

AGRY 515: What do you know? In 10 minutes, fill out what you can. “Educated guesses” are strongly encouraged.

Criteria for Essential Elements

A.

B.

C.

Essential Elements (17):

Nonmineral (3):

Mineral (14):

Beneficial Elements (3):

Lower Plants only (2):

There are several classification systems for mineral nutrients. Do you have a clue what some/any of them are...?

A.

B.

C.

D.

Can genetic solutions solve Gulf of Mexico hypoxia? Crop productivity problems in Africa?

A man hauls his boat and parks it in his wife’s vegetable garden for winter storage and spring maintenance. The next summer, their lettuce fails to thrive (“looks sick”).

A. Is this a nutritional problem? If “yes,” which nutrient? If “no,” what is it?

B. Should they eat the lettuce?

C. List three (3) pieces of additional information that will help you answer or confirm your answer to QA and QB.

**AGRY 515 - Plant Mineral Nutrition - Introduction**  
**Reading Assignment: Marschner, chapters 1 and 6.**

**Historical Perspective on Plant Nutrition Research:**

Democritus (460 - 360 B.C.) - advanced an atomic theory of matter

Aristotle (384-322 B.C.) - all matter consists of 4 “elements”

J.B. van Helmont (1577 - 1644) - conducted first quantitative experiments in plant nutrition - willow tree in 200 lb. of soil.

John Woodward (1665 - 1728) - “terrestrial matter” enters the plant with water through pores.

Stephan Hales (1677 - 1761) - the first physiologist - quantified root surface area, leaf area, amount of water taken up and transpired, velocity of water movement in the plant.

J Priestly (1733 - 1804) - took the first steps in clarifying photosynthesis - green plants emit the same gas that is released by heated mercuric oxide.

Jan Ingen-Housz (1730 - 1799) - light essential for the evolution of oxygen by green plants.

Jean Senebier (1742 - 1809) - the amounts of oxygen evolved by plants kept in water proportional to carbon dioxide dissolved in the water.

Antoine Lavoisier (1743 - 1794) - first modern chemist - chemical reactions consist of changes in the combinations of elements.

Theodore de Saussure (1767 - 1845) - selectivity in the absorption of solutes by plants and laid down the principle of essentiality.

Jean-Baptiste Boussingault (1802 - 1887) - estimated the first nutrient budgets for agricultural systems and provided the first evidence of N fixation.

Justus von Liebig (1803 - 1873) - did away with the humus theory (organic matter in the soil was the source of all plant carbon).

## Absorption of Essential Elements:

C, H and O are absorbed by the plant as oxides.

C	CO <sub>2</sub>	carbon dioxide
H	H <sub>2</sub> O	water
O	CO <sub>2</sub> , H <sub>2</sub> O, O <sub>2</sub>	

N, P, S, Mo, and B, are absorbed as their oxyanions

N	NO <sub>3</sub> <sup>-</sup>	nitrate
P	H <sub>2</sub> PO <sub>4</sub> <sup>-</sup> , HPO <sub>4</sub> <sup>2-</sup>	phosphate
S	SO <sub>4</sub> <sup>2-</sup>	sulfate
Mo	MoO <sub>4</sub> <sup>2-</sup>	molybdate
B	H <sub>3</sub> BO <sub>3</sub> , H <sub>2</sub> BO <sub>3</sub> <sup>-</sup>	boric acid, borate

N in the above group is also absorbed as a hydride

N	NH <sub>4</sub> <sup>+</sup>	ammonium
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The following essential elements are absorbed as their metallic ions or, in some cases for Fe, as an ion-chelate complex.

K	K <sup>+</sup>	potassium
Ca	Ca <sup>2+</sup>	calcium
Mg	Mg <sup>2+</sup>	magnesium
Fe	Fe <sup>2+</sup> , Fe <sup>3+</sup> -chelate	iron
Mn	Mn <sup>2+</sup>	manganese
Cu	Cu <sup>2+</sup>	copper
Zn	Zn <sup>2+</sup>	zinc
Ni	Ni <sup>2+</sup>	nickel

Chlorine is absorbed as the halide ion.

Cl	Cl <sup>-</sup>	chloride
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<b>Element</b>	<b>Symbol</b>	<b>Atomic weight</b>	<b>Form taken up by plants</b>	<b>Primary natural sources</b>
<b>Carbon</b>	<b>C</b>	<b>12.01</b>	<b>CO<sub>2</sub></b>	<b>air</b>
<b>Hydrogen</b>	<b>H</b>	<b>1.01</b>	<b>H<sub>2</sub>O</b>	<b>water</b>
<b>Oxygen</b>	<b>O</b>	<b>16.00</b>	<b>CO<sub>2</sub>, H<sub>2</sub>O, O<sub>2</sub></b>	<b>air, water</b>
<b>Nitrogen</b>	<b>N</b>	<b>14.01</b>	<b>NO<sub>3</sub><sup>-</sup>, NH<sub>4</sub><sup>+</sup></b>	<b>SOM*</b>
<b>Phosphorus</b>	<b>P</b>	<b>30.98</b>	<b>H<sub>2</sub>PO<sub>4</sub><sup>-</sup>, HPO<sub>4</sub><sup>-2</sup></b>	<b>apatite, SOM</b>
<b>Potassium</b>	<b>K</b>	<b>39.10</b>	<b>K<sup>+</sup></b>	<b>feldspars, micas, clay minerals</b>
<b>Calcium</b>	<b>Ca</b>	<b>40.08</b>	<b>Ca<sup>+2</sup></b>	<b>limestone, gypsum</b>
<b>Magnesium</b>	<b>Mg</b>	<b>24.32</b>	<b>Mg<sup>+2</sup></b>	<b>dolomite</b>
<b>Sulfur</b>	<b>S</b>	<b>32.07</b>	<b>SO<sub>4</sub><sup>-2</sup></b>	<b>SOM</b>

<b>Element</b>	<b>Symbol</b>	<b>Atomic weight</b>	<b>Form taken up by plants</b>	<b>Primary natural sources</b>
<b>Iron</b>	<b>Fe</b>	<b>55.85</b>	<b>Fe<sup>+2</sup>, Fe<sup>+3</sup>-chelates</b>	<b>Fe oxides, goethite, SOM</b>
<b>Manganese</b>	<b>Mn</b>	<b>54.94</b>	<b>Mn<sup>+2</sup></b>	<b>Mn-oxides, SOM</b>
<b>Copper</b>	<b>Cu</b>	<b>63.54</b>	<b>Cu<sup>+2</sup></b>	<b>SOM, chalcopyrite</b>
<b>Zinc</b>	<b>Zn</b>	<b>65.38</b>	<b>Zn<sup>+2</sup></b>	<b>SOM</b>
<b>Boron</b>	<b>B</b>	<b>10.82</b>	<b>H<sub>3</sub>BO<sub>3</sub>, H<sub>2</sub>BO<sub>3</sub><sup>-</sup></b>	<b>tourmaline</b>
<b>Molybdenum</b>	<b>Mo</b>	<b>95.95</b>	<b>MoO<sub>4</sub><sup>-2</sup></b>	<b>Miscellaneous minerals</b>
<b>Nickel</b>	<b>Ni</b>	<b>58.71</b>	<b>Ni<sup>+2</sup></b>	<b>Miscellaneous minerals</b>
<b>Chlorine</b>	<b>Cl</b>	<b>35.46</b>	<b>Cl<sup>-</sup></b>	<b>salts</b>

**TABLE 5.1**  
Adequate tissue levels of elements that may be required by plants (Part 1)

Element	Chemical symbol	Concentration in dry matter (% or ppm) <sup>a</sup>	Relative number of atoms with respect to molybdenum
<b>Obtained from water or carbon dioxide</b>			
Hydrogen	H	6	60,000,000
Carbon	C	45	40,000,000
Oxygen	O	45	30,000,000
<b>Obtained from the soil</b>			
<b>Macronutrients</b>			
Nitrogen	N	1.5	1,000,000
Potassium	K	1.0	250,000
Calcium	Ca	0.5	125,000
Magnesium	Mg	0.2	80,000
Phosphorus	P	0.2	60,000
Sulfur	S	0.1	30,000
Silicon	Si	0.1	30,000

Source: Epstein 1972, 1999.

<sup>a</sup> The values for the nonmineral elements (H, C, O) and the macronutrients are percentages. The values for micronutrients are expressed in parts per million.

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**TABLE 5.1**  
Adequate tissue levels of elements that may be required by plants (Part 2)

Element	Chemical symbol	Concentration in dry matter (% or ppm) <sup>a</sup>	Relative number of atoms with respect to molybdenum
<b>Obtained from the soil</b>			
<b>Micronutrients</b>			
Chlorine	Cl	100	3,000
Iron	Fe	100	2,000
Boron	B	20	2,000
Manganese	Mn	50	1,000
Sodium	Na	10	400
Zinc	Zn	20	300
Copper	Cu	6	100
Nickel	Ni	0.1	2
Molybdenum	Mo	0.1	1

Source: Epstein 1972, 1999.

<sup>a</sup> The values for the nonmineral elements (H, C, O) and the macronutrients are percentages. The values for micronutrients are expressed in parts per million.

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**Typical concentrations of nutrients in the soil solution and fresh and dry plant tissue.**

<b>Nutrient</b>	<b>Soil Solution Concentration</b>	<b>Fresh Plant Material Concentration</b>	<b>Plant Dry Matter Concentration</b>
	<b>ppm</b>		<b>%</b>
<b>N</b>	<b>37</b>	<b>0.15</b>	<b>1.5</b>
<b>P</b>	<b>0.8</b>	<b>0.02</b>	<b>0.2</b>
<b>K</b>	<b>14</b>	<b>0.10</b>	<b>1.0</b>
<b>Ca</b>	<b>60</b>	<b>0.05</b>	<b>.5</b>
<b>Mg</b>	<b>40</b>	<b>0.02</b>	<b>0.2</b>
<b>S</b>	<b>26</b>	<b>0.01</b>	<b>0.1</b>

## AGRY 515: Plant Mineral Nutrition - Experimental Methods

### **Considerations - Media and Scale**

Media -

- Soil

- Specialized solids - sand, vermiculite, resins

- Solution culture (hydroponics)

Scale -

- system level

- plant growth stage

- plant parts

### **Advantages and Disadvantages:**

Solution culture:

Advantages:

- maintain precise external concentrations

Disadvantages:

- realism

- time and growth stage constraints

- pH maintenance

- contamination

- oxygenation

- mixing

- iron supply

Specialized solids:

Advantages:

- supporting media

- easier system maintenance

Disadvantages:

- maintenance of external concentrations not as precise

- problems of solution culture mitigated but not removed

Soil:

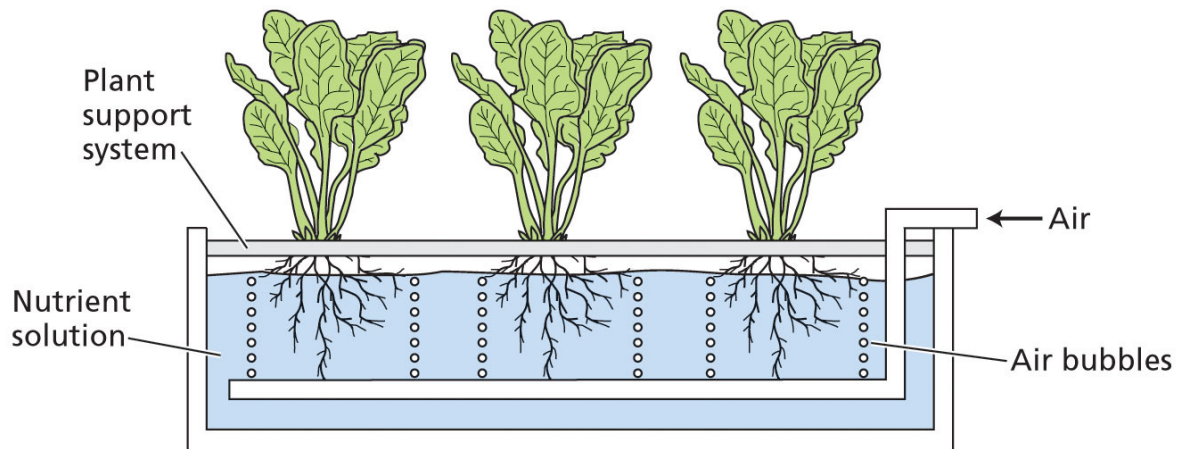
Advantages:

- realistic

Disadvantages:

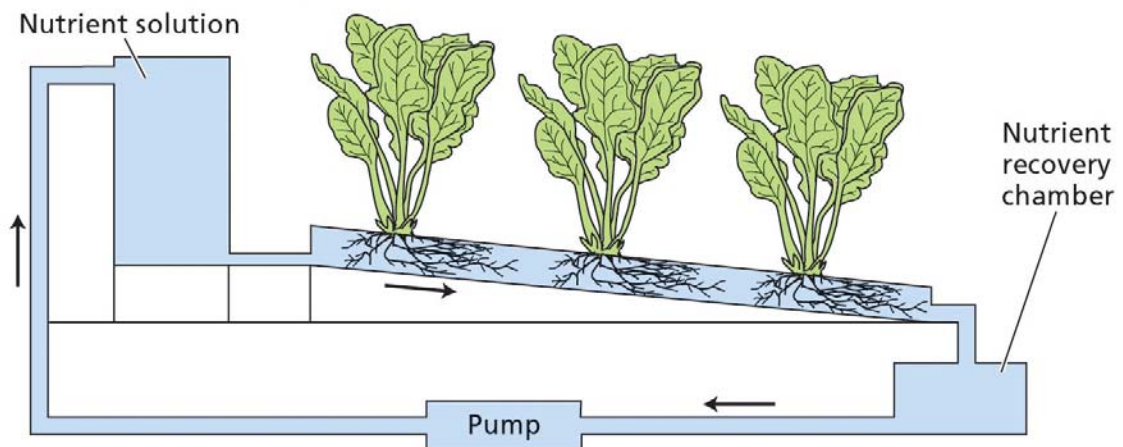
poor control of root environment  
complex biotic/abiotic system

(A) Hydroponic growth system



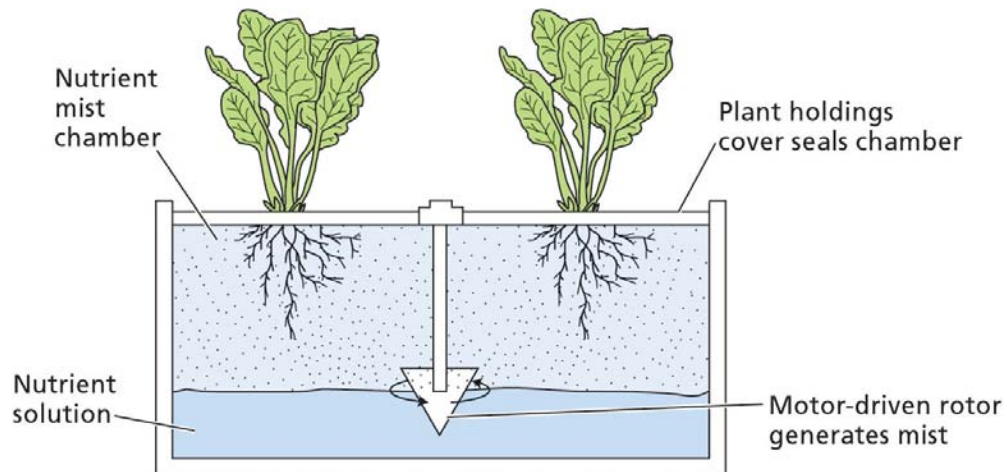
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(B) Nutrient film growth system



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(C) Aeroponic growth system



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**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	
	$\text{g mol}^{-1}$	$\text{mM}$	$\text{g L}^{-1}$	$\text{mL}$		$\mu\text{M}$	$\text{ppm}$
<b>Macronutrients</b>							
$\text{KNO}_3$	101.10	1,000	101.10	6.0	N	16,000	224
$\text{Ca}(\text{NO}_3)_2 \cdot 4\text{H}_2\text{O}$	236.16	1,000	236.16	4.0	K	6,000	235
$\text{NH}_4\text{H}_2\text{PO}_4$	115.08	1,000	115.08	2.0	Ca	4,000	160
$\text{MgSO}_4 \cdot 7\text{H}_2\text{O}$	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.

<sup>a</sup>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.

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**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	
	$\text{g mol}^{-1}$	$\text{mM}$	$\text{g L}^{-1}$	$\text{mL}$		$\mu\text{M}$	$\text{ppm}$
<b>Micronutrients</b>							
KCl	74.55	25	1.864	2.0	Cl	50	1.77
$\text{H}_3\text{BO}_3$	61.83	12.5	0.773		B	25	0.27
$\text{MnSO}_4 \cdot \text{H}_2\text{O}$	169.01	1.0	0.169		Mn	2.0	0.11
$\text{ZnSO}_4 \cdot 7\text{H}_2\text{O}$	287.54	1.0	0.288		Zn	2.0	0.13
$\text{CuSO}_4 \cdot 5\text{H}_2\text{O}$	249.68	0.25	0.062		Cu	0.5	0.03
$\text{H}_2\text{MoO}_4$ (85% $\text{MoO}_3$ )	161.97	0.25	0.040		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
<b>Optional<sup>a</sup></b>							
$\text{NiSO}_4 \cdot 6\text{H}_2\text{O}$	262.86	0.25	0.066	2.0	Ni	0.5	0.03
$\text{Na}_2\text{SiO}_3 \cdot 9\text{H}_2\text{O}$	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.

<sup>a</sup>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.

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