e-GRO Research Update
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Symptoms of Common Nutrient Deficiencies in Hydroponic Arugula

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In hydroponic production, the fertilizer solution must provide all plant essential elements as a growing substrate is either not present or merely provides physical support and access to water and oxygen. Monitoring plants to look for visual symptoms is an important tool that can be used to detect plant nutrient deficiencies. Arugula, or rocket (*Eruca sativa*) is an increasingly popular hydroponically-grown leafy green for salads. Currently there are few resources in the literature regarding photographs and descriptions of common nutrient disorders in hydroponic arugula. Therefore, the objective of this study was to grow arugula in nutrient solutions deficient of individual macro- and micro-nutrients to document visual symptoms of nutrient deficiencies and the timeline and progression of their development.

Materials and Methods

Arugula seeds were sown in 1-inch (200-cell) rockwool cubes that were previously soaked in reverse osmosis water for 5 minutes and then drained and soaked and drained in a Sonneveld's nutrient solution for lettuce (Mattson and Peters, 2014). Seedlings were placed in a greenhouse at 68-72 °F with ambient light and hand watered daily (or as needed) with the Sonneveld's nutrient solution. Two week old seedlings in rockwool were placed in the lid of 1 gallon buckets filled with the Sonneveld's solution. Each bucket had air bubbled in from plastic tubing with an air stone on the end, which was connected to an aquarium air pump. There was 1 plant per bucket. After the plants had been established in hydroponics for 1 week the nutrient solutions for each bucket were replaced with either a control solution prepared in reverse osmosis water (Table 1) or the control solution minus 1 nutrient element of interest (-N, -P, -K, etc.). Every other day reverse osmosis water was used to raise the solution level in each container back to 1 gallon. Every week the nutrient solution in each container was completely replaced with new solution. Plants were monitored every week and symptoms of visible symptoms of nutrient deficiency (with reference to the control plants) were noted. There was 1 plant for each nutrient deficiency condition, the experiment was repeated over time for a total of 3 replications.

Summary of Findings

- Our experimental design led to noticeable deficiency symptoms of N, P, K, and Mg on mature leaves. In many cases symptoms progressed over time to recently developed leaves.
- Deficiency of Ca, Fe, and B affected new growth (young leaves).

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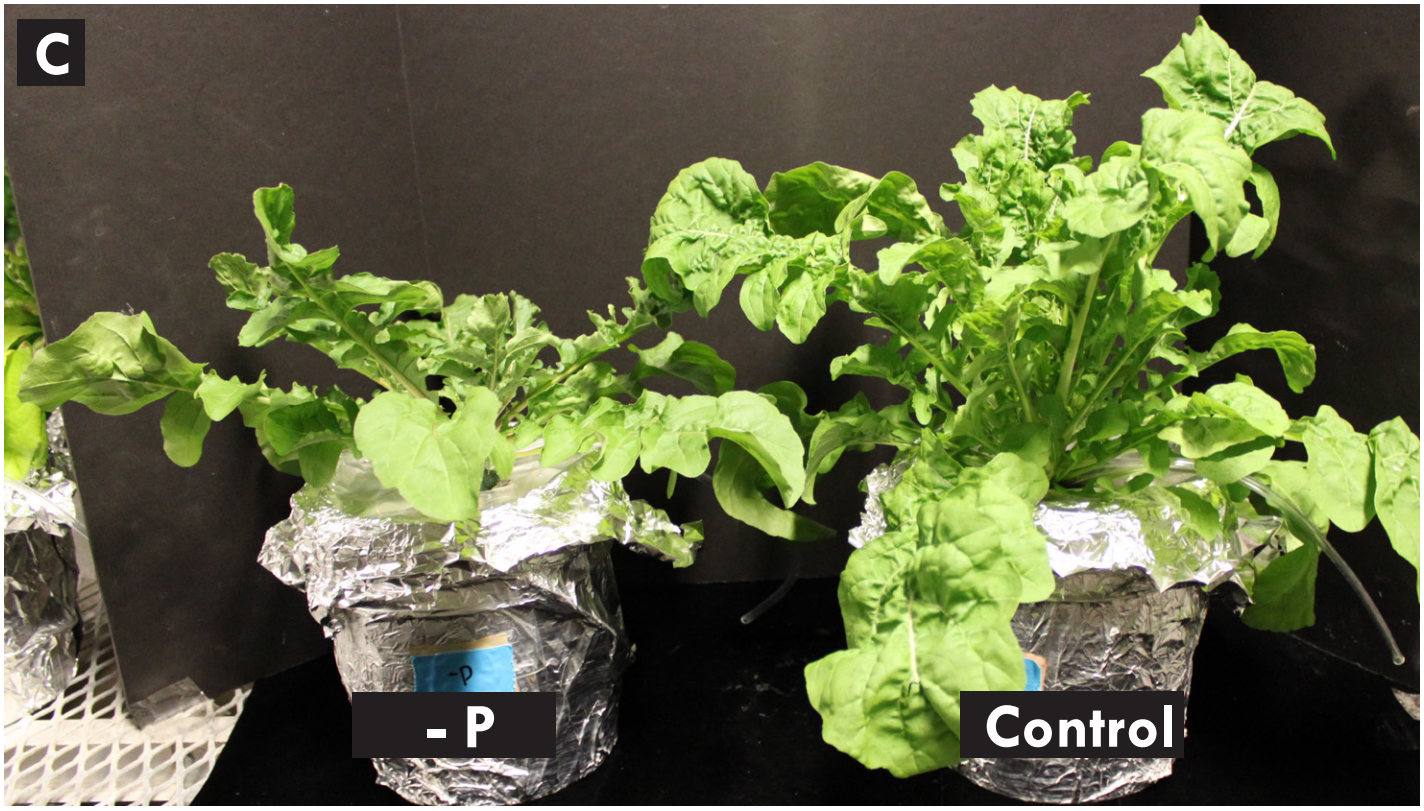
Nitrogen (N)

Nitrogen deficiency resulted in plants developing purple veins and stems (A), and uniform chlorosis (yellowing) of old leaves (B) which was observed after two weeks of deficient conditions. Plant size and leaf area was severely restricted as compared wiht control plants (C). Chlorosis of leaves further progressed to early necrosis (browning) of old leaves by week 3 as well as early bolting (flower stalk formation).

Phosphorus (P)

Phosphorus deficiency was first evident as purpling beginning along leaf margins, (A) evident three weeks after deficienct conditions. Over time, purpling of leaf margins progressed and inward and leaf edges turned necrotic (B). Plants were much smaller and with less unfolded leaves than control plants (C)

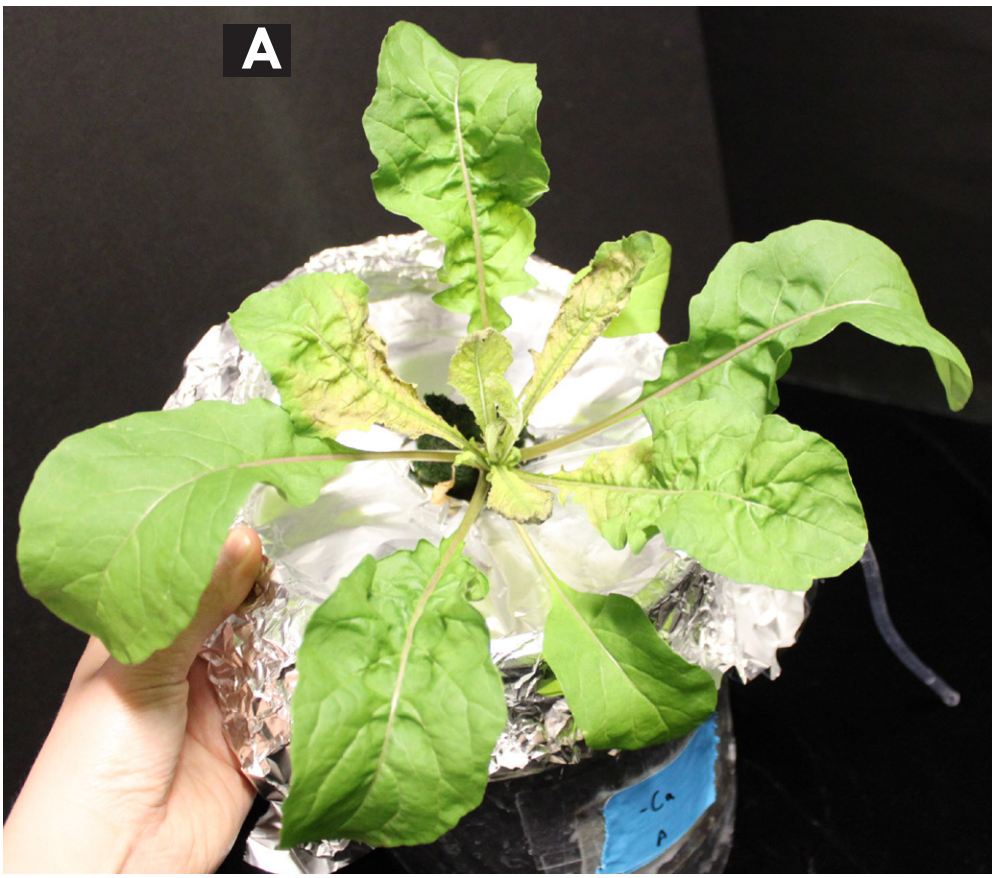


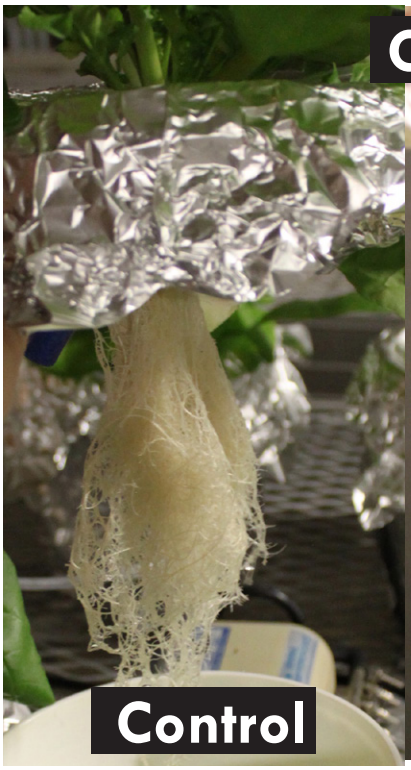
Potassium (K)

Within two weeks of deficient conditions old leaves exhibit marginal necrosis (A) and middle leaves exhibit some upward cupping (B). As the deficiency continues marginal necrosis of older leaves becomes more severe and progresss further into the leaf and by week three some scattered interveinal chlorosis and necosis is present on older leaves (C).

Calcium (Ca)

Symptoms of calcium deficiency within 1 week of deficient conditions were chlrorosis and necrosis beginning towards the base of young leaves (A, B). Young leaves are straplike. Roots become markedly brown within two weeks of Ca deficiency (C). Death of the apical meristem (growing point) is apparent by 3 weeks of Ca deficiency.





Magnesium (Mg)

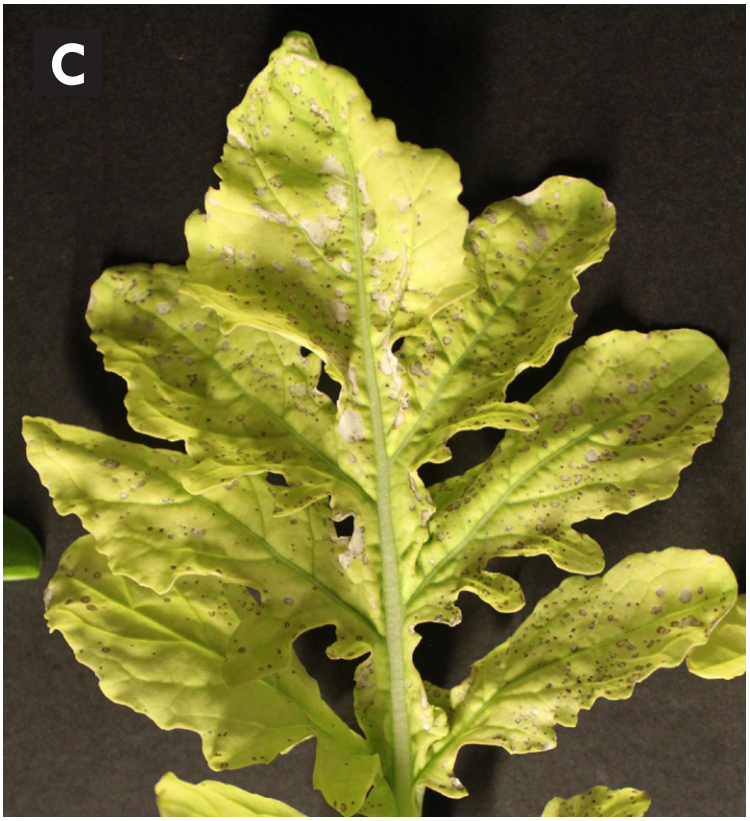
Magnesium deficiency presents itself initially as faint interveinal chlorosis on old leaves within two weeks of deficient conditions (A). As the deficiency advanced interveinal chlorosis progress to more severe interveinal chlororosis with scattered necrotic spots (B, C) and also begins to work its way up the plant affecting more recently expanded leaves.

Sulfur (S)

Within two weeks of sulfur deficiency, plants exhibited uniform chlorosis across the entire leaf blade with recently mature and youner leaves uniformly affected (A). As symptoms progress the yellowing becomes more severe with young and recently mature leaves developing marginal necrosis; older leaves are less affected (B).

Iron (Fe)

Iron deficiency resulted in interveinal chlorosis and minor necrotic spots across of upper (young) leaves within two weeks of deficiency (A) Over time interveinal chlorosis and numerous small necrotic spots between veins became more severe (B, C).



Boron (B)

Boron deficiency was first evident as chlorotic/necrotic leaf margins of the youngest leaves, noticeable which was first noticeable after 3 weeks of deficient conditions (A). As the deficiency progressed to week 4, young and recently mature leaves exhibited irregular interveinal chlorosis (B). New growth was rosette-like and very compact (C)..

Discussion

While visual diagnosis is an important tool, it should be noted that many nutrient disorders are similar in appearance. Therefore laboratory leaf tissue analysis is necessary to verify symptoms. Laboratory tissue analysis (Table 2) can help identify a nutritional problem after it has occurred. A more proactive approach, which will help you avoid economic losses from nutritional disorders, is to periodic laboratory nutrient solution analysis. Based on nutrient solution analysis, the fertilizer regime can be modified to ensure adequate supply of nutrients.

It should be noted that the timeline for development of symptoms may vary based on your environmental conditions. In our experiment plants were well-fertilized before we began the ideficient conditions. Therefore the symptoms may have taken longer to develop than if they had been lacking from the beginning. In many cases nutrient deficiencies may be due to environmental or biotic causes rather than to lack of nutrients in the fertilizer solution. For example, high pH (>6.5) reduces solubility of iron, manganese, boron, etc. and can lead to nutrient deficiencies. Disease or insect damage may also look like nutrient disorders. Therefore, the plant must be examined carefully to ascertain the true cause of symptoms.

Table 1. Control nutrient solution used during the experimental period, single elements were removed to imposed the nutrient deficiencies.

Element	ppm
Nitrogen	210
Phosphorus	31
Potassium	235
Calcium	200
Magnesium	49
Sulfur	64
Iron	4.0
Manganese	0.5
Zinc	0.1
Boron	0.5
Copper	0.10
Molybdenum	0.01

Table 2. Average tissue analysis range of field-grown arugula in research test plots in summer. Tissue samples taken from most recently mature leaves. (From H.A. Mills and J. Benton Jones, Jr. 1996. Plant Analysis Handbook II. MicroMacro Publishing, Inc.)

Macronutrients (%)		Micronutrients (ppm)	
N	2.86-3.97	Fe	187-215
P	0.61-0.72	Mn	38-44
K	4.80-5.16	B	20-25
Ca	2.40-2.46	Cu	3-5
Mg	0.28-0.29	Zn	40-45
S	0.52-0.55	Mo	5.7-5.9

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