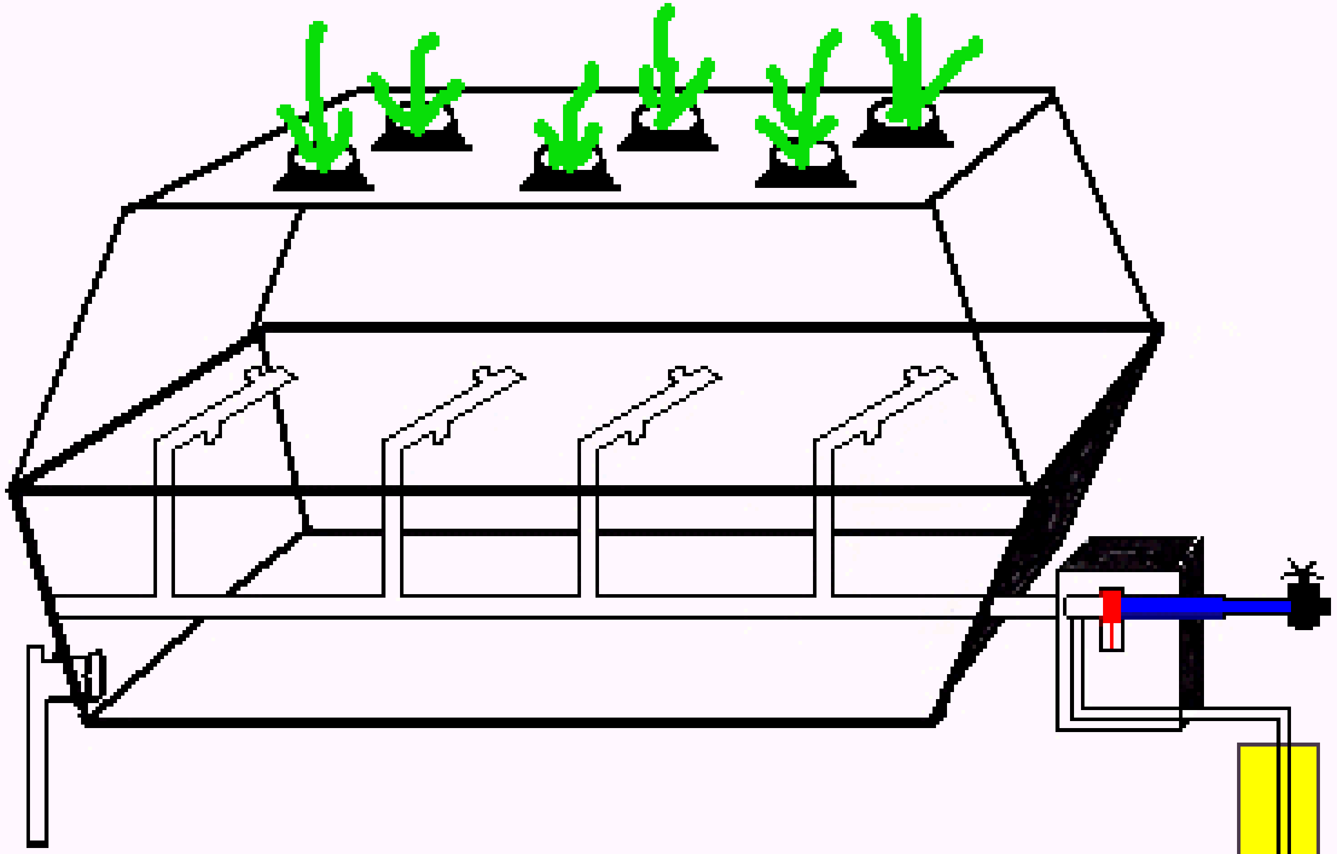


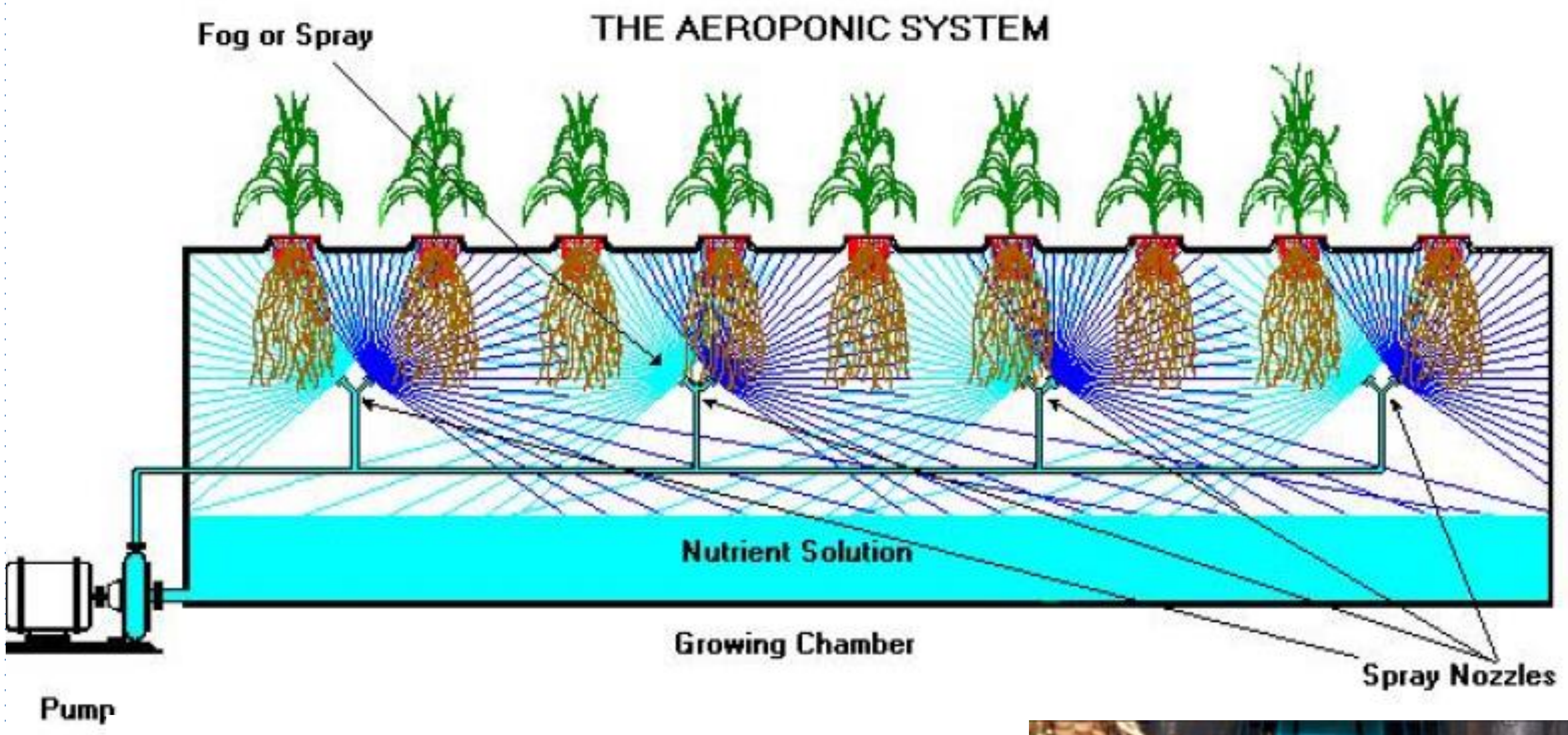
Amount of water used

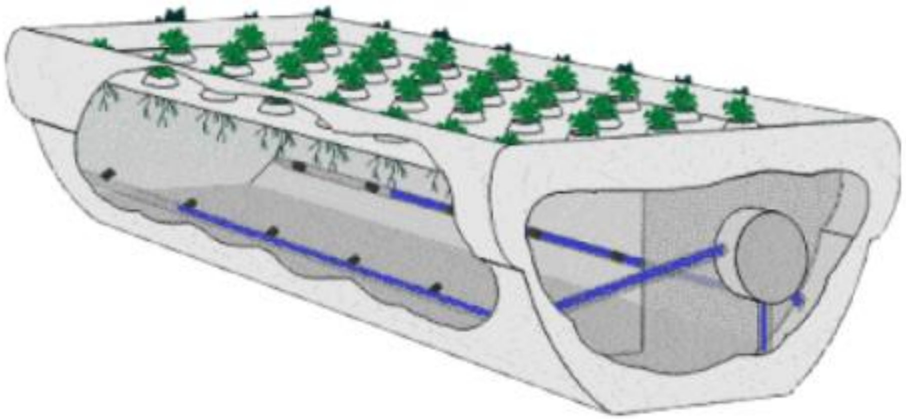
NFT < E&F < DFT

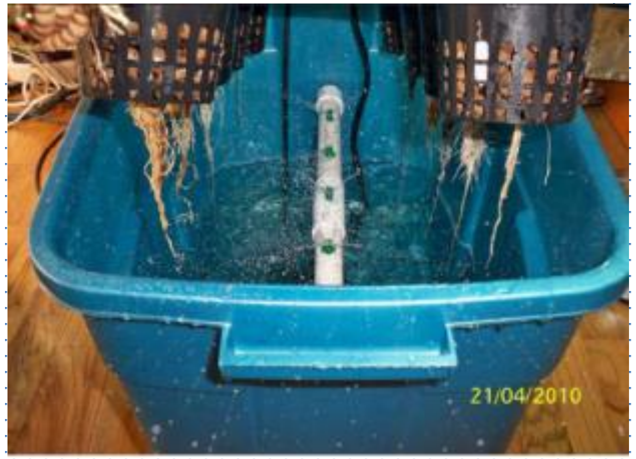
1. Little water used, no room for error, less forgiving
2. More water used, more fertilizer required, higher operating cost
3. More water used, heavier the static load to the growth shelf, higher hardware fixed cost

Aeroponics




THE AEROPONIC SYSTEM
Fog or Spray
Nutrient Solution
Growing Chamber
Spray Nozzles
Pump




21/04/2010

Aeroponics



Tuber plants

Potato

Sweetpotato

Jingsung

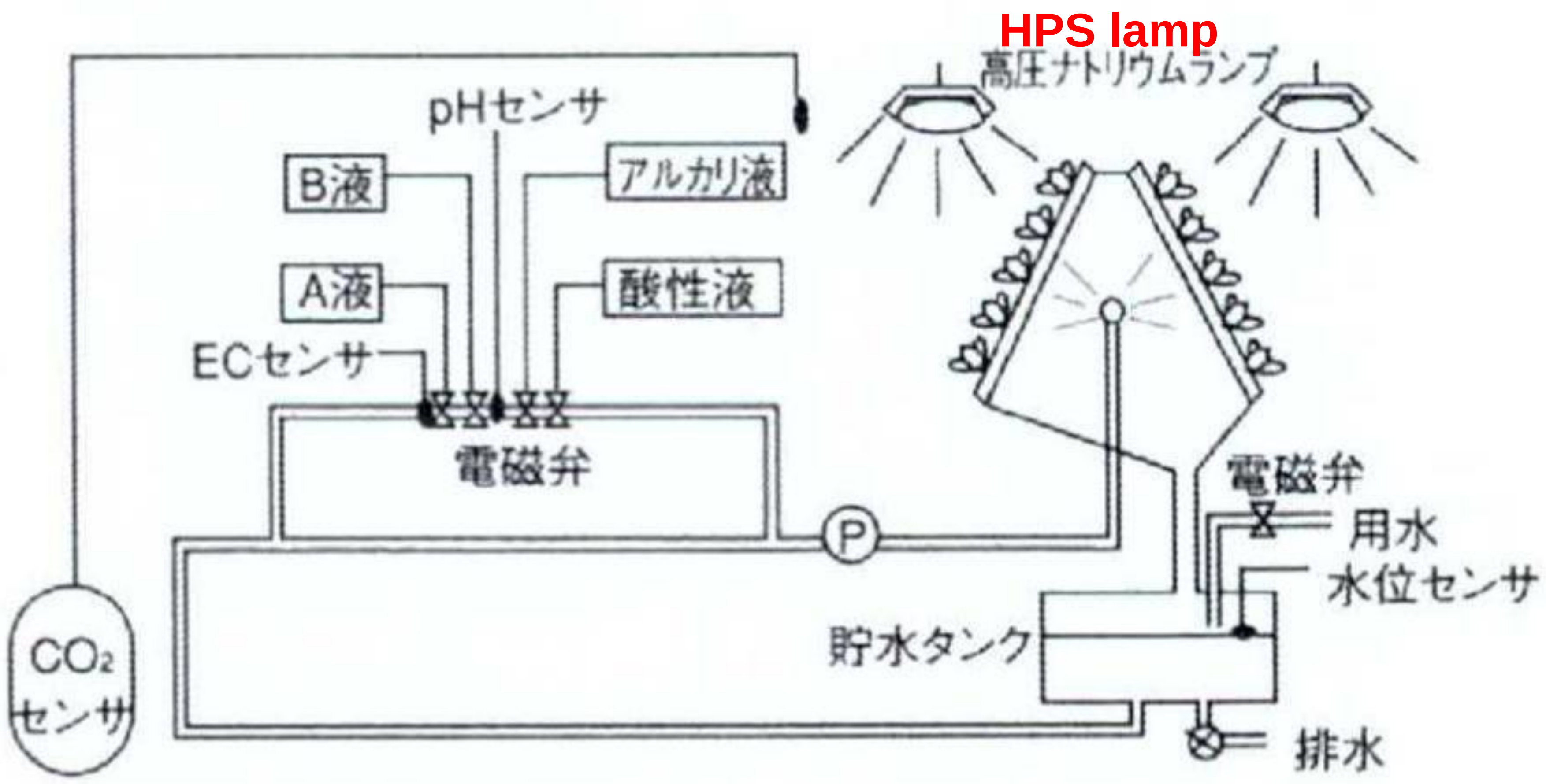
TS type PFAL: Aeroponics
T: triangle, S: spray

TS 700 and TS 1000

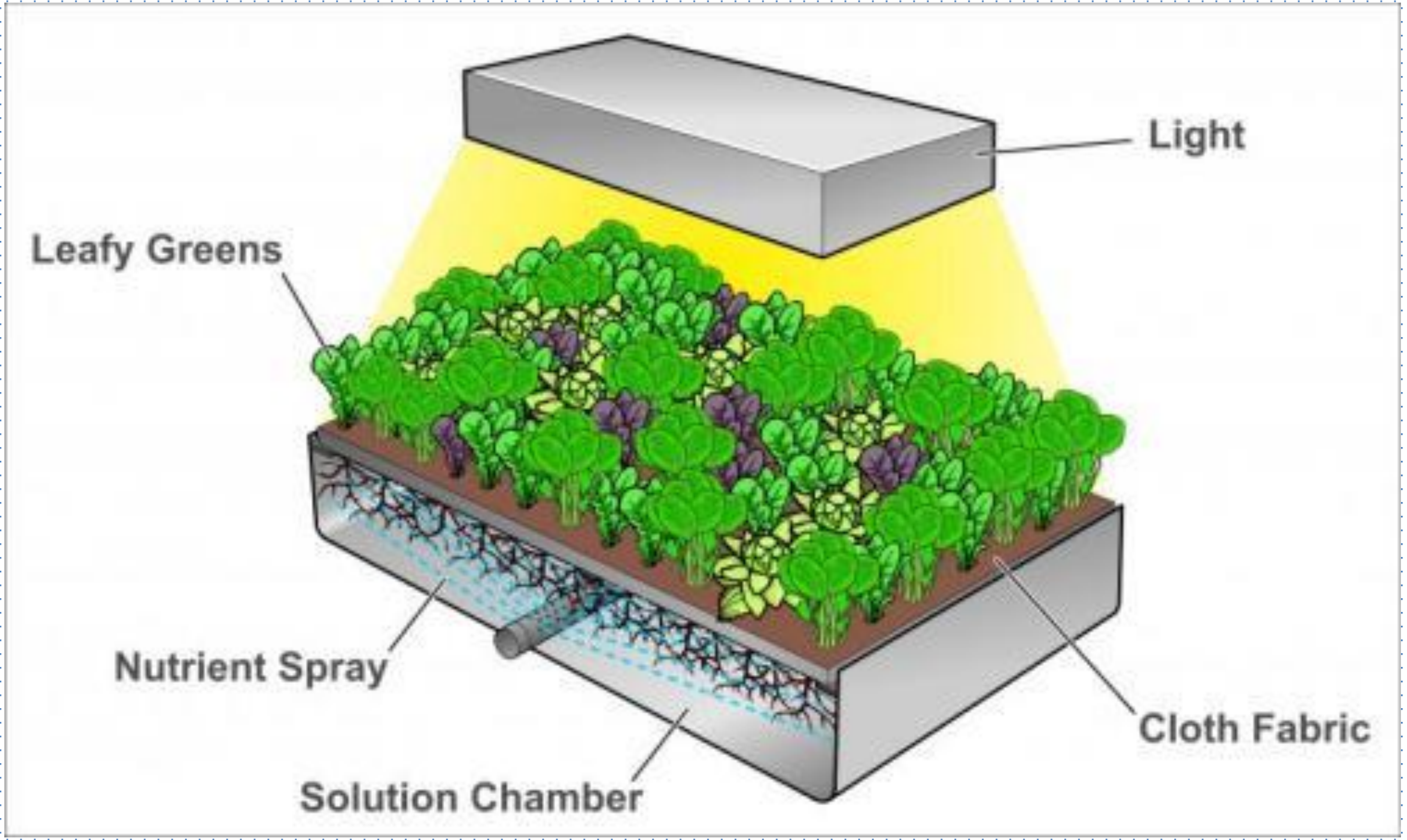
- 1993, Kyoto, Japan
- 400 m^2
- Production 700 plant/day (TS700)
- 4 employee

- 2001, Kyoto, Japan
- 500 m^2
- Production 1000 plant/day (TS1000)
- 6 employee

TS type PFAL: Aeroponics



Aeroponics


Light
Leafy Greens
Nutrient Spray
Cloth Fabric
Solution Chamber

AeroFarms: The largest PFAL in US

https://www.youtube.com/watch?v=ME_rprRlmMM&t=32s

https://www.youtube.com/watch?v=1m9U-AZ98_k

https://youtu.be/YDQQj-WzT_U

Ratio of nutrient solutions

$$R = U : B$$

U: total amount of **solution on cultural shelf**

B: amount of **solution in buffering tank**

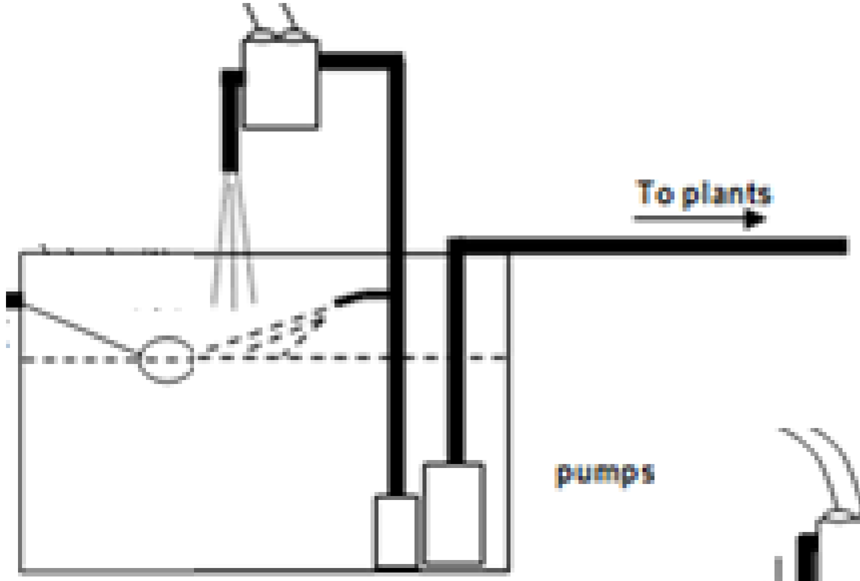
- R small, easy to operate, but required large buffering tank
- Manually operated system, R should be minimized
- Automatic control system, R should be maximized

Circulation control

- Continuous type
  - NFT (Nutrient Film Technique)
  - DFT (Deep Flow Technique, also named DWC, deep water culture)
- Intermittent type
  - Ebb and Flow type
  - Aeroponic type
  - DFT (DWC)

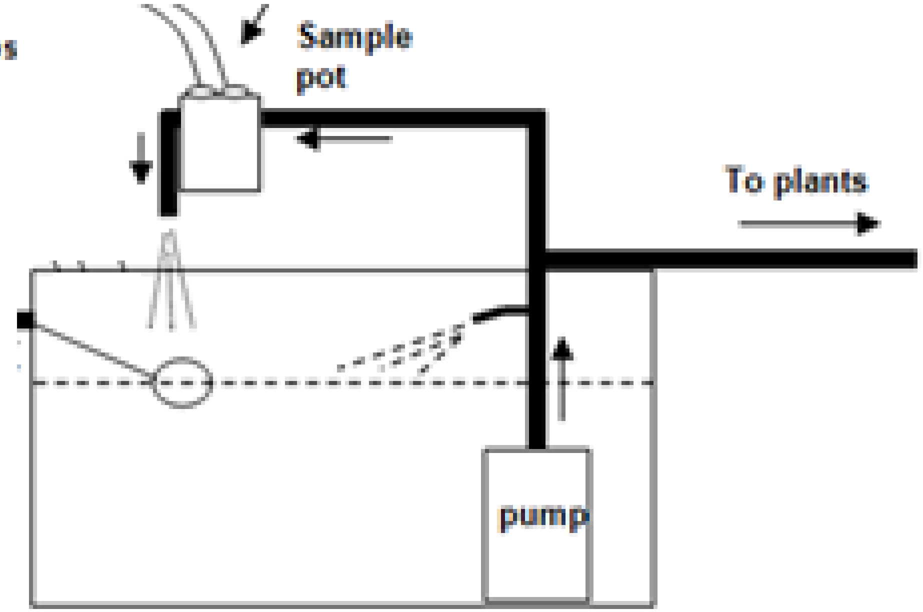
Timer for continuous or intermittent control of pump

Plumbing Design of circulating pumps



For Intermittent flow

- Sensor required flowing solution
- Buffer tank required stir/Agitating all the time to ensure better mixing and proper DO



For Continuous flow

Outline

Preparation of nutrient solution

pH, EC Management

pH adjustment

Hydroponic systems

Literature Review

Literature Review

1. Influence of sources of N
2. Influence of NO_3/NH_4
3. Influence of water temperature
4. Influence of concentration of K^+
5. Growing Komatsuna with supplemental micro elements

L1. Hoagland for lettuce - With different source of N

Compound	Concentration of stock	Final concentration of element (ppm)	
Potassium nitrate (NO_3^-) or ammonium sulfate (NH_4^+) or potassium nitrite (NO_2^-)		N	50
Potassium sulfate (K_2SO_4)	0.25 M	K	226
Magnesium sulfate ($MgSO_4$)	0.5 M	Mg	120
Calcium phosphate [Ca $(H_2PO_4)_2$]	0.025 M	Ca	58
Calcium sulfate ($CaSO_4$)	0.005 M	Ca	136
Boric acid (H_3BO_3)	0.005 M	B	0.25
Manganese sulfate ($MnSO_4$)	0.005 M	Mn	0.25
Zinc sulfate ($ZnSO_4$)	0.005 M	Zn	0.025
Copper sulfate ($CuSO_4$)	0.005 M		
Sodium molybdate ($NaMoO_3$)	0.005 M		

pH=6.0~6.5

Communications in Soil Science and Plant Analysis, 2008, 39: 207–216

L1. Hoagland for lettuce - With different source of N

Table 1. Influence of sources of N and type of lettuce on different attributes of lettuce

Measurements	Sources of N		
	NO_3	NO_2	NH_4
Plant height (cm)	14.2 a	12.6 b	12.8 b
Number of leaves/plant	9.4 a	7.4 c	8.4 b
Root vascular Discoloration[a]	0.4 b	1.6 a	1.4 a
Root fresh wt (g)	8.1 a	4.5 b	5.0 b
Leaf fresh wt (g)	46.1 a	35.6 b	39.2ab
Fresh biomass yield (g)	54.2 a	40.1 b	44.2 ab
Dry biomass yield (g)	6.6	4.5	5.0
Plant NO_3-N (mg kg^{-1})	3453 a	3030 a	2100 b

[a]Root vascular discoloration, rated as 1=low, 2=medium, and 3=high.
Note. Means in the same row followed by different letters are significantly different at the P<0.05 level.
Ns=nonsignificant; , indicate significance at P <0.05 and 0.01 levels, respectively.

Communications in Soil Science and Plant Analysis, 2008, 39: 207–216

L2. Influence of NO_3/NH_4 ratio on plant height. leaves number, leaf area, yield and RCC of Spinach

Table 1. Influence of NO_3^-/NH_4^+ ratio on the plant height, number of leaves, leaf area, yield and relative chlorophyll content (R.C.C.) in spinach.

NO_3^-/NH_4^+ Ratio	Plant height (cm)	Number of leaves	Leaf area (mm^2/plant)	Yield (kg/m^2)	R.C.C. (SPAD)
100/0	12.1a	5.1a	4525.1a	2.5a	47.5a
75/25	17.1b	5.4b	6943.9a	4.3b	40.2a
50/50	13.2a	5.9c	5298.7a	3.2a	43.9a
25/75	13.3a	5.6b	5352.0a	2.4a	46.9a

Means with a common letter are not significantly different ($p<0.05$) based on the Duncan's test.

Table 3. Influence of NO_3^-/NH_4^+ ratio on nitrates, oxalates (mg/kg FW) and vitamin C contents (mg/100 g FW) in spinach

NO_3^-/NH_4^+ Ratio	Spinach		
	Nitrates	Oxalates	Vit. C
100/0	4935.8d	4365.4c	13.7a
75/25	3978.7c	2913.6b	30.5c
50/50	3252.3b	2518.5a	23.8b
25/75	2731.3a	2536.3a	23.0b

Acta Hort. 2009. 843: 269–274

L3. Water Temperature affects leaf number and length of Spinach

Table 1. Effects of variation in water temperatures on leaf number of *S. olearacea*. Values presented are means ± SE.

Treatment	Temperature (ºC)	Leaf numbers: Measurements taken 2 weeks after transplanting		Leaf numbers: Measurements taken 8 week after transplanting	
Control	10	4.5	±0.24a	4.9	±0.21c*
A	24	4.6	±0.34a	6.5	±0.24a
B	26	4.9	±0.23a	6.4	±0.34ab
C	28	4.6	±0.19a	5.7	±0.40bc
F statistic		0.61 ns		5.91**	

** = significant at P ≤ 0.01. *Means followed by the same letter are not significantly different from each other at P ≤ 0.05.

Table 2. Effects of variation in water temperatures on leaf length of *S. olearacea*. Values presented are means ± SE.

Treatment	Temperature (ºC)	Leaf length (mm): Measurements taken 2 weeks after transplanting		Leaf length (mm): Measurements taken 8 weeks after transplanting	
Control	10	68.3	±4.22a	280	±11.06b*
A	24	70.7	±3.23a	347	±11.2a
B	26	73.1	±3.29a	371	±9.2a
C	28	74.2	±2.64a	356	±10.7a
F statistic		0.62 ns		14.7***	

*** = significant at P ≤ 0.001. *Means followed by the same letter are not significantly different from each other at P ≤ 0.05.

African Journal of Agricultural Research (2009) 4 (12): 1442 - 1446

L3. Water Temperature affects yield of Spinach

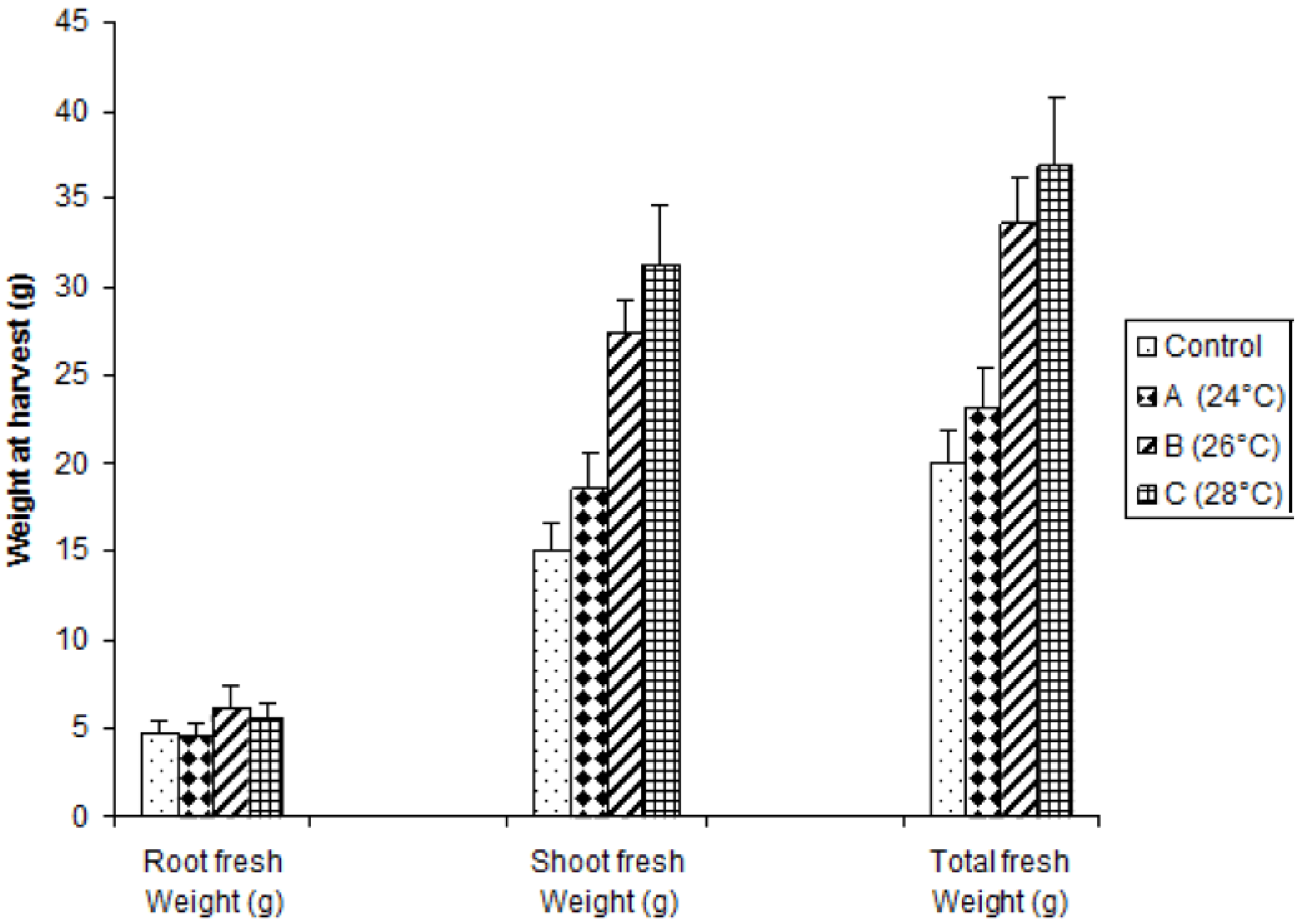


Figure 1. Effects of changing water temperature on fresh weight per plants (g) of *Spinacia olearacea*. (A = 24°C; B = 26°C; C = 28°C). Measurements were taken at 8 weeks after transplanting. *Means followed by the same letter are not significantly different from each other at P ≤ 0.05.

African Journal of Agricultural Research (2009) 4 (12): 1442 - 1446

L4. Concentrations (in mM) of elements in nutrient solution for 5 treatments

KNO_3 replaced by $Ca(NO_3)_2$

Element (mM)	1/1K	1/2K	1/4K	1/8K	1/16K
K	3.000	1.500	0.750	0.375	0.188
Ca	2.000	2.750	3.125	3.313	3.406
N	7.500	7.500	7.500	7.500	7.500
NO_3-N	7.000	7.000	7.000	7.000	7.000
NH_4-N	0.500	0.500	0.500	0.500	0.500
P	0.500	0.500	0.500	0.500	0.500
Mg	1.000	1.000	1.000	1.000	1.000
S	1.000	1.000	1.000	1.000	1.000
Fe	0.02600	0.02600	0.02600	0.02600	0.02600
Mn	0.00460	0.00460	0.00460	0.00460	0.00460
Zn	0.00038	0.00038	0.00038	0.00038	0.00038
Cu	0.00016	0.00016	0.00016	0.00016	0.00016
B	0.024000	0.024000	0.024000	0.024000	0.024000
Mo	0.00011	0.00011	0.00011	0.00011	0.00011
Na	0.05200	0.05200	0.05200	0.05200	0.05200

L4. Lower K^+ in nutrient solution leads to higher Ca^{+2} and lower Mg^{+2} in leaves

Table 22. Leaves elemental analysis of rocket grown in hydroponic culture with Ogawa formula with different potassium concentrations for 24 days

Potassium (K) concentration	Leaf mineral concentration (mg/100g FW)				
	K	Na	Ca	Mg	P
1/1 K[z]	347.95 ± 172.99 a[y]	2.76 ± 1.52 a	176.79 ± 54.34 a	35.68 ± 11.99 a	16.07 ± 4.17 a
1/2 K	341.03 ± 112.52 a	3.90 ± 1.63 a	217.08 ± 97.40 a	31.31 ± 10.78 a	16.87 ± 2.73 a
1/4 K	299.79 ± 163.83 ab	2.96 ± 1.13 a	237.37 ± 128.35 a	30.40 ± 15.35 a	16.33 ± 7.42 a
1/8 K	142.15 ± 109.40 b	5.61 ± 5.43 a	237.41 ± 186.40 a	29.13 ± 21.58 a	22.91 ± 24.17 a
1/16 K	219.17 ± 70.18 ab	4.21 ± 1.02 a	228.18 ± 87.79 a	32.48 ± 13.18 a	17.57 ± 4.14 a

[z]K concentration modified from reference to Ogawa et al., 2012.

[y]Mean±standard derivation (N=1, n=5). Means followed by different letters between different K concentrations are significantly different by least significant difference (LSD) test at 5% level (p<0.05).

*Sown on 08/05/2016. Seedlings were treated with 1/2 modified Hoagland solution before transplant. Seedling were transplanted to plant factory of NTU on 29/05/2016 and cultivated with 1/1 K, 1/2 K, 1/4 K, 1/8K and 1/16 K of Ogawa solution for 24 days. Harvested on 15/06/2016.

Results of above 4 papers

1. **Influence of sources of N for lettuce**
   - **$NO_3 > NH_4 > NO_2$**
2. **Influence of NO_3/NH_4 for spinach**
   - **75/25 > 50/50 > 25/75 > 100/0**
3. **Influence of water temperature for spinach**
   - **28 ^oC > 26 > 24 ~ 10 ^oC**
4. **Influence of concentration of K^+**
   - **Lower concentration of K^+ leads to higher Ca^{+2} and lower Mg^{+2}**

L5. Growing Komatsuna with supplemental Micro elements
Aiming at reducing nitrate concentration with no sacrifice on shoot fresh mass

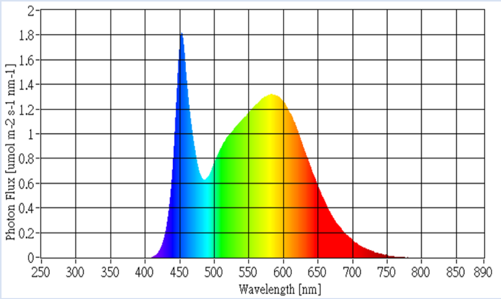
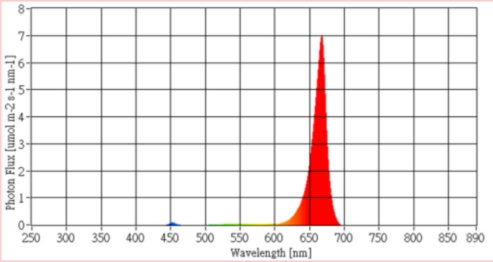
Huang, 2021 (Thesis)

Micro-elements of NTU solution (mg L^{-1}) in EXP 1

Treatments	Fe	Mn	B	Cu	Zn	Mo	Na
NTU (CK)	3.2	0.5	0.52	0.02	0.05	0.01	1.31
NTU + Mn		**1**				0.01	
NTU + Mo		0.5				**0.45**	
NTU + MnMo		**1**				**0.45**	

Macro-elements of NTU solution

NO_3-N:83.9 NH_4-N:7.3 PO_4-P:16.6 K:154.8 Ca:40.7 Mg:16.6 SO_4-S:16.6

Treatment code of EXP1	LED light	Recipe code
CW_NTU (CK)		NTU
CW_NTU + Mn		NTU + Mn
CW_NTU + Mo		NTU + Mo
CW_NTU + MnMo		NTU + MnMo
RW_NTU		NTU
RW_NTU + Mn		NTU + Mn
RW_NTU + Mo		NTU + Mo
RW_NTU + MnMo		NTU + MnMo

LED type	Blue (%)	Green (%)	Red (%)	PPFD (μmol m^{-2} s^{-1})
CW	27	48	25	236
RW	1	4	95	232

Treatment code of EXP1	Seedling stage (DAS = 8~14)		Mature stage (DAS = 15~28)	
CW_NTU (CK)	L1_236_H24_d182_A25_	N1_E1.2	L1_236_H16_d47_A25/20_	N1_E0.6
CW_NTU + Mn		N2_E1.2		N2_E0.6
CW_NTU + Mo		N3_E1.2		N3_E0.6
CW_NTU + MnMo		N4_E1.2		N4_E0.6
RW_NTU	L2_232_H24_d182_A25_	N1_E1.2	L2_232_H16_d47_A25/20_	N1_E0.6
RW_NTU + Mn		N2_E1.2		N2_E0.6
RW_NTU + Mo		N3_E1.2		N3_E0.6
RW_NTU + MnMo		N4_E1.2		N4_E0.6

DAS=0： H0_N0_E0_ A25

Stage 1 (DAS=1~3)： L1_230_H24_d772_N0_E0 _ A25

Stage 2 (DAS=4~7)： L1_230_H24_d772_N1_E1.2_ A25

Seedling stage (DAS = 8~14) ： Lx_y_H24_d182_Nx_E1.2_A25

Mature stage (DAS = 15~28) ：Lx_y_H16_d47_Nx_E0.6_A25/20

Lx_y：L：LED type，x=1：CW，x=2：RW，
y：PPFD in μmol·m^{-2}·s^{-1}

Hx：H: Light period, x：hrs, in h d^{-1}

dx：d: cropping density, x：density in plt·m^{-2}

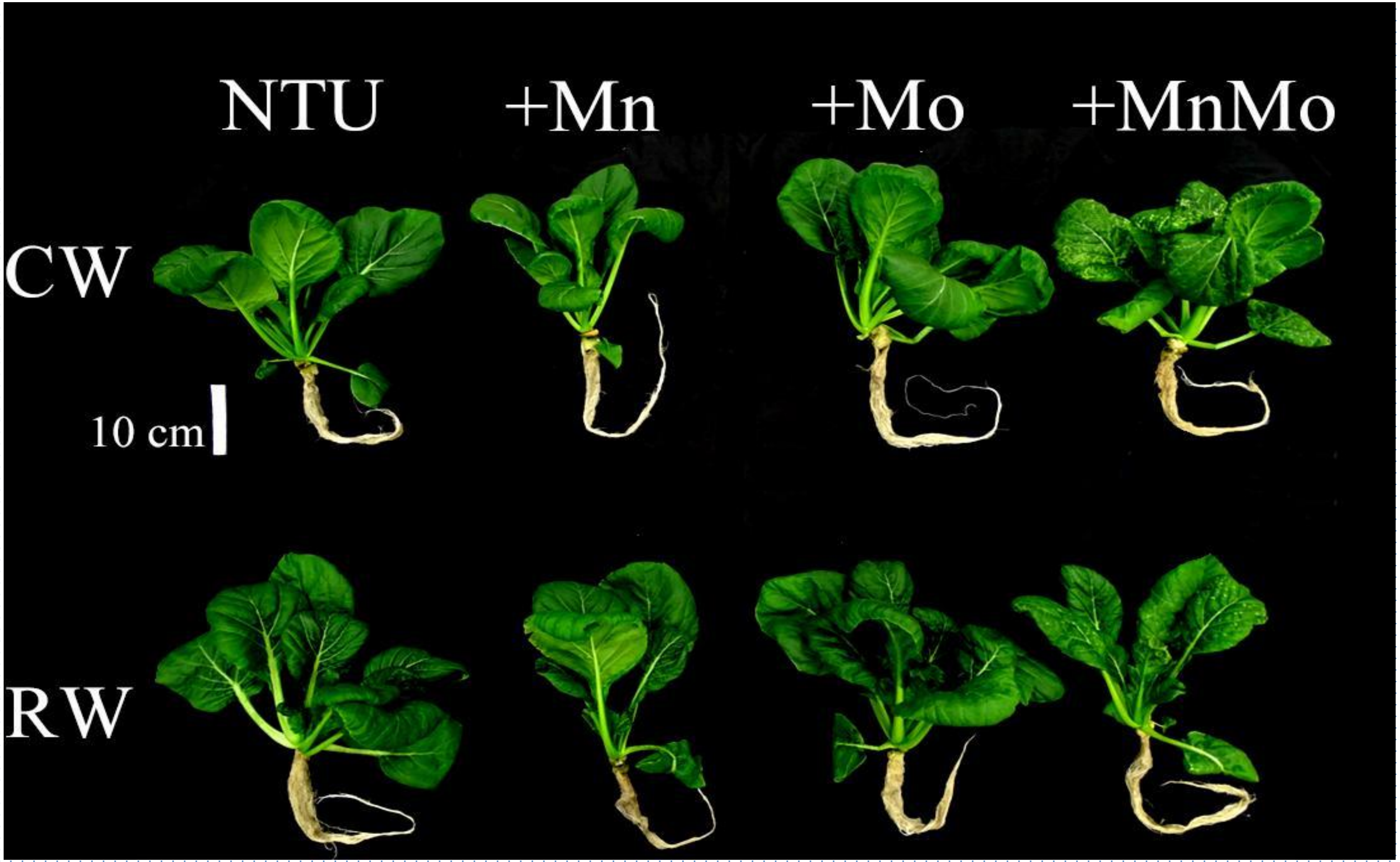
Ex：E: EC of nutrient solution, x: EC value in mS·cm^{-1}

Ax/y：A: Indoor temperature, x/y: day/night temperature in °C

Nx：N: Nutrient recipe,

x: type, x=0, tap water, x=1, NTU formula, x=2, NTU + Mn, x=3, NTU + Mo, x=4, NTU + MnMo

DAS = 28



DAS = 28

Treatment code of EXP1	Shoot fresh mass ($g \cdot plt^{-1}$)		Nitrate concentration ($mg \cdot kg^{-1}$)
CW_NTU (CK)	78.5 ± 20.3	ab	7268 ± 717 ab
CW_NTU + Mn	81.6 ± 18.1	ab	8003 ± 541 ab
CW_NTU + Mo	90.0 ± 16.4	ab	8336 ± 1003 ab
CW_NTU + MnMo	72.0 ± 21.4	b	7913 ± 295 ab
RW_NTU	88.0 ± 28.4	ab	6777 ± 703 c
RW_NTU + Mn	75.5 ± 31.7	ab	7113 ± 975 abc
RW_NTU + Mo	107.9 ± 38.0	a	7503 ± 1141 bc
RW_NTU + MnMo	71.9 ± 25.7	b	7794 ± 478 ab

EU suggestion: $NO_3 \leq 3000$ ppm

- NTU + Mo is the best recipe for shoot fresh mass
- NTU + MnMo leads to biological disorder
- High proportion of red light can be used
- EC drop from 1.2 to 0.6 at 2 weeks before harvest does not help in reducing nitrate concentration, which is still very high (>> 3000 ppm)
- Drop of EC leads to the low shoot fresh mass.

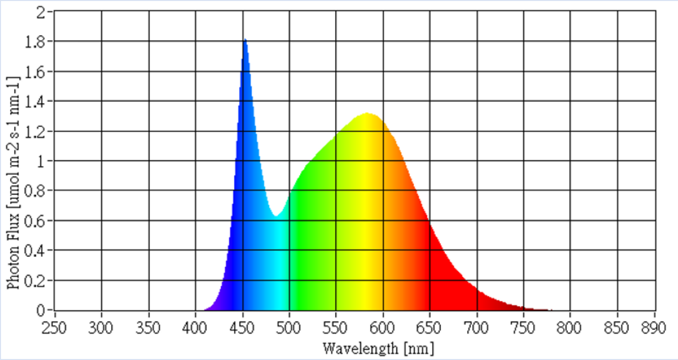
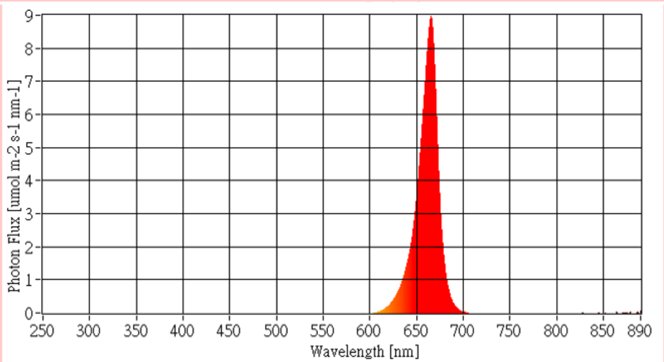
L5. Growing Komatsuna with supplemental Micro elements
Aiming at reducing nitrate concentration with no sacrifice on shoot fresh mass

Treatments of EC reduction at various stages (EC in $mS \cdot cm^{-1}$) in EXP2

EC reduction code	Seeding stage DAS = 4~7	Seedling stage DAS = 8~14	Mature stage 1 DAS = 15~21	Mature stage 2 DAS = 22~28
EC-48 (no drop)	1.2	1.2	1.2	1.2
EC-39 (1 rapid drop)	1.2	1.2	1.2	0.3
EC-36 (1 mild drop)	1.2	1.2	0.6	0.6
EC-33 (2 mild drops)	1.2	1.2	0.6	0.3
EC-24 (2 mild drops)	1.2	0.6	0.3	0.3

L5. Growing Komatsuna with supplemental Micro elements

Aiming at reducing nitrate concentration with no sacrifice on shoot fresh mass

Treatment code of EXP2	Recipe	LED	EC reduction code
CW_EC-48 (1.2 for 4 weeks)	NTU + Fe		EC-48
CW_EC-39 (1.2 x 3 + 0.3)			EC-39
CW_EC-36 (1.2 x 2 + 0.6 x 2)			EC-36
CW_EC-33 (1.2 x 2 + 0.6 + 0.3)			EC-33
CW_EC-24 (1.2 + 0.6 + 0.3 x 2)			EC-24
R_EC-48			EC-48
R_EC-39			EC-39
R_EC-36			EC-36
R_EC-33			EC-33
R_EC-24			EC-24

L5. Growing Komatsuna with supplemental Micro elements

Aiming at reducing nitrate concentration with no sacrifice on shoot fresh mass

Code of EXP2	Seedling stage (DAS = 8~14)		Mature stage 1 (DAS = 15~21)		Mature stage 2 (DAS = 22~28)	
CW_EC-48		E1.2		E1.2		E1.2
CW_EC-39		E1.2		E1.2		E0.3
CW_EC-36	L1_248_H24_d182_A25/20_	E1.2	L1_248_H16_d47_A25/20_	E0.6	L1_248_H16_d47_A25/20_	E0.6
CW_EC-33		E1.2		E0.6		E0.3
CW_EC-24		E0.6		E0.3		E0.3
R_EC-48		E1.2		E1.2		E1.2
R_EC-39		E1.2		E1.2		E0.3
R_EC-36	L2_245_H24_d182_A25/20_	E1.2	L2_245_H16_d47_A25/20_	E0.6	L2_245_H16_d47_A25/20_	E0.6
R_EC-33		E1.2		E0.6		E0.3
R_EC-24		E0.6		E0.3		E0.3

Nutrient recipe is NTU + Fe for all treatments

L5. Growing Komatsuna with supplemental Micro elements

Aiming at reducing nitrate concentration with no sacrifice on shoot fresh mass

Treatment code of EXP2	Shoot fresh mass ($g \cdot plt^{-1}$)	Root fresh mass ($g \cdot plt^{-1}$)	Nitrate concentration ($mg \cdot kg^{-1}$)
CW_EC-48	157.3 ± 37.2 a [x]	16.3 ± 3.8 a	6193 ± 691 b
CW_EC-39	149.6 ± 33.5 ab	10.1 ± 3.9 cd	4846 ± 535 d
CW_EC-36	154.7 ± 16.1 a	13.0 ± 3.9 b	5357 ± 622 cd
CW_EC-33	140.4 ± 6.5 abc	12.9 ± 0.9 bc	2271 ± 260 e
CW_EC-24	82.7 ± 7.7 d	10.9 ± 1.7 bcd	2798 ± 151 e
R_EC-48	144.2 ± 6.8 abc	10.1 ± 0.6 cd	7935 ± 688 a
R_EC-39	126.1 ± 9.2 b	9.4 ± 1.9 d	5782 ± 846 bc
R_EC-36	133.1 ± 17.6 bc	10.3 ± 2.3 bcd	5054 ± 512 d
R_EC-33	124.4 ± 5.4 b	11.5 ± 0.7 bcd	2669 ± 362 e
R_EC-24	80.9 ± 10.8 d	10.4 ± 1.0 bcd	2261 ± 394 e

- Shoot fresh mass (FM) is in direct proportion with total EC
- CW is better than pure R in shoot fresh mass production using **NTU+Fe recipe**
- 4 out of 10 treatments (CW or R_EC-33 and EC-24) have nitrate concentration less than 3000 ppm
- EC-24 (1.2-0.6-0.3-0.3) treatments have least amount of fresh mass, 2 weeks of EC 0.3 reduced fresh mass a lot.
- **CW_EC-33 (1.2-1.2-0.6-0.3) is the best treatment with shoot FM > 140 g, Nitrate < 3000 ppm)**.

DAS = 28

L5. Growing Komatsuna with supplemental Micro elements

Aiming at reducing NO_3 with no sacrifice on shoot fresh mass

Micro-elements of NTU solution (mg L^{-1}) in EXP3

<table>
<tr><th>Treatments</th><th>Fe</th><th>Mn</th><th>B</th><th>Cu</th><th>Zn</th><th>Mo</th><th>Na</th></tr>
<tr><td>NTU</td><td>3.2</td><td rowspan="4">0.5</td><td rowspan="4">0.52</td><td rowspan="4">0.02</td><td rowspan="4">0.05</td><td>0.01</td><td>1.31</td></tr>
<tr><td>NTU + Mo</td><td>3.2</td><td>0.45</td><td>1.31</td></tr>
<tr><td>NTU + Fe</td><td>4.8</td><td>0.01</td><td>2.06</td></tr>
<tr><td>NTU + MoFe</td><td>4.8</td><td>0.45</td><td>2.06</td></tr>
</table>

EDTA-Fe (Chelated iron): $C_{10}H_{12}FeN_2NaO_8.3H_2O$

化學名稱：Ethylenediaminete-traacetic acid, ferric sodium complex
分子式：C10H12FeN2NaO8 . 3H2O
分子量：421.10
純度：> 99%
鐵(Fe)含量：13%
水不溶物：<0.1%

LED type	Blue (%)	Green (%)	Red (%)	PPFD (μmol m^{-2} s^{-1})
CW	27	48	25	248
R	0	0	100	245

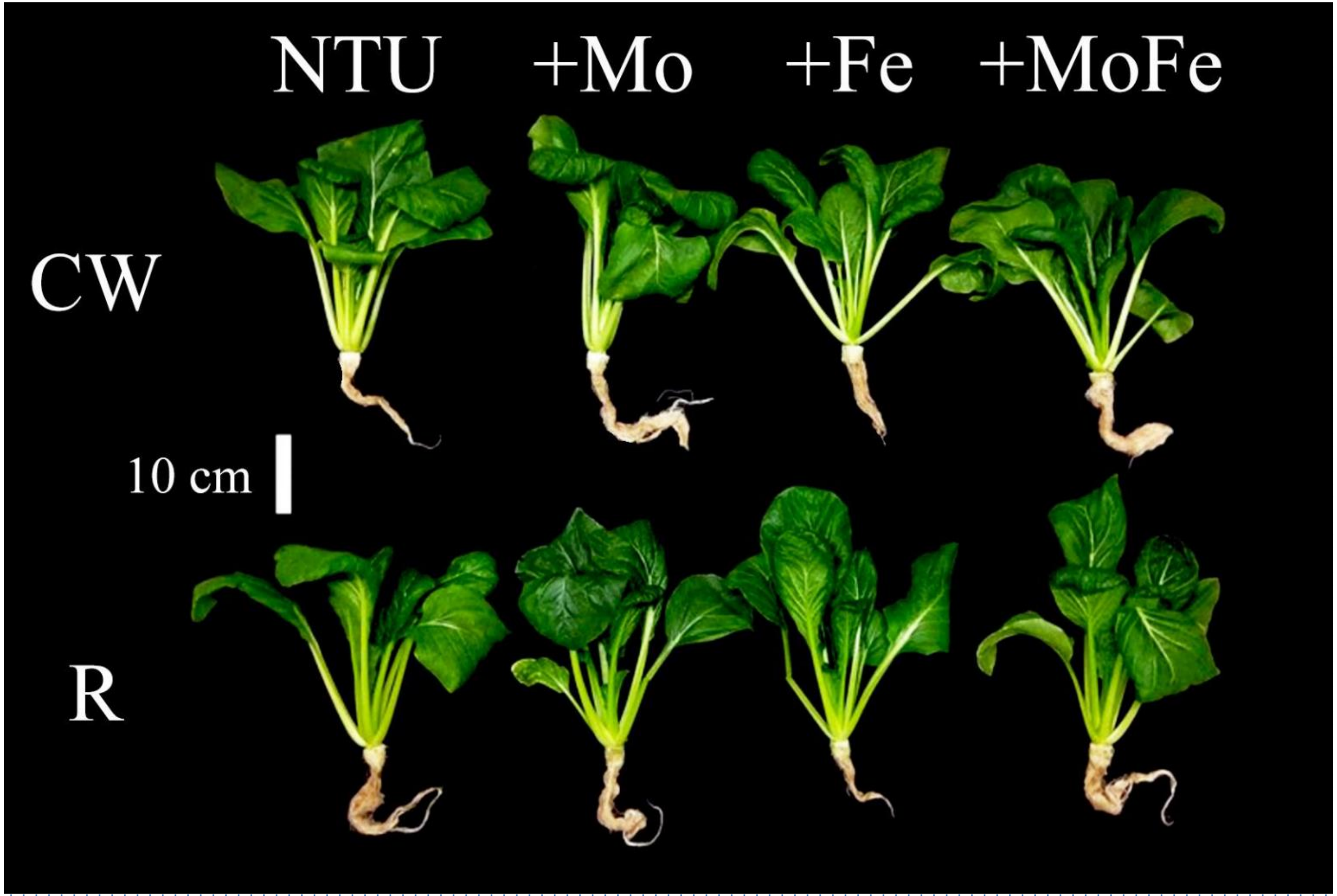
Treatment codes of EXP3	LED type	Nutrient Recipe
CW_NTU (CK)	CW	NTU
CW_NTU + Mo		NTU + Mo
CW_NTU + Fe		NTU + Fe
CW_NTU + MoFe		NTU + MoFe
R_NTU	R	NTU
R_NTU + Mo		NTU + Mo
R_NTU + Fe		NTU + Fe
R_NTU + MoFe		NTU + MoFe

Treatments	Seedling stage (DAS = 8~14)		Mature stage 1 (DAS = 15~21)		Mature satge 2 (DAS = 22~28)	
CW_NTU (CK)	L1_248_H24_d182_A25_	N1_E1.2	L1_248_H16_d47_A25/20_	N1_E0.6	L1_248_H16_d47_A25/20_	N1_E0.3
CW_NTU + Mo		N2_E1.2		N2_E0.6		N2_E0.3
CW_NTU + Fe		N3_E1.2		N3_E0.6		N3_E0.3
CW_NTU + MoFe		N4_E1.2		N4_E0.6		N4_E0.3
R_NTU	L2_245_H24_d182_A25_	N1_E1.2	L2_245_H16_d47_A25/20_	N1_E0.6	L2_245_H16_d47_A25/20_	N1_E0.3
R_NTU + Mo		N2_E1.2		N2_E0.6		N2_E0.3
R_NTU + Fe		N3_E1.2		N3_E0.6		N3_E0.3
R_NTU + MoFe		N4_E1.2		N4_E0.6		N4_E0.3

Nx：Nutrient recipe type

x=0, tap water, x=1: NTU formula, x=2, NTU+Mo, x=3, NTU+Fe, x=4, NTU+MoFe

DAS = 28



L5. Growing Komatsuna with supplemental Micro elements
Aiming at reducing NO_3 with no sacrifice on shoot fresh mass

Treatment code of EXP3	Shoot fresh mass (g·plt^{-1})	Root Fresh mass (g·plt^{-1})	Nitrate concentration (mg·kg^{-1})
CW_NTU (CK)	159.1 ± 8.3 a ^{x}	21.6 ± 1.2 abc	3013 ± 542 a
CW_NTU + Mo	155.5 ± 6.9 ab	21.9 ± 2.6 abc	2265 ± 291 c
CW_NTU + Fe	165.2 ± 7.7 a	23.1 ± 1.6 abc	2271 ± 260 c
CW_NTU + MoFe	129.3 ± 13.1 e	22.0 ± 2.4 abc	2977 ± 607 a
R_NTU	139.8 ± 9.0 bc	22.7 ± 1.9 ab	2747 ± 496 abc
R_NTU + Mo	135.5 ± 8.9 de	19.8 ± 1.6 cd	2395 ± 400 bc
R_NTU + Fe	146.4 ± 6.4 bcd	20.5 ± 1.3 bcd	2669 ± 362 abc
R_NTU + MoFe	133.5 ± 9.7 de	19.1 ± 2.8 d	2972 ± 508 ab

3-steps EC reduction works: 7 out of 8 treatments, Nitrate concentration < 3000 ppm

CW is better than just R

DAS = 28

NTU+Fe is better than NTU+Mo in shoot FM

L5. Growing Komatsuna with supplemental Micro elements
Aiming at reducing NO3 & increasing Ca with no sacrifice on shoot fresh mass

處理組代號	光質	養液配方	養液電導度調降策略
CW_NTU (CK)	CW	NTU	EC-48
CW_ NTU-D		NTU	EC-33
CW_NTU-D + Fe		NTU + Fe	EC-33
CW_0.125 K		0.125 K	EC-33
CW_0.5 K + Ca		0.5 K + Ca	EC-33
R_NTU	R	NTU	EC-48
R_ NTU-D		NTU	EC-33
R_NTU-D + Fe		NTU + Fe	EC-33
R_0.125 K		0.125 K	EC-33
R_0.5 K + Ca		0. 5 K + Ca	EC-33

養液電導度調降策略：(DAS = 0~7 / DAS = 8~14 / DAS = 15~21 / DAS = 22~28)

Ex：E 當養液電導度，x：電導度值，單位：$mS{\cdot}cm^{-1}$

EC-48：E1.2 / E1.2 / E1.2 / E1.2

EC-33：E1.2 / E1.2 / E0.6 / E0.3

Aiming at reducing NO3 & increasing Ca with no sacrifice on shoot fresh mass

Treatments	Seedling stage (DAS = 8~14)		Mature stage 1 (DAS = 15~21)		Mature stage 2 (DAS = 22~28)	
CW_NTU (CK)		N1_E1.2		N1_E1.2		N1_E1.2
CW_ NTU-D		N1_E1.2		N1_E0.6		N1_E0.3
CW_NTU-D + Fe	L1_248_H24_d182_A25_	N2_E1.2	L1_248_H16_d47_A25/20_	N2_E0.6	L1_248_H16_d47_A25/20_	N2_E0.3
CW_0.125 K		N3_E1.2		N3_E0.6		N3_E0.3
CW_0.5 K + Ca		N4_E1.2		N4_E0.6		N4_E0.3
R_NTU		N1_E1.2		N1_E1.2		N1_E1.2
R_ NTU-D		N1_E1.2		N1_E0.6		N1_E0.3
R_NTU-D + Fe	L2_245_H24_d182_A25_	N2_E1.2	L2_245_H16_d47_A25/20_	N2_E0.6	L2_245_H16_d47_A25/20_	N2_E0.3
R_0.125 K		N3_E1.2		N3_E0.6		N3_E0.3
R_0.5 K + Ca		N4_E1.2		N4_E0.6		N4_E0.3

催芽期 (DAS=0)： H0_N0_E0_ A25

播種期 1 (DAS=1~3)： L1_230_H24_d772_N0_E0 _ A25

播種期 2 (DAS=4~7)： L1_230_H24_d772_N1_E1.2_ A25

育苗期 (DAS = 8~14) ： Lx_y_H24_d182_Nx_E1.2_A25

育成期 (DAS = 15~28) ：Lx_y_H16_d47_Nx_E0.6_A25/20

Nx：N 營養液配方

Lx_y：L：LED燈管，L1： CW ，L2： R，y：PPFD，單位：$\mu mol \cdot m^{-2} \cdot s^{-1}$，波長 λ= 300 nm ~700 nm

Hx：H 開燈時數，x：小時數，單位：小時·天$^{-1}$

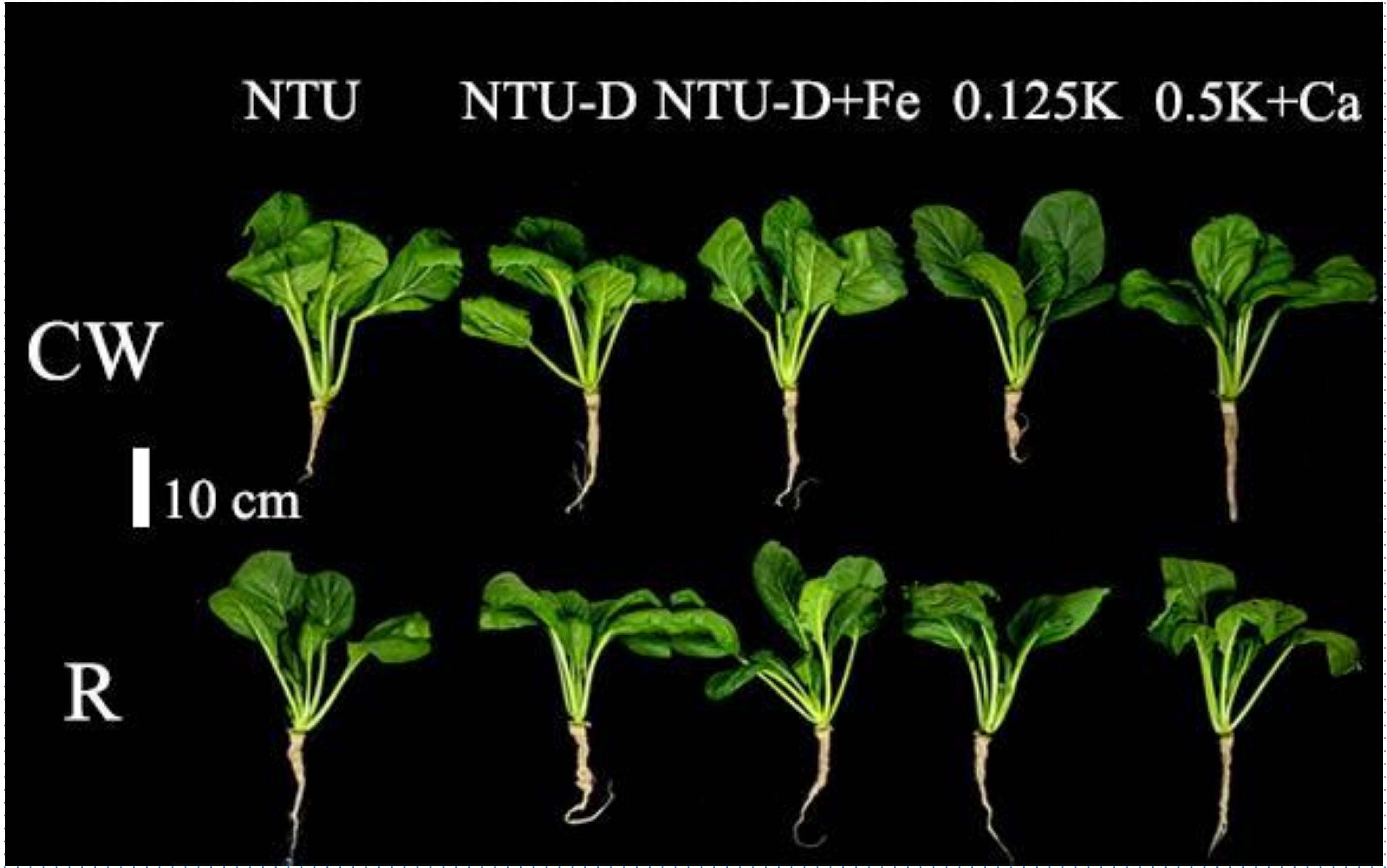
dx：d 栽培密度，x：密度，單位：plt·m^{-2}

Ex：E 營養液電導度，x：電導度值，單位：mS·cm^{-1}

Ax/y：A 栽培環境溫度，x：日間溫度，y：夜間溫度，單位：℃

N0：清水, N1：台大配方, N2：NTU+Fe, N3：0.125K, N4：0. 5K +Ca

Aiming at reducing NO3 & increasing Ca with no sacrifice on shoot fresh mass



Aiming at reducing NO_3 & increasing Ca with little sacrifice on shoot fresh mass

DAS = 28

Treatments	Shoot FM (g·plt^{-1})	Root FM (g·plt^{-1})	NO3 (mg·kg^{-1})	Ca (mg·100g^{-1})
CW_NTU (CK)	167.2 ± 7.2 a	15.3 ± 7.4 a	6972 ± 635 b	122.0 ± 12.4 b
CW_ NTU-D	145.9 ± 17.2 bc	13.1 ± 4.4 a	2549 ± 206 c	131.3 ± 5.1 b
CW_NTU-D + Fe	157.2 ± 10.8 ab	13.3 ± 5.1 a	2479 ± 384 c	129.0 ± 8.8 b
CW_0.125 K	134.5 ± 13.2 cd	14.2 ± 0.6 a	2761 ± 727 c	177.8 ± 12.8 a
CW_0.5 K + Ca	97.4 ± 9.8 e	10.2 ± 2.9 a	2744 ± 268 c	171.8 ± 9.9 a
R_NTU	142.4 ± 7.7 bcd	14.4 ± 4.3 a	7834 ± 254 a	123.0 ± 13.2 b
R_ NTU-D	130.8 ± 8.3 cd	12.8 ± 3.4 a	2441 ± 311 c	124.5 ± 10.5 b
R_NTU-D + Fe	137.5 ± 11.7 cd	11.6 ± 2.2 a	2500 ± 233 c	121.5 ± 14.0 b
R_0.125 K	127.1 ± 14.0 d	13.7 ± 3.5 a	3021 ± 134 c	175.5 ± 7.9 a
R_0.5 K + Ca	88.5 ± 6.1 e	10.8 ± 2.7 a	2951 ± 678 c	171.8 ± 13.0 a

- CW is better than total R for Komatsuna
- Strategy of 3 steps reduction of EC works to reduce NO3 to less than 3000 ppm
- Reducing K by half (0.5 K) or to 1/8 (0.125 K) can increase Ca
- CW_NTU-D + Fe ((EC-33)) can reduce NO3 by 65%, however also reduced shoot FM by 15%
- NTU-D 0.125 K (EC-33) reduced 57% NO3, increase 43 % of Ca

Komatsuna 小松菜

Objective	Treatments	FM ($g \cdot plt^{-1}$)	vs. market	NO_3 ($mg \cdot kg^{-1}$)	vs. market	Ca ($mg \cdot 100g^{-1}$)	vs. market
Low NO_3	CW_NTU-D + Fe (EC 1.2-1.2-0.6-0.3)	157.2 ± 10.8	4.09	2479 ± 384	42.6%	129.0 ± 8.8	1.13
Low NO_3 & High Ca	CW_0.125 K (EC 1.2-1.2-0.6-0.3)	134.5 ± 13.2	3.50	2761 ± 727	47.5%	177.8 ± 12.8	1.56
Products from supermarket		38.4	1	5811 ± 848	100%	114 ± 16	1
CW_EC 1.2-1.2-1.2-1.2		167	4.35	6972	119%	122	1.07

Komatsuna	Ca ($mg \cdot 100g^{-1}$)	Fe ($mg \cdot 100g^{-1}$)
Values from MOHW, Taiwan	126	2.5
紅莧菜 Red Amaranth		
Values from MOHW, Taiwan	150	8.5
Values from our previous study	337~430	34.2~48.6

Hydroponics is a perfect tool for nutrient deficiency research

養液化學成分 Chemical composition of nutrient solution.	Modified Hoagland nutrient solution (mg/L)	缺氮 -N (mg/L)	缺磷 -P (mg/L)	缺鉀 -K (mg/L)	缺鈣 -Ca (mg/L)
硝酸鈣 $Ca(NO_3)_2 \cdot 4H_2O$	1180	($CaCl_2 \cdot 2H_2O$=735)	1180	1180	(NH_4NO_3=400)
硝酸鉀 KNO_3	505	(KCl=370)	605	(NH_4Cl=2.67；NH_4NO_3=198)	505
硫酸鎂 $MgSO_4 \cdot 7H_2O$	495	495	495	495	495
磷酸一鉀 KH_2PO_4	135	135	(KNO_3=100)	(H_3PO_4=97.2)	135
鉗形鐵 Fe · EDTA ($EDTA_2Fe$)	7.34	7.34	7.34	7.34	7.34
硼酸 H_3BO_3	1.546	1.546	1.546	1.546	1.546
硫酸銅 $CuSO_4 \cdot 5H_2O$	0.125	0.125	0.125	0.125	0.125
硫酸鋅 $ZnSO_4 \cdot 7H_2O$	0.575	0.575	0.575	0.575	0.575
硫酸錳 $MnSO_4 \cdot H_2O$	0.845	0.845	0.845	0.845	0.845
氯化鉀 KCl	3.728	3.728	3.728	X	3.728
鉬酸銨 $(NH_4)_6Mo_7O_{24} \cdot 4H_2O$	0.0184	0.0184	0.0184	0.0184	0.0184
EC	1.2	1.2	1.2	1.2	1.2
pH	6.0	6.0	6.0	6.0	6.0

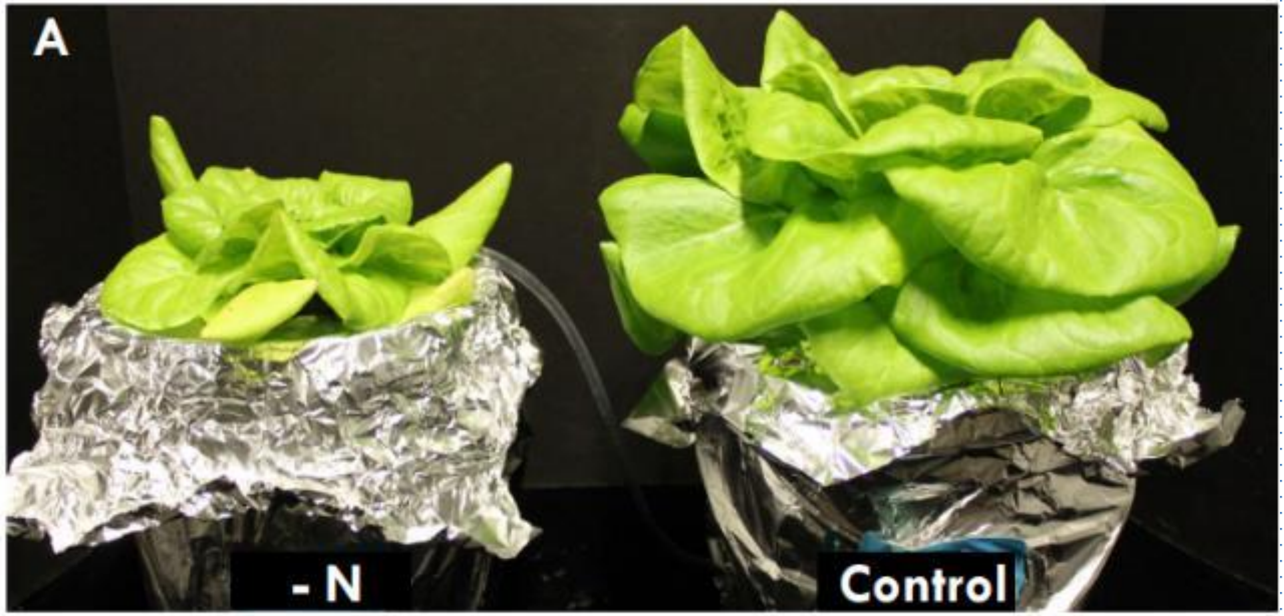
Why Are My Leaves Turning Yellow?

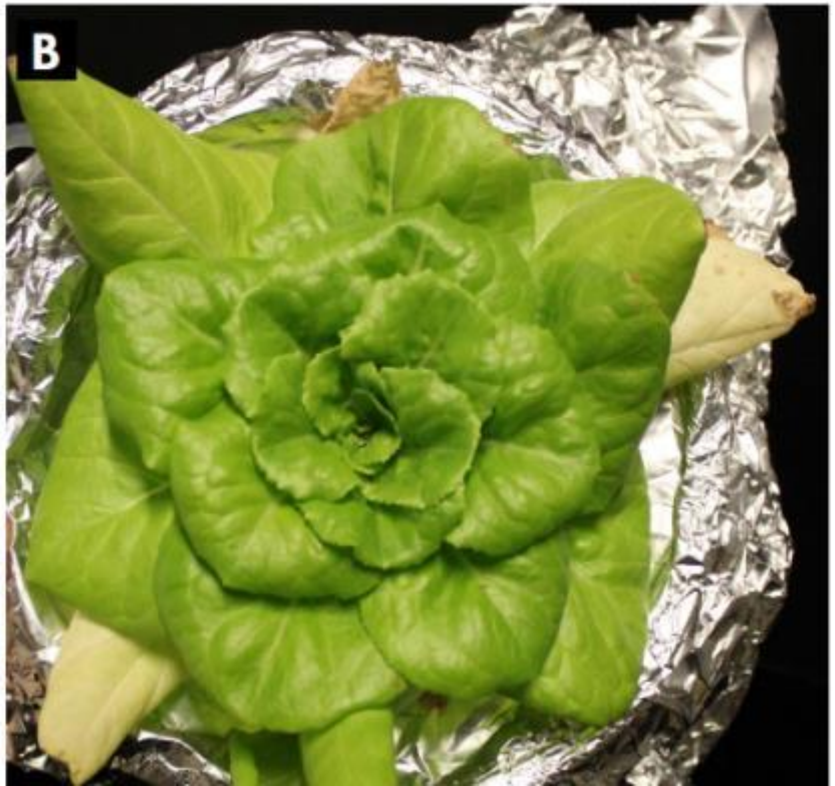
N	Mg	Fe
NO_3 Nitrate NH_4 Ammonium	Bottom of the Plant	Top of the Plant

more on nutrient deficiencies

N

Nitrogen deficiency initially resulted in lighter green color which proceeded to uniform chlorosis (yellowing) of older leaves. Reduced growth was noticeable within the first two weeks of exposure to the deficient conditions (A). Severe chlorosis of older leaves was observed after three weeks of deficient conditions (B)



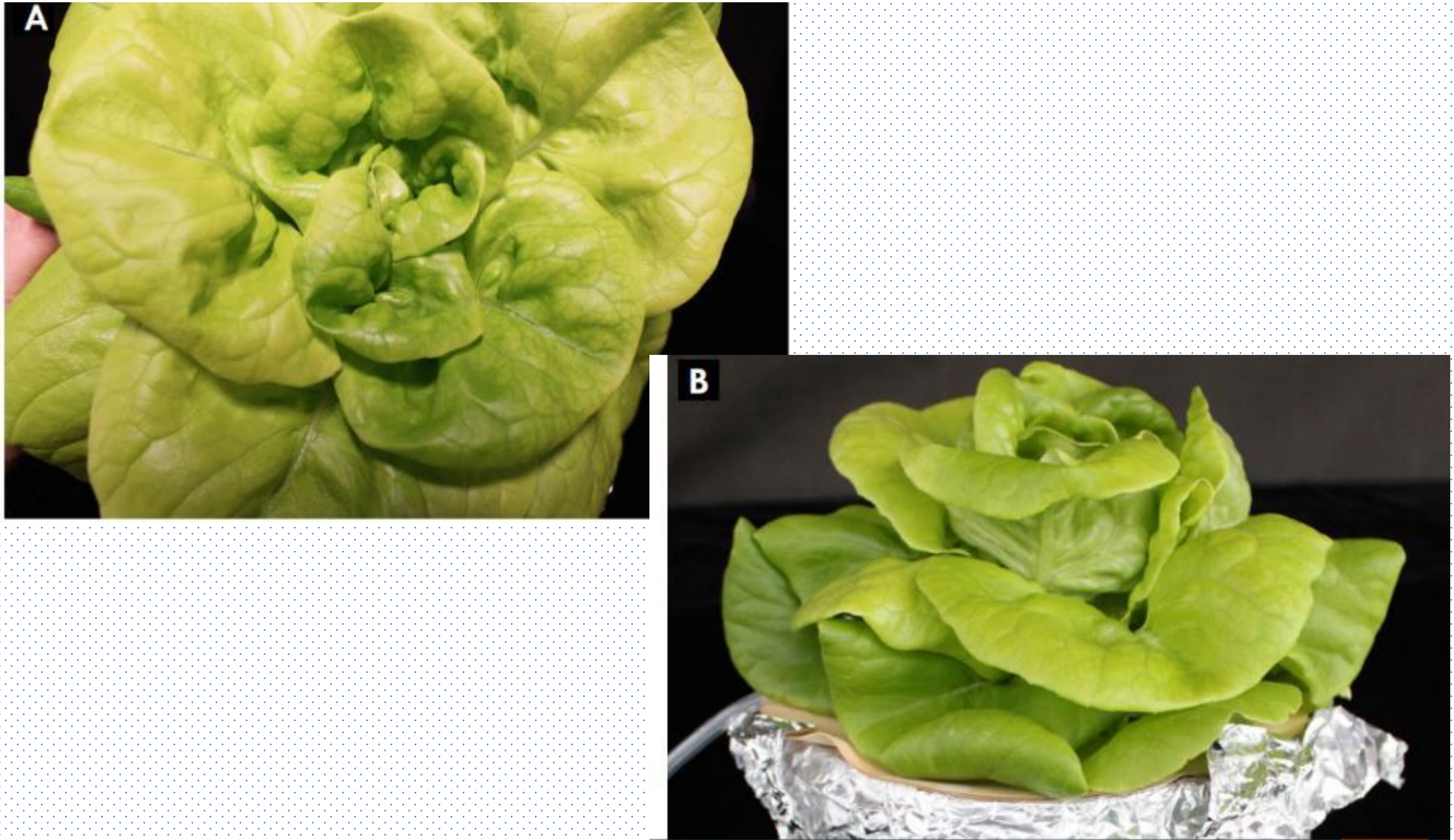


Mg

About 10 days after deficient conditions mature leaves exhibited light interveinal chlorosis (A) and shortly thereafter marginal necrosis was visible (B). After three weeks of Mg deficient conditions, all lower leaves exhibited severe interveinal chlorosis as well as marginal necrosis and some scattered necrotic spots along the leaf blade (C)

Fe

Iron deficiency resulted in interveinal chlorosis of new growth within 10 days of exposure to deficient conditions (A). By the third week similar symptoms became more advanced on the plant and were presented on recently mature and younger leaves (B).



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