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USDA Agricultural Research Service

Plant Response to Environmental Conditions: Plant Nutrition

Jennifer Boldt

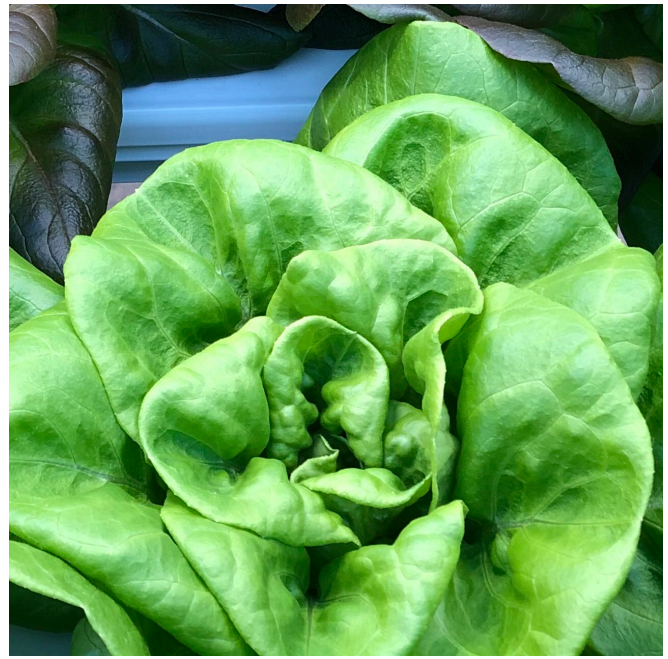
Application Technology Research Unit

Agricultural Research Service

U.S. Department of Agriculture

Essential plant nutrients

- Macronutrients (% dry weight)
  - Nitrogen (N)
  - Phosphorus (P)
  - Potassium (K)
  - Calcium (Ca)
  - Magnesium (Mg)
  - Sulfur (S)
- Micronutrients (ppm or mg/kg)
  - Boron (B)
  - Chlorine (Cl)
  - Copper (Cu)
  - Iron (Fe)
  - Manganese (Mn)
  - Molybdenum (Mo)
  - Zinc (Zn)
- Non-essential
  - Aluminum (Al)
  - Silicon (Si)
  - Sodium (Na)



* Macroelement ≠ more important, just that they are required in higher concentrations than the micronutrients

Nutrient uptake and growing conditions

- Plants acquire nutrients from their environment – soil and soil amendments, substrates, water, fertilizer
- In controlled environment agriculture (CEA), the main source of plant nutrients is from the fertilizer or nutrient solution supplied
- The growing environment affects plant growth and nutrient uptake
- Goal: balance plant growth and nutrient availability to minimize risk of nutrient deficiencies or toxicities

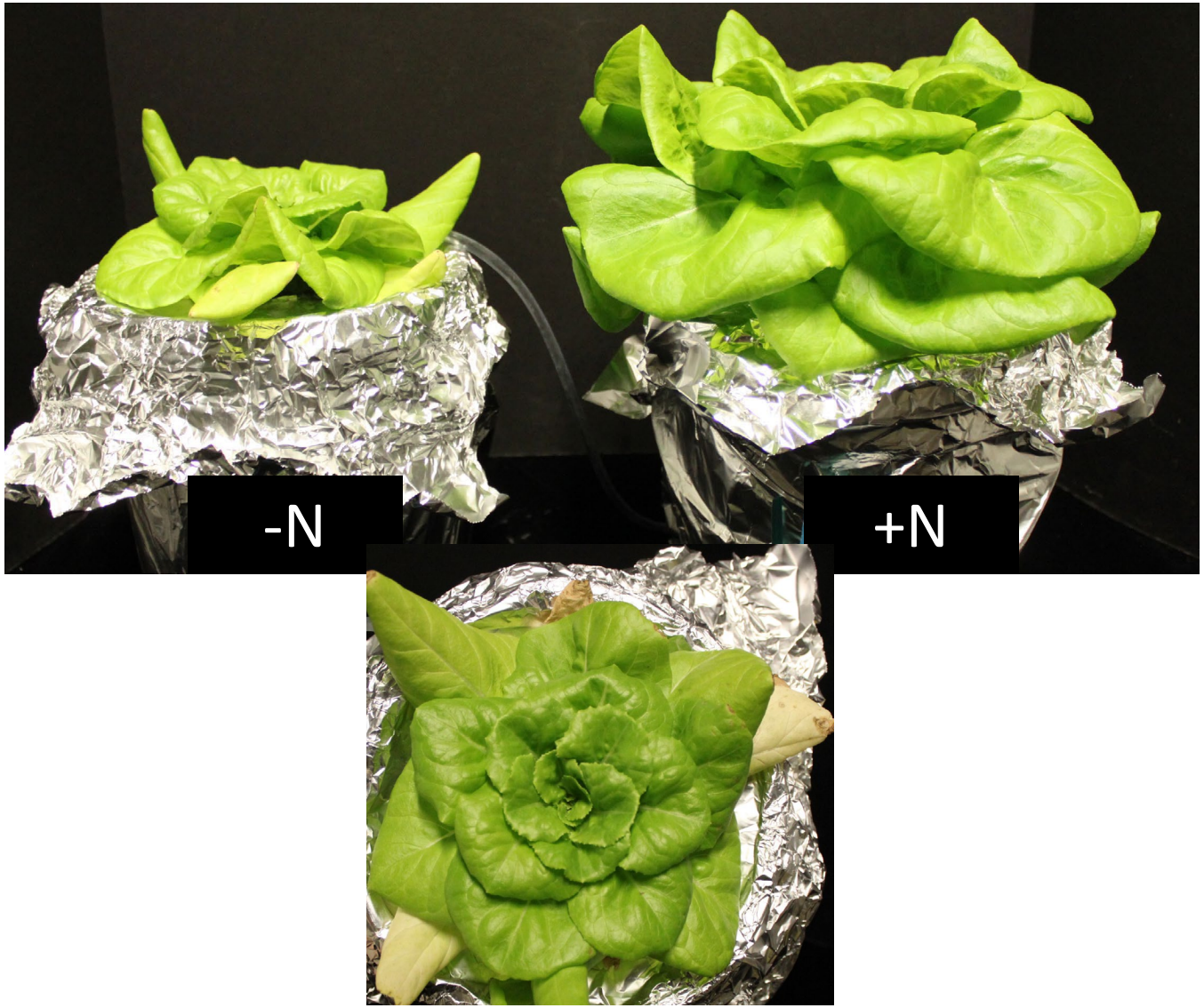
Fertilizer considerations

- Growing system – soilless substrate or liquid culture
  - Soilless substrate – can provide controlled release fertilizer and/or liquid feed
  - Liquid culture – nutrient solution only
- Preference for supplying a pre-mixed blend or mixing components on-site
- Target electrical conductivity (EC)
- Target substrate/nutrient solution pH
- Crop
- Plant growth stage
- Environmental conditions

Nutrient Deficiency Symptoms

Nitrogen (N)

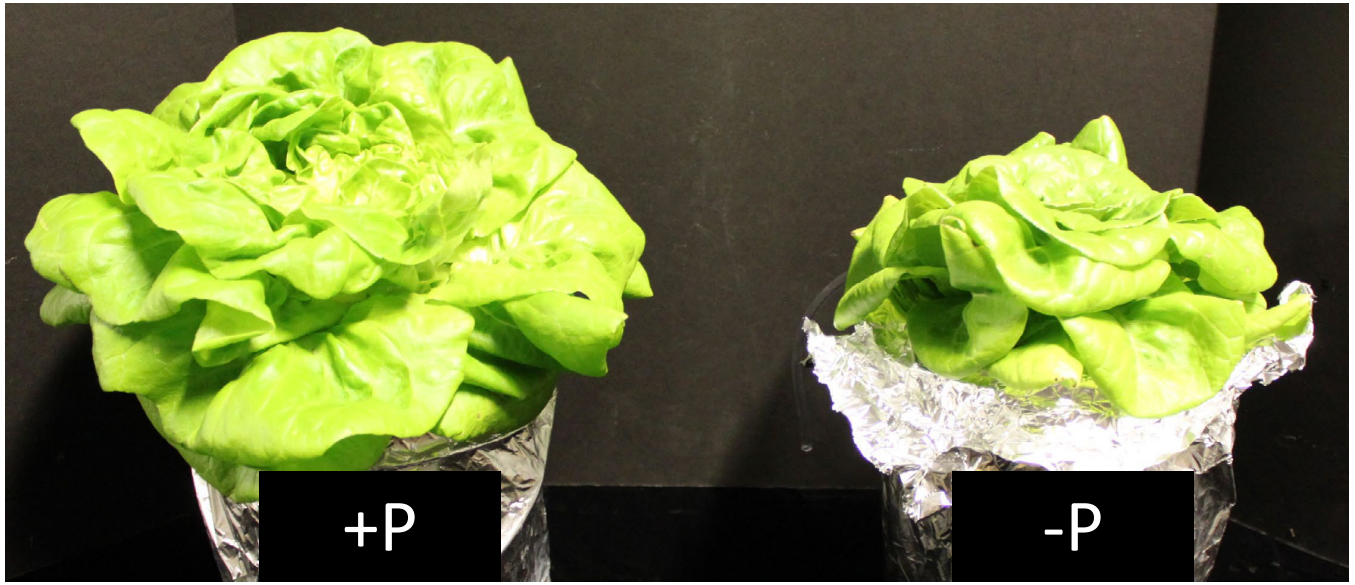
- Function
  - Key component of proteins and amino acids
- Supplied as ammonium (NH_4^+) or nitrate (NO_3^-) in nutrient solution
- Mobile in plants = deficiencies appear first in older leaves
- Deficiency symptoms
  - Leaf chlorosis
  - Smaller leaves
  - Stunted growth



Picture credit: Tanya Merrill, https://www.e-gro.org/pdf/Mattson_Lettuce_2015_9.pdf

Phosphorus (P)

- Function
  - Key component of DNA/RNA, ATP/ADP, $NADP^+$/NADPH
  - Cell formation, photosynthesis, energy-requiring reactions
- Deficiency symptoms
  - Necrosis of lower leaf margins
  - Purpling of lower leaves



Picture credit: Tanya Merrill; https://www.e-gro.org/pdf/Mattson_Lettuce_2015_9.pdf, https://www.e-gro.org/pdf/2016-4.pdf

Potassium (K)

- Function
  - Stomatal regulation
  - Cell turgor
  - Translocation of newly-synthesized carbohydrates
- Deficiency symptoms
  - Light green leaf color
  - Necrosis on lower leaves

Picture credit: Tanya Merrill; https://www.e-gro.org/pdf/Mattson_Lettuce_2015_9.pdf, https://www.e-gro.org/pdf/2016-4.pdf

Calcium (Ca)

- Function
  - Component of the “glue” between cell walls (e.g., like mortar for bricks)
  - Cell elongation
- Taken up through mass flow
- Immobile in plants
- Deficiency systems
  - “Tip burn” in new leaves
  - Distorted leaf growth
  - Necrosis along leaf tip edge

Picture credit: Tanya Merrill, https://www.e-gro.org/pdf/Mattson_Lettuce_2015_9.pdf

Magnesium (Mg)

- Function
  - Key component of chlorophyll
  - Co-factor for enzymatic reactions
  - Activates CO_2-fixation enzymes
- Deficiency systems
  - Interveinal chlorosis of older leaves
  - Progresses to leaf necrosis

Picture credit: Tanya Merrill; https://www.e-gro.org/pdf/Mattson_Lettuce_2015_9.pdf, https://www.e-gro.org/pdf/2016-4.pdf

Sulfur (S)

- Function
  - Protein structure (di-sulfide bonds)
  - Component of ferredoxin
- Deficiency systems
  - General chlorosis of entire plant
  - Progresses to leaf edge necrosis
  - Stunted growth

Picture credit: Tanya Merrill, https://www.e-gro.org/pdf/Mattson_Lettuce_2015_9.pdf

Boron (B)

- Function
  - Meristem growth and development
- Deficiency systems
  - Distorted new growth
  - Shorter roots

Picture credit: Tanya Merrill, https://www.e-gro.org/pdf/Mattson_Lettuce_2015_9.pdf

Copper (Cu)

- Function
  - Component of enzymes involved in electron transport and oxidation reactions
- Deficiency systems
  - Stunted growth
  - Narrow, cupped leaves
  - Distorted young leaves

63. Copper deficiency in lettuce (cv. Deci-Minor) grown in water culture.

64. Leaves of a copper-deficient plant (cv. Deci-Minor) grown on sphagnum peat.

Photo credit: Roorda van Eysinga and Smilde (1981)

Iron (Fe)

- Function
  - Component of enzymes involved in photosynthesis, energy production, and N assimilation
  - Chlorophyll biosynthesis
- Deficiency systems
  - Interveinal chlorosis of young leaves
  - Appears similar to Mg deficiency but differs in localization
  - More prevalent at high root zone pH

Picture credit: Tanya Merrill; https://www.e-gro.org/pdf/Mattson_Lettuce_2015_9.pdf, https://www.e-gro.org/pdf/2016-4.pdf

Manganese (Mn)

- Function
  - Involved in redox reactions
  - Component of key enzyme involved in free radical quenching
- Deficiency systems
  - Lighter green coloration
  - Progresses to interveinal chlorosis

67. Manganese deficiency in lettuce (cv. Noran) grown in water culture.

Photo credit: Roorda van Eysinga and Smilde (1981)

Molybdenum (Mo)

- Function
  - Key component of two enzymes involved in N assimilation
- Deficiency systems
  - Leaf chlorosis
  - Progresses to marginal curling and necrosis

68. Molybdenum-deficient plant (cv. Desico) grown in a peat block.

69. Leaves of a molybdenum-deficient lettuce plant showing necrotic spots.

Photo credit: Roorda van Eysinga and Smilde (1981)

Zinc (Zn)

- Function
  - Involved in enzymatic reactions
  - Component of enzyme that quenches oxygen radicals
  - RNA synthesis and chloroplast development
- Deficiency systems
  - Short internodes (= rosette appearance)
  - Necrotic spots along leaf edges
  - “Scorched” appearance

70. Zinc deficiency in lettuce (cv. Deci-Minor) grown in water culture.

71. Lettuce leaf showing zinc deficiency (bottom and right top of the leaf were shaded by other leaves during growth).

Photo credit: Roorda van Eysinga and Smilde (1981)

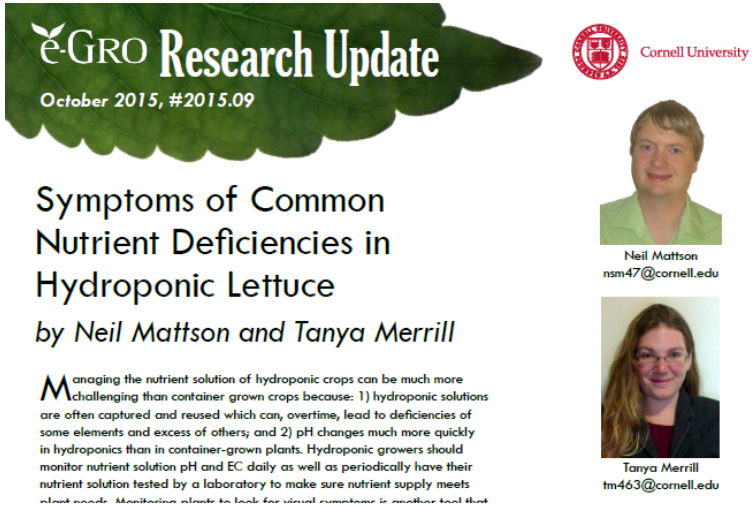
Leaf tissue nutrient ranges for “healthy” lettuce

	Roorda van Eysinga and Smilde (1981) Nutritional disorders in glasshouse tomatoes, cucumbers and lettuce	Bryson and Mills (2014) Plant Analysis Handbook IV Hydroponic lettuce	Mills and Jones (1996) Plant Analysis Handbook II Greenhouse butterhead lettuce
Macronutrients (% dry weight)			
N	2.10 – 5.60	3.75 – 5.60	4.20 – 5.60
P	0.40 – 0.93	0.45 – 0.77	0.62 – 0.77
K	3.91 – 9.78	3.00 – 6.50	7.82 – 13.68
Ca	0.60 – 1.48	1.25 – 2.50	0.80 – 1.20
Mg	0.53 – 1.22	0.45 – 0.78	0.24 – 0.73
S	0.19 – 0.42	0.25 – 0.35	0.26 – 0.32
Micronutrients (ppm or $mg \cdot kg^{-1}$ dry weight)			
B	22 – 65	15 – 45	32 – 43
Cu	5 – 17	6 – 16	6 – 16
Fe	56 – 559	50 – 150	168 – 223
Mn	30 – 198	55 – 110	55 – 110
Mo	0.2 – 4.0	0.33 – 0.58	0.29 – 0.58
Zn	33 - 196	25 – 60	33 – 196

Hydroponic solution adjustment/replacement

- Plants do not take up all elements equally
- In a hydroponic reservoir, nutrient concentrations will not maintain original ratios
- Options for maintaining reservoir volume:
  1. “Top off” with water if EC remains above minimum threshold
  2. “Top off” reservoir volume with original nutrient solution
  3. Complete nutrient solution replacement at target intervals
  4. Real (or semi-real) time replacement of ions back to desired ratios
     - Trickier to do but less waste water
     - Requires in-line measurement of ions or frequent water testing
  5. Mass balance approach
     - Estimates can be made from tissue analyses of previous crop, water use, and biomass

Resources


e-GRO Research Update
October 2015, #2015.09
Cornell University

Symptoms of Common Nutrient Deficiencies in Hydroponic Lettuce

by Neil Mattson and Tanya Merrill

Managing the nutrient solution of hydroponic crops can be much more challenging than container grown crops because: 1) hydroponic solutions are often captured and reused which can, overtime, lead to deficiencies of some elements and excess of others; and 2) pH changes much more quickly in hydroponics than in container-grown plants. Hydroponic growers should monitor nutrient solution pH and EC daily as well as periodically have their nutrient solution tested by a laboratory to make sure nutrient supply meets

Neil Mattson
nsm47@cornell.edu
Tanya Merrill
tm463@cornell.edu

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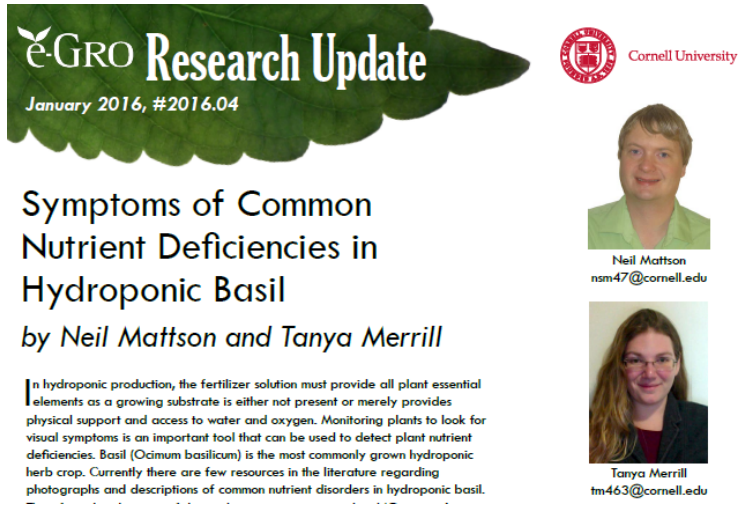

e-GRO Research Update
January 2016, #2016.04
Cornell University

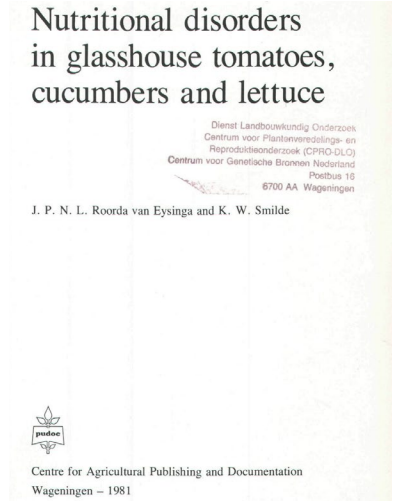
Symptoms of Common Nutrient Deficiencies in Hydroponic Basil

by Neil Mattson and Tanya Merrill

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. Basil (Ocimum basilicum) is the most commonly grown hydroponic herb crop. Currently there are few resources in the literature regarding photographs and descriptions of common nutrient disorders in hydroponic basil.

Neil Mattson
nsm47@cornell.edu
Tanya Merrill
tm463@cornell.edu

https://www.e-gro.org/pdf/2016-4.pdf


Nutritional disorders in glasshouse tomatoes, cucumbers and lettuce

Dienst Landbouwkundig Onderzoek
Centrum voor Plantenveredelings- en Reproduktieonderzoek (CPRO-DLO)
Centrum voor Genetische Bronnen Nederland
Postbus 16
6700 AA Wageningen

J. P. N. L. Roorda van Eysinga and K. W. Smilde

pudoc
Centre for Agricultural Publishing and Documentation
Wageningen – 1981

https://edepot.wur.nl/411848


e-GRO Nutritional Monitoring

Josh Henry[1] Brian E. Whipker[1] W. Garrett Owen[2] Christopher Currey[3]

Volume 1 Number 13 April 2018

Nutritional Monitoring Series

Lettuce

(Lactuca sativa)

Lettuce requires medium levels of fertilization, growing best with 150 to 200 ppm N or 1.0 to 2.0 mS/cm for hydroponic nutrient solutions. Lettuce transplants grown in soilless substrates have a wider optimal pH range of 5.5 to 6.5. Hydroponic solution pH values should be maintained between 5.5 and 6.0 with an optimal

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Target Nutrition Parameters

pH Category II to IV:
5.5 to 6.5 (substrate)
5.5 to 6.0 (hydroponic)

Lettuce

http://fertdirtandsquirt.com/pdf/lettuce.pdf


e-GRO Nutritional Monitoring

Volume 1 Number 14 April 2018

Nutritional Monitoring Series

Basil

(Ocimum basilicum)

Basil requires low levels of fertilization, growing best with 100 to 150 ppm N for containerized crops or 0.5 to 1.5 mS/cm for hydroponic nutrient solutions. Plants prefer a pH within the range of 5.8 to 6.2 for both soilless substrates and hydroponic solutions. This range prevents low substrate pH-induced iron (Fe) and manganese toxicities and Fe deficiency.

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Target Nutrition Parameters

pH Category III:
5.8 to 6.2
(substrate & hydroponic)

Fertility Category: Low
100 to 150 ppm N (substrate)
0.5 to 1.5 mS/cm (hydroponic)

Basil

http://fertdirtandsquirt.com/pdf/basil.pdf


Open Access Review

Principles of Nutrient and Water Management for Indoor Agriculture

by Noah James Langenfeld [1,*], Daniel Fernandez Pinto [2], James E. Faust [3], Royal Heins [1,4] and Bruce Bugbee [1]

[1] Crop Physiology Laboratory, Utah State University, Logan, UT 84322, USA
[2] Department of Chemistry, Universidad Nacional de Colombia, Bogotá 111321, Colombia
[3] Department of Plant and Environmental Sciences, Clemson University, Clemson, SC 29634, USA
[4] Department of Horticulture, Michigan State University, East Lansing, MI 48824, USA
* Author to whom correspondence should be addressed.

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https://www.mdpi.com/2071-1050/14/16/10204

Thanks for listening!

For questions, please contact:
jennifer.boldt@usda.gov

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