Macro- and micronutrients rehabilitate HLB-affected citrus trees

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Roles of nutrients in improving plant health

Justud von Liebig's Law of the minimum: The Law of the Minimum, made by Justus von Liebig, describes how plant growth is constrained by resource limitation. Plants need many nutrients to grow well. If only one of these nutrients is deficient, plant growth will be inhibited, even if all the other essential nutrients are available in abundance. This is also true for all other resources such as light, temperature and water for the respective plant species. **The scarcest resource always restricts plant growth and therefore is referred to as the limiting factor!!**

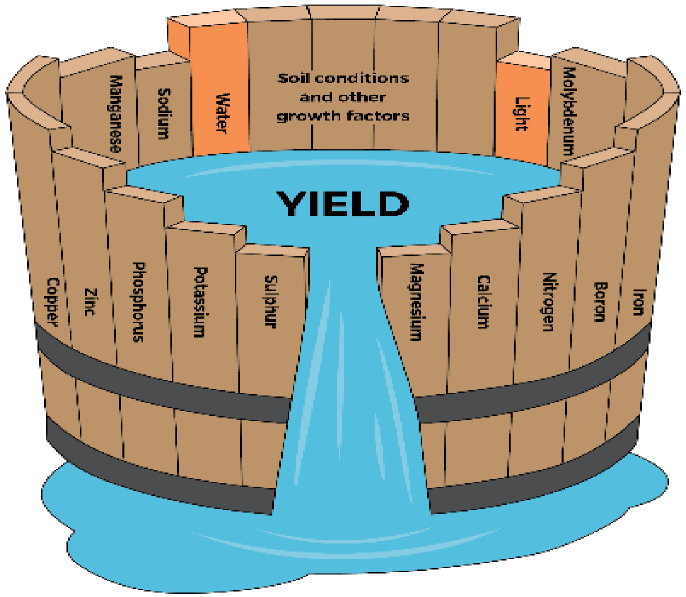

Figure 1. Liebig's Law of Minimum illustrated for plant growth and nutrition with a leaking barrel. Credit UF/IFAS Communications

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Interactive role of nutrients in defense

Modes of action of nutrients

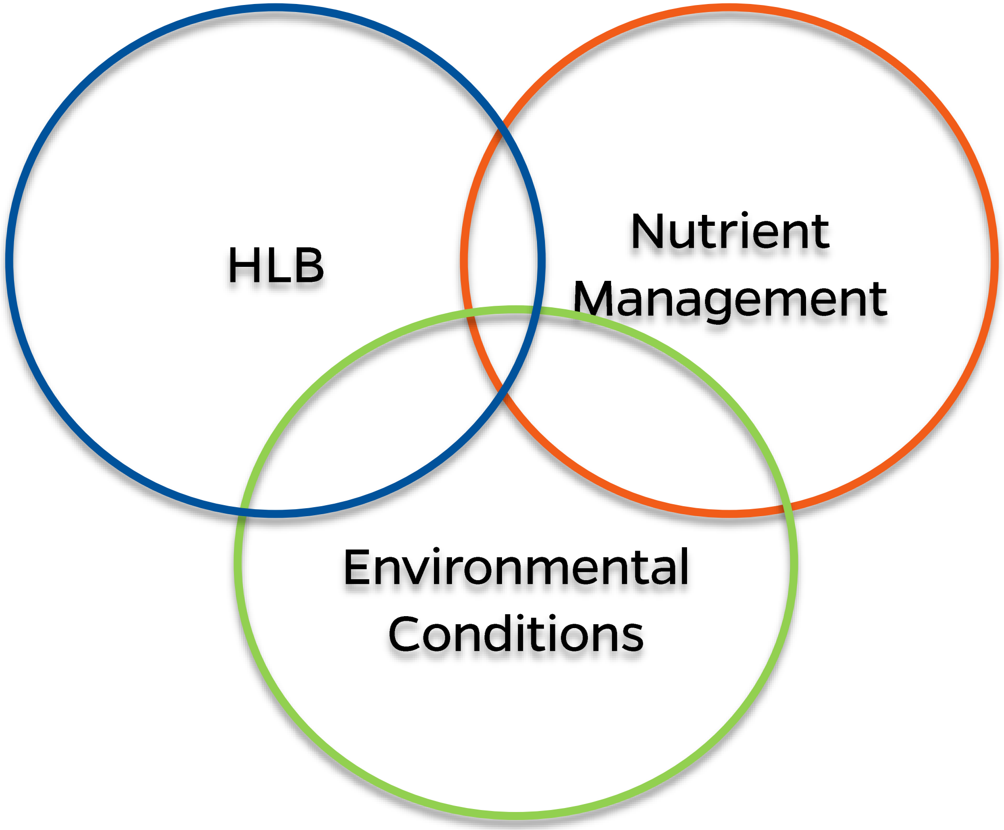
Nutritional-related effect
Improving plant potential strength.

Nutritional-physiological-related action
Intervention in expression of natural plant defense mechanisms.

Elicitor-related action
Activation of pathways involved in defense mechanisms, even in the absence of attack of the pathogen.

Pesticide-related action
Inhibition of the development and growth of a pathogen.

The HLB-Nutrient-Environment Nexus



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Key hypotheses

- Citrus fruit yields, canopy size and development will be enhanced with a balanced nutrition approach for HLB-affected citrus.

- Root health and overall plant health and immunity are strengthened with elevated rates of micronutrients compared to current recommendations.

Role of Mn in HLB management

- HLB (kg Mn ha^{-1})
  - 0.0 (control)
  - 5.6 (1x)
  - 11.2 (2x)
  - 22.4 (4x)
- Healthy (Non HLB) (kg Mn ha^{-1})
  - 0.0 (control)
  - 5.6 (1x)
  - 11.2 (2x)
  - 22.4 (4x)

Goal: To evaluate the effect of variable rates of Mn on the growth and development of 1-3-year-old ‘Valencia’ (*Citrus sinensis*) trees on Kuharske citrange rootstock (*Citrus sinensis* x *Poncirus trifoliata*) under greenhouse conditions.

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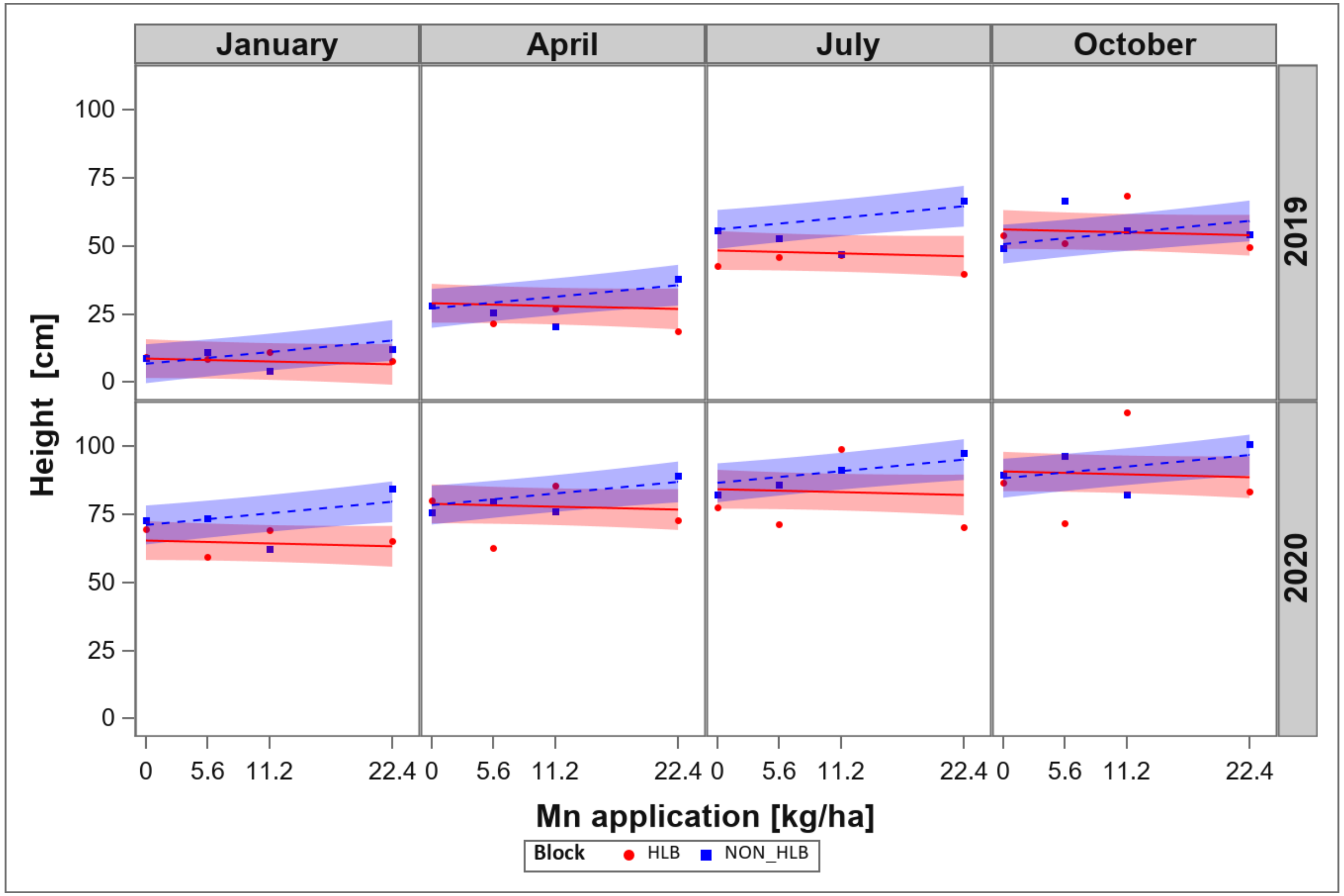
Kwakye et al. 2022a. HORTSCIENCE. https://doi.org/10.21273/HORTSCI16337-21

Effect of treatment on height



- Height was not different between Mn rates
- Tree height increased over time, irrespective of the Mn rate

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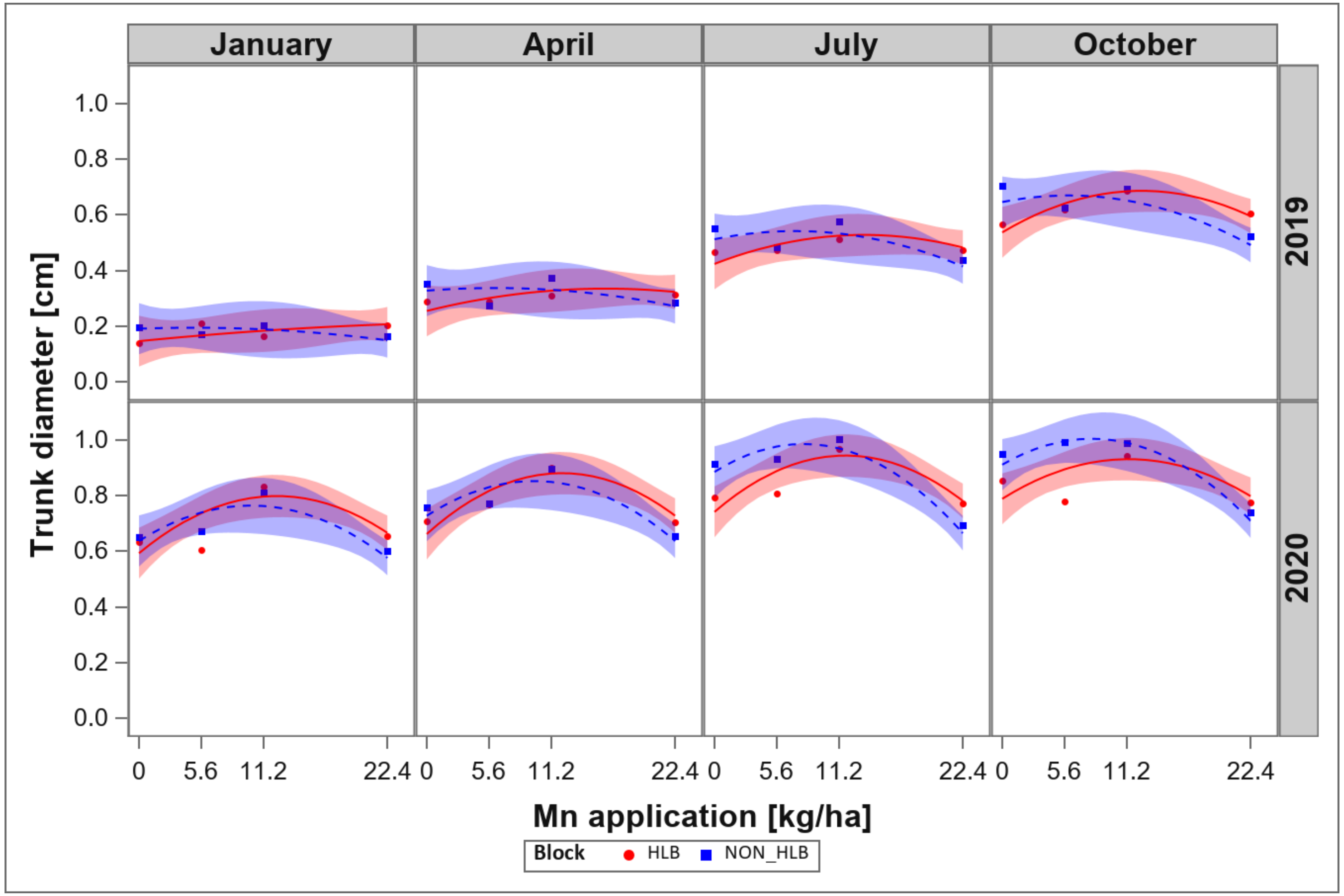
Kwakye et al. 2022a. HORTSCIENCE. https://doi.org/10.21273/HORTSCI16337-21

Effect of treatment on trunk diameter



- Trunk diameter increased over time for all treatments in the year one
- The 2x rate increased trunk diameter by 23% when compared to trees that received 1x and 4x in year two

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Kwakye et al. 2022a. HORTSCIENCE. https://doi.org/10.21273/HORTSCI16337-21

Pearson's Correlation of soil Mn with B, Zn, Fe, and Cu

	HLB		Non HLB	
Element	R	*P*-value	R	*P*-value
Boron	-0.76	0.0045	-0.58	0.0498
Zinc	-0.69	0.0127	-0.52	0.0837
Iron	0.49	0.1041	-0.02	0.9490
Copper	0.65	0.0215	0.33	0.3008

- Soil Mn correlated positively with Fe and Cu and negatively with B and Zn
- B and Zn seemed to be absorbed better than Fe and Cu

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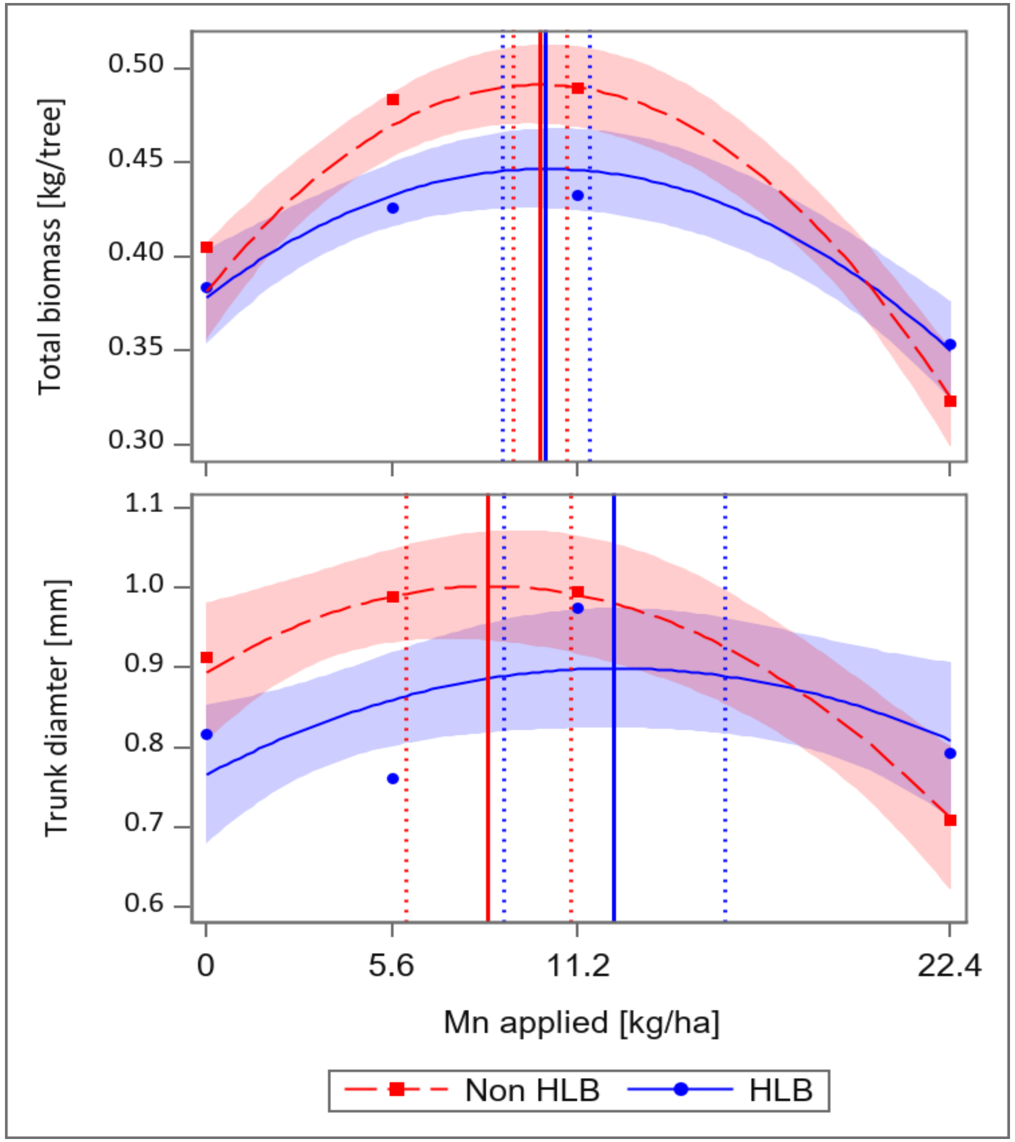
Kwakye et al. 2022a. HORTSCIENCE. https://doi.org/10.21273/HORTSCI16337-21

Maximum dry biomass and trunk diameter in response to Mn rates

- The 2x rate had the maximum dry weight compared to other rates
- Non HLB trees had an overall biomass between 5-13% greater (P <0.001) than the corresponding fertility level for HLB trees
- Mn rate of 8.9 to 11.5 kg ha-1 was calculated as the optimum Mn level



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Role of iron (Fe) in HLB management

HLB (kg Fe ha^{-1})

- 0.0 (control)
- 5.6 (1x)
- 11.2 (2x)
- 22.4 (4x)

Non HLB (kg Fe ha^{-1})

- 0.0 (control)
- 5.6 (1x)
- 11.2 (2x)
- 22.4 (4x)

Goal: To evaluate the effect of variable rates of Fe on the growth and development of 1-3-year-old 'Bingo' (Citrus reticulata) trees on Kuharske citrange (Citrus sinensis x Poncirus trifoliata) rootstock under greenhouse conditions.

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Kwakye et al. 2022b. HORTSCIENCE. https://doi.org/10.21273/HORTSCI16548-22

Effect on Fe on height, trunk and leaf for 2019 and 2020

HLB status	Fe rate	Height [cm]				Trunk diam [cm]				Leaf Fe [ppm]			
	kg Fe ha^{-1}												
						2019							
HLB	0	35.1	±	5.41	b	0.48	±	0.038	b	44.7	±	3.18	d
	5.6	62.2	±	4.55	a	0.48	±	0.037	b	62.3	±	3.24	c
	11.2	42.9	±	5.04	b	0.62	±	0.039	a	81.5	±	2.94	b
	22.4	62.4	±	5.04	a	0.56	±	0.038	ab	94.9	±	3.17	a
Non HLB	0	50.9	±	5.13	a	0.57	±	0.040	a	51.5	±	3.79	d
	5.6	41.4	±	4.89	a	0.55	±	0.040	a	91.2	±	3.48	c
	11.2	41.3	±	4.59	a	0.56	±	0.038	a	102.0	±	3.52	b
	22.4	48.9	±	5.31	a	0.62	±	0.037	a	157.4	±	3.85	a
						2020							
HLB	0	53.2	±	4.61	b	0.62	±	0.036	b	29.2	±	3.68	c
	5.6	53.5	±	6.07	b	0.67	±	0.039	ab	53.4	±	3.64	b
	11.2	77.7	±	4.79	a	0.75	±	0.039	a	62.2	±	3.51	b
	22.4	65.0	±	4.78	ab	0.63	±	0.038	b	75.3	±	3.63	a
Non HLB	0	73.9	±	4.80	a	0.76	±	0.039	a	35.8	±	2.88	c
	5.6	63.2	±	5.09	a	0.64	±	0.040	b	54.2	±	3.28	b
	11.2	67.4	±	5.33	a	0.71	±	0.039	ab	59.5	±	2.92	b
	22.4	62.9	±	4.56	a	0.74	±	0.041	ab	71.0	±	2.92	a
Sources of variation													
HLB_Status|Fe rate|Year		<0.001				<0.001				<0.001			
Time(HLB_Status*Fe*Year)		<0.001				<0.001				<0.003			
Time*Time(HLB_Status*Fe*Year)		<0.001				<0.001				0.487			

- For both years, tree height and trunk diameter were significantly different (P <0.001) among Fe rates
- A linear response of Fe was observed for HLB-affected and non HLB trees

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Kwakye et al. 2022b. HORTSCIENCE. https://doi.org/10.21273/HORTSCI16548-22

Relationship between Fe accumulation and other nutrients in plant parts

Part	N	P	K	Mg	Ca	S	B	Zn	Mn	Cu
					r					
					HLB					
Above-ground										
Leaves	0.56^{ns}	0.51^{ns}	0.15^{ns}	0.51^{ns}	0.52^{ns}	0.74**	0.57^{ns}	0.46^{ns}	0.58*	0.49^{ns}
Twigs	0.58*	0.42^{ns}	0.36^{ns}	0.72**	0.68*	0.76**	0.70**	0.79**	0.65*	0.58*
Branch	0.83***	0.85***	0.88***	0.92***	0.93***	0.90***	0.87***	0.86***	0.90***	0.72**
Trunk	0.72*	0.38^{ns}	0.8**	0.84**	0.88***	0.82**	0.86**	0.69*	-0.32^{ns}	0.56^{ns}
Below-ground										
Root (< 1 mm)	0.65*	0.71**	0.62*	0.68*	0.50	0.82**	0.74*	0.80**	0.80**	0.60*
Root (1-3 mm)	0.73**	0.49^{ns}	0.47^{ns}	0.56	0.58*	0.63*	0.67*	0.91***	0.82**	0.55^{ns}
Root (> 3 mm)	0.26^{ns}	0.36^{ns}	0.39^{ns}	0.41^{ns}	0.3^{ns}	0.52^{ns}	0.42^{ns}	0.45^{ns}	0.64*	0.25^{ns}
					Non HLB					
Above-ground										
Leaves	0.45^{ns}	0.13^{ns}	0.22^{ns}	0.09^{ns}	0.20^{ns}	0.87***	0.86***	0.69**	0.66*	0.15^{ns}
Twigs	0.58*	0.29^{ns}	0.21^{ns}	0.34^{ns}	0.39^{ns}	0.48^{ns}	0.42^{ns}	-0.01^{ns}	0.46^{ns}	0.41^{ns}
Branch	0.75**	0.67*	0.74**	0.82***	0.85***	0.92***	0.84***	0.83***	0.6*	0.79**
Trunk	0.48^{ns}	0.66*	0.63*	0.40^{ns}	0.35^{ns}	0.82**	0.17^{ns}	0.46^{ns}	0.37^{ns}	0.00^{ns}
Below-ground										
Root (< 1 mm)	0.37^{ns}	0.25^{ns}	0.24^{ns}	0.36^{ns}	0.45^{ns}	0.43^{ns}	0.43^{ns}	0.60*	0.68*	0.2^{ns}
Root (1-3 mm)	0.37^{ns}	0.18^{ns}	0.13^{ns}	0.34^{ns}	0.32^{ns}	0.45^{ns}	0.15^{ns}	0.98***	0.85***	0.39^{ns}
Root (> 3 mm)	0.19^{ns}	0.14^{ns}	0.08^{ns}	0.23^{ns}	0.31^{ns}	0.3^{ns}	0.26^{ns}	0.35^{ns}	0.72*	0.18^{ns}

- In general Fe had strong correlation with all studied nutrients for HLB-affected trees than for non HLB trees
- In small and medium roots, there was a strong (positive) correlation with Fe and other nutrients in HLB-affected trees

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Effect of Fe rates on dry weight biomass

Fe [kg ha-1]	Dry matter [g/plant]		
	Total	Above-ground	Below-ground
	---------- HLB ----------		
0.0 (Control)	275 ±12.2 bc	177±9.7 ab	99±9.2 a
5.6 (1x)	307 ±2.5 a	185±2.1 a	123±3.1 a
11.2 (2x)	310 ±7.2 a	199±6.7 a	112±8.7 a
22.4 (4x)	270 ±8.5 c	162±5.0 b	109±10.2 a
	---------- Non HLB ----------		
0.0 (Control)	338 ±5.0 a	209±5.3 a	128±6.5 a
5.6 (1x)	306 ±1.5 b	191±0.4 b	115±2.5 ab
11.2 (2x)	294 ±0.3 c	178±2.0 c	116±2.2 ab
22.4 (4x)	310 ±5.6 b	199±7.1 ab	111±0.7 b
	Source of variation		
Status	<0.001	0.001	0.007
Fe	0.155	0.168	0.304
Status*Fe	<.0001	0.001	0.009

- Above-ground biomass for HLB-affected varied between 33% to 44% more than below-ground for the corresponding Fe fertilization

- The 1x and 2x rate had the greatest total biomass, 10-12% greater than the control and 4x, respectively

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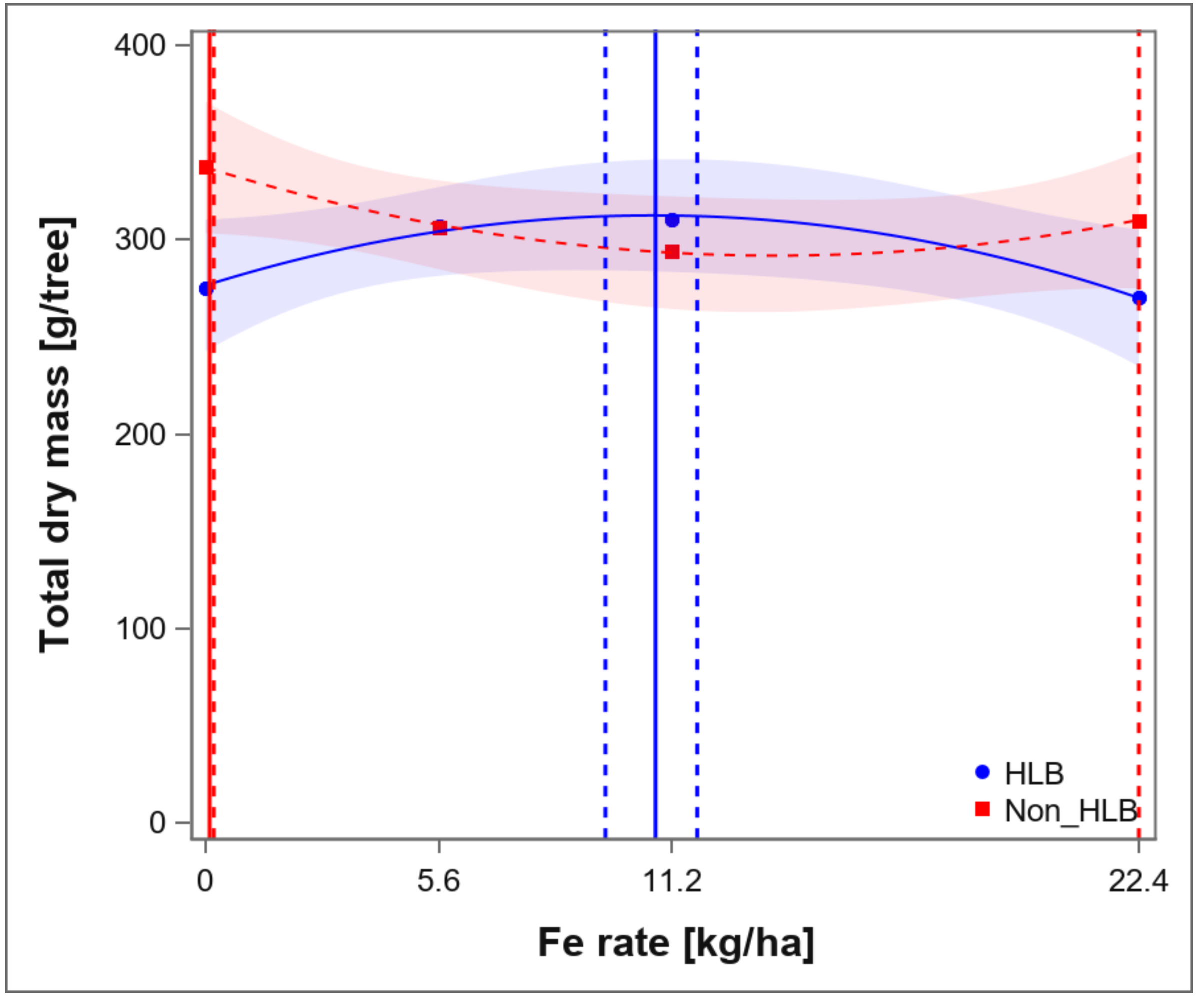
Maximum dry biomass in response to Fe rates



- A 95% confidence interval (CI) at which total biomass was nearly maximum corresponded with an Fe rate of 9.6 to 11.8 kg ha-1 for HLB-affected trees

- This rate was close to the 2x rate (11.2 kg ha-1)

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Effect of foliar micronutrient fertilization on HLB-affected citrus

Treatment	Fertilization rate (kg nutrient ha^{-1})
1 (control)	Control: Standard fertilization (S) No extra K, Mg, Ca, Mn, Fe, B and Zn via fertigation
2	S + (40 & 220) MA via soil + 1x (5) MI via foliar
3	S + (40 & 220) MA via soil + 2x (10) MI via foliar
4	S + (40 & 220) MA via soil + 4x (20) MI via foliar
5	S + (80 & 440) MA via soil + 1x (5 MI) via foliar
6	S + (80 & 440) MA via soil + 2x (10 MI) via foliar
7	S + (80 & 440) MA via soil + 4x (20) MI via foliar

MA= macronutrient; MI= micronutrient;
Mg and Ca = 40 & 80 lbs/ac; K = 220 & 440 lbs/ac

Goal: To determine the effect of optimal nutrient concentrations on growth, fruit yield and juice quality of HLB-affected citrus trees, by supplementing the standard fertilization with foliar application of micronutrients at two citrus production sites in Florida from 2019 to 2021

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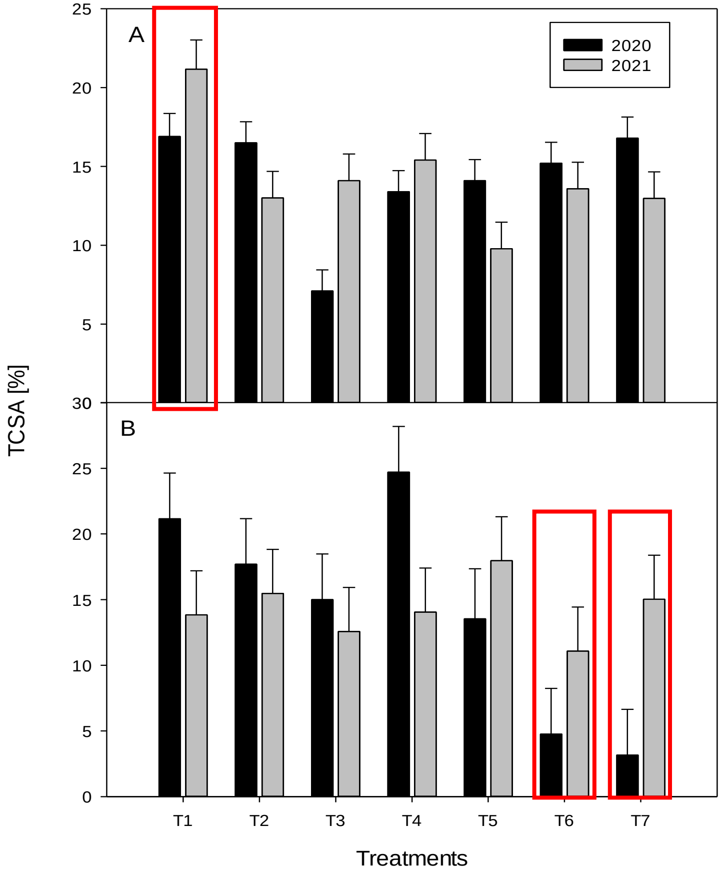
Kwakye et al. 2022c. SSSAJ 87:365–377. https://doi.org/10.1002/saj2.20497

Effect of treatments on trunk cross sectional area (TCSA)

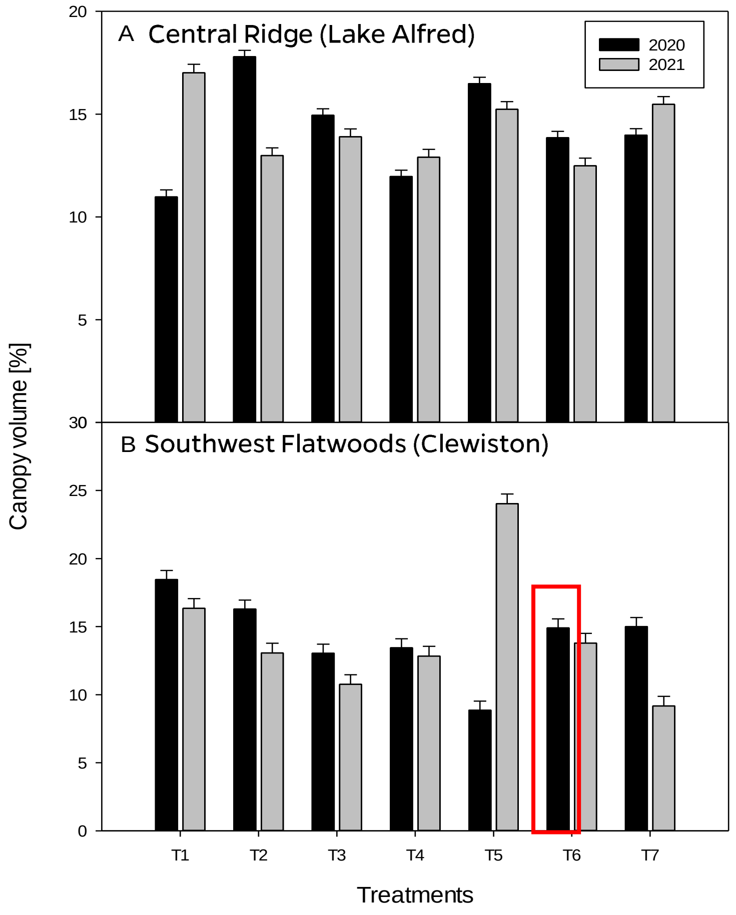


A = Central Ridge (Lake Alfred)
B = Southwest Flatwoods (Clewiston)

Trt	
1	S
2	S + 1 MA + 1 MI
3	S + 1 MA + 2 MI
4	S + 1 MA + 4 MI
5	S + 2 MA + 1 MI
6	S + 2 MA + 2 MI
7	S + 2 MA + 4 MI

- The control had the greatest change (%) in TCSA at the central Ridge (A)
- However, treatments 6 and 7, showed at least 6% increase in TCSA from 2020 to 2021 at southwest Flatwood (B)

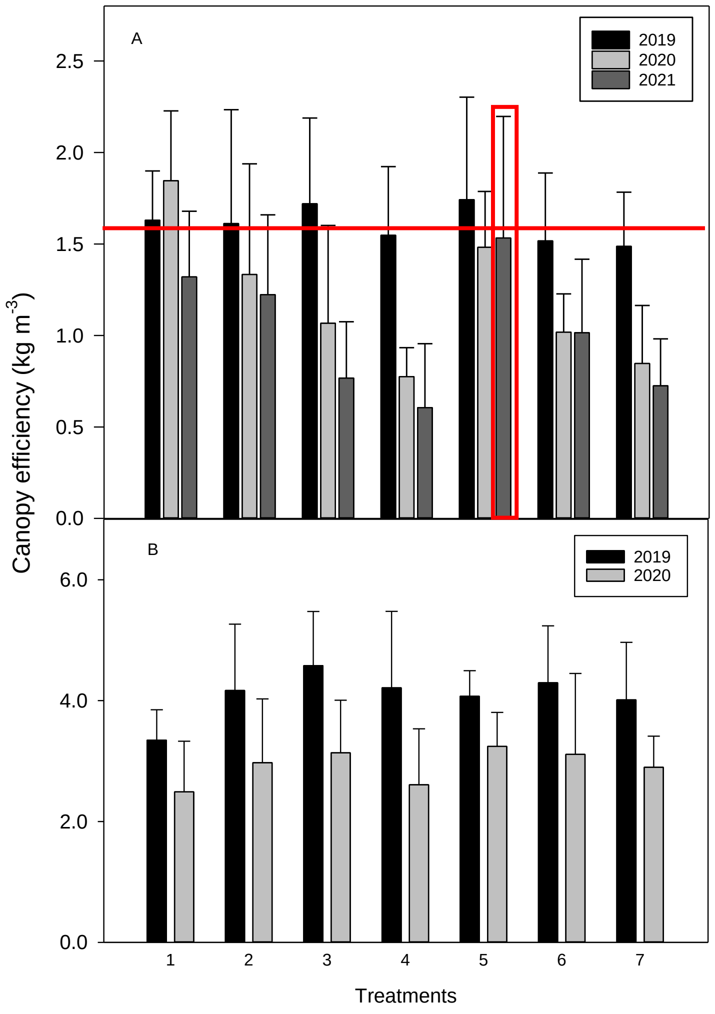
Effect of treatments on canopy volume



Trt	
1	S
2	S + 1 MA + 1 MI
3	S + 1 MA + 2 MI
4	S + 1 MA + 4 MI
5	S + 2 MA + 1 MI
6	S + 2 MA + 2 MI
7	S + 2 MA + 4 MI

- There was no effect of our treatment on canopy volume at the central Ridge site.
- 15% increase for treatment 5 from 2020 to 2021 at the southwest Flatwoods.

Effect on canopy efficiency



Trt	
1	S
2	S + 1 MA + 1 MI
3	S + 1 MA + 2 MI
4	S + 1 MA + 4 MI
5	S + 2 MA + 1 MI
6	S + 2 MA + 2 MI
7	S + 2 MA + 4 MI

- Significantly different for 2020 (P = 0.002) and 2021 (P = 0.005)at the central Ridge site (A)
- For 2021, treatment 5 had a greater canopy efficiency than the rest of the treatments at central Ridge site

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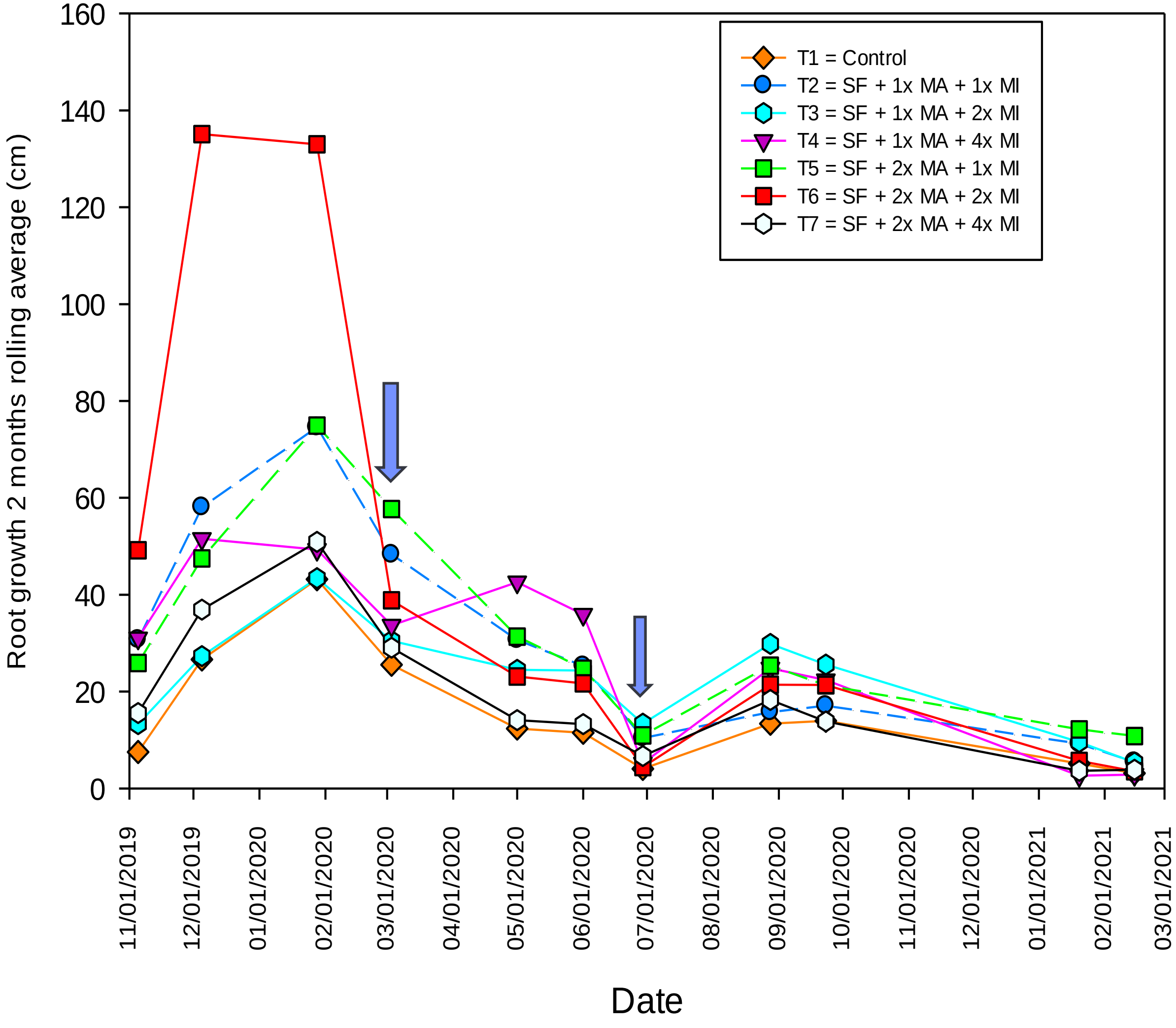
Effect of varied fertilization rates on root growth at Flatwoods site

- Root growth increased from November 2019 till February 2020 (fall / winter season).

- At the end of study (winter season), root growth had decreased again, and Treatment 5 had the greatest root growth.



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Kadyampakeni et al. 2023. Hortscience. https://doi.org/10.21273/HORTSCI17372-23

Effects of treatments on yield

Trt	Central Ridge 2020	Central Ridge 2021	Southwest Flatwoods 2021
	%		
1 (S)	33.9 ± 0.6	22.5 ± 0.9	18.5 ± 1.3
2 (S+1MA+1MI)	16.3 ± 0.8	20.3 ± 1.1	12.3 ± 1.5
3 (S+1MA+2MI)	13.1 ± 0.6	9.1 ± 0.8	16.6 ± 1.7
4 (S+1MA+4MI)	1.5 ± 0.9	0.1 ± 0.9	7.9 ± 1.4
5 (S+2MA+1MI)	20.5 ± 1.2	27.2 ± 1.1	23.4 ± 1.4
6 (S+2MA+2MI)	10.8 ± 0.6	18.9 ± 1.0	13.7 ± 1.7
7 (S+2MA+4MI)	3.9 ± 0.9	1.9 ± 0.8	7.5 ± 1.7
sources of variation			
Treatment	<.0001		0.614
Year	0.060		-
Treatment*year	0.109		-

- The control showed the highest average yield in 2020
- Treatments 5 showed an increase in yield of 4%, in 2021 at the central Ridge
- Treatment 5 had at least 5% increase over control from 2019 to 2021 at the southwest Flatwoods.

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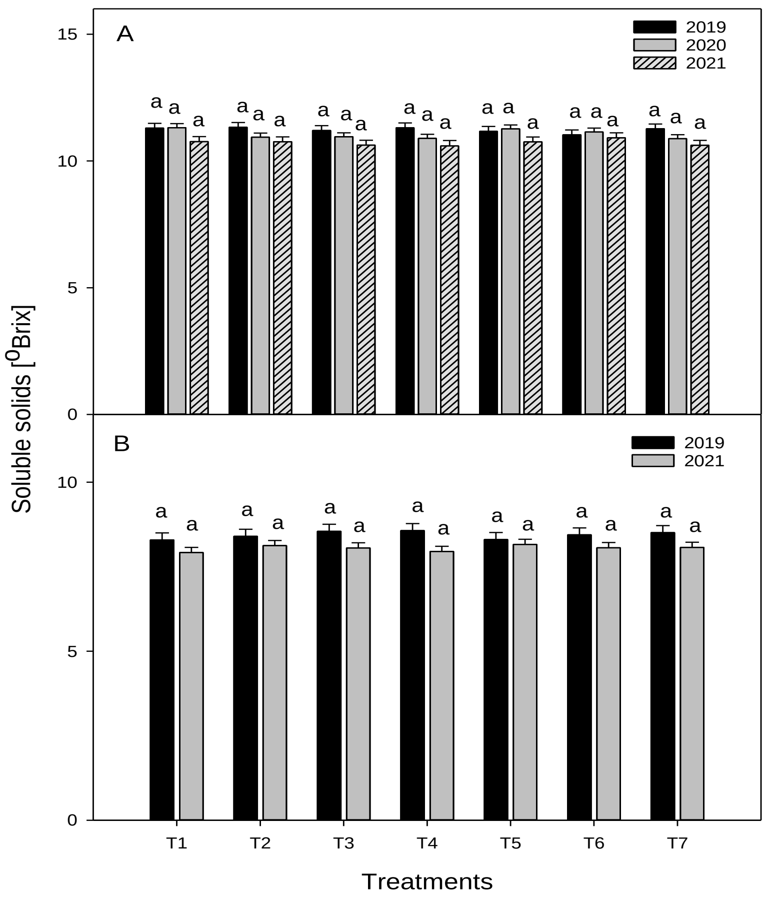
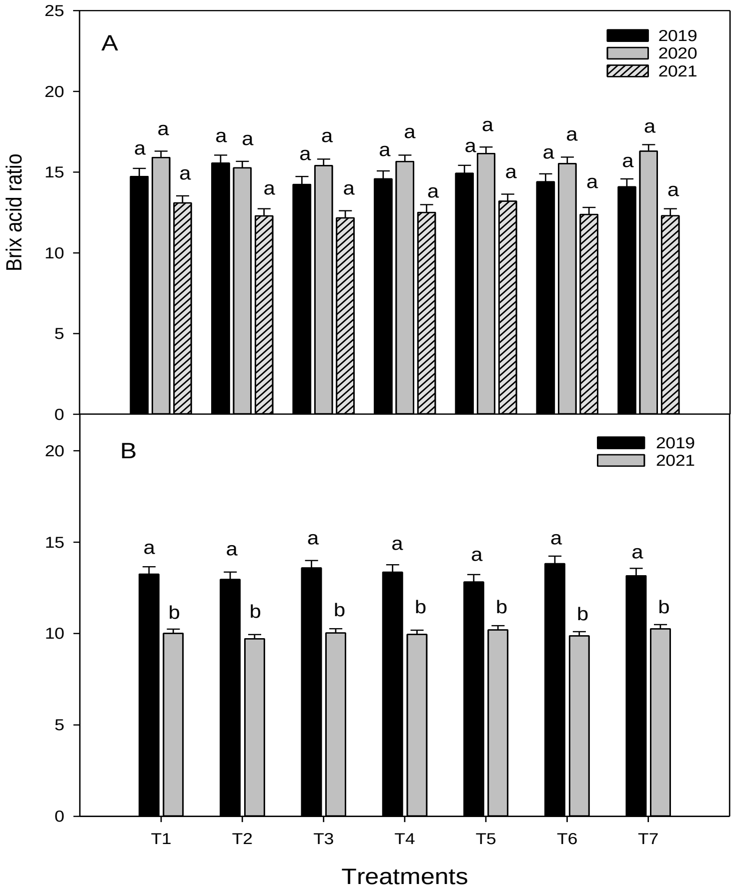
Effect of treatments on °Brix and Brix-acid ratio





Trt	
1	S
2	S + 1 MA + 1 MI
3	S + 1 MA + 2 MI
4	S + 1 MA + 4 MI
5	S + 2 MA + 1 MI
6	S + 2 MA + 2 MI
7	S + 2 MA + 4 MI

A = Central Ridge (top)

B = Southwest Flatwoods (bottom)

- Treatments showed similar °Brix and brix/acid ratio within year

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Kadyampakeni et al. 2023. Hortscience. https://doi.org/10.21273/HORTSCI17372-23

Impact of micronutrients (B, Mn, Zn) on growth and yields

- Treatment plots contained ten trees where the middle eight trees were used for measurements.
- There were nine rows with each row sub-divided into four plots receiving B+Mn+Zn applications in three splits per year as follows:
- 1) standard soil B+Mn+Zn applied (control),
- 2) standard soil B+Mn+Zn applied + foliar applied B+Mn+Zn based at 1× UF/IFAS recommendations (Morgan and Kadyampakeni, 2020),
- 3) 2× foliar applied B+Mn+Zn at UF/IFAS recommendations+ standard soil B+Mn+Zn application, and 4) 2× soil applied UF/IFAS recommendations (1× = 1 lb B/ac; 9 lbs Mn/ac; 5 lbs Zn/ac).
- Nitrogen was applied at 150, 200 and 250 lbs N/ac

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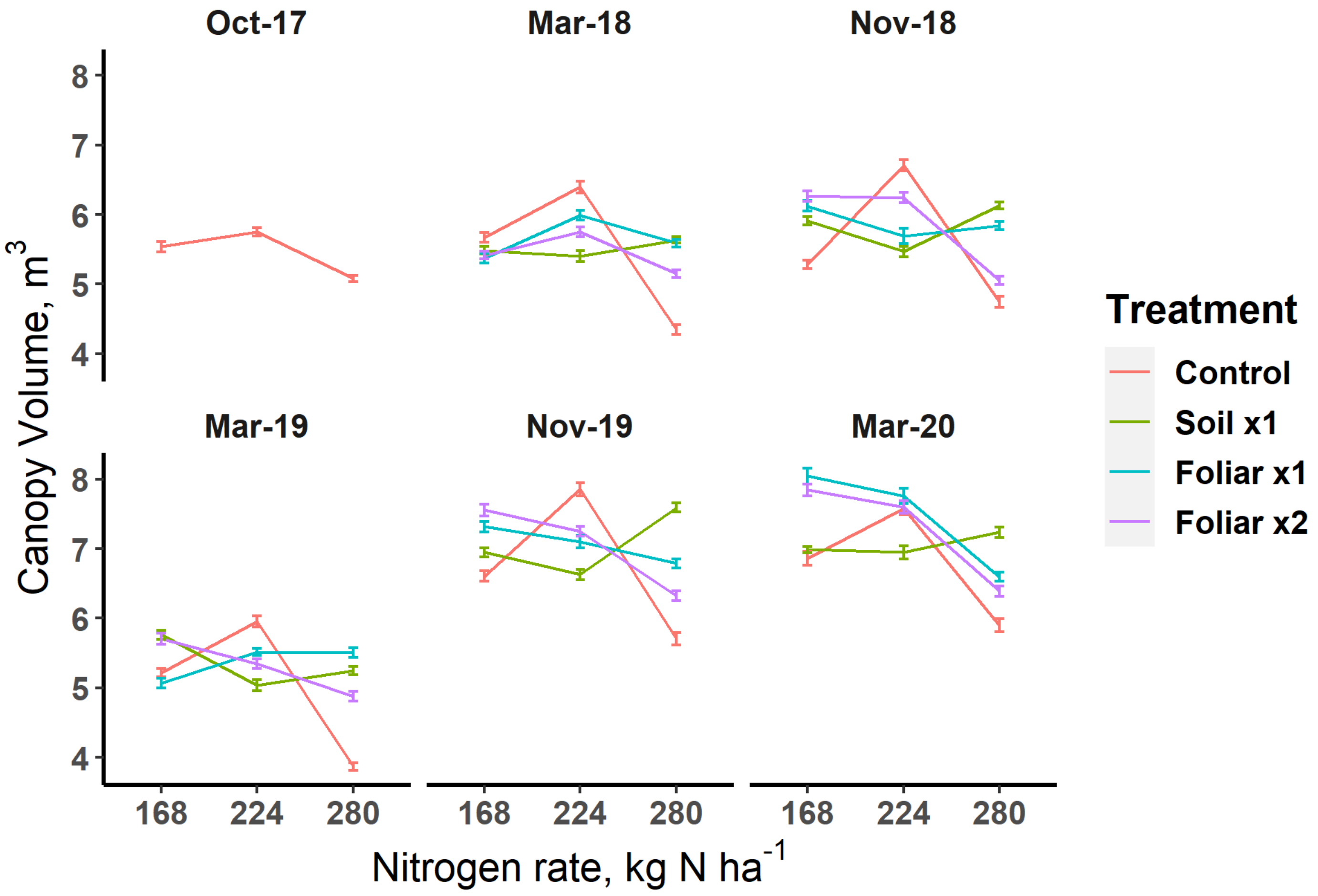
Impact of micronutrients canopy size



168, 224 and 280 kg N/ha are: **150, 200 and 250 lbs N per acre**, respectively

Greater growth at lower N rates but with either foliar or soil fertilization in 2020.

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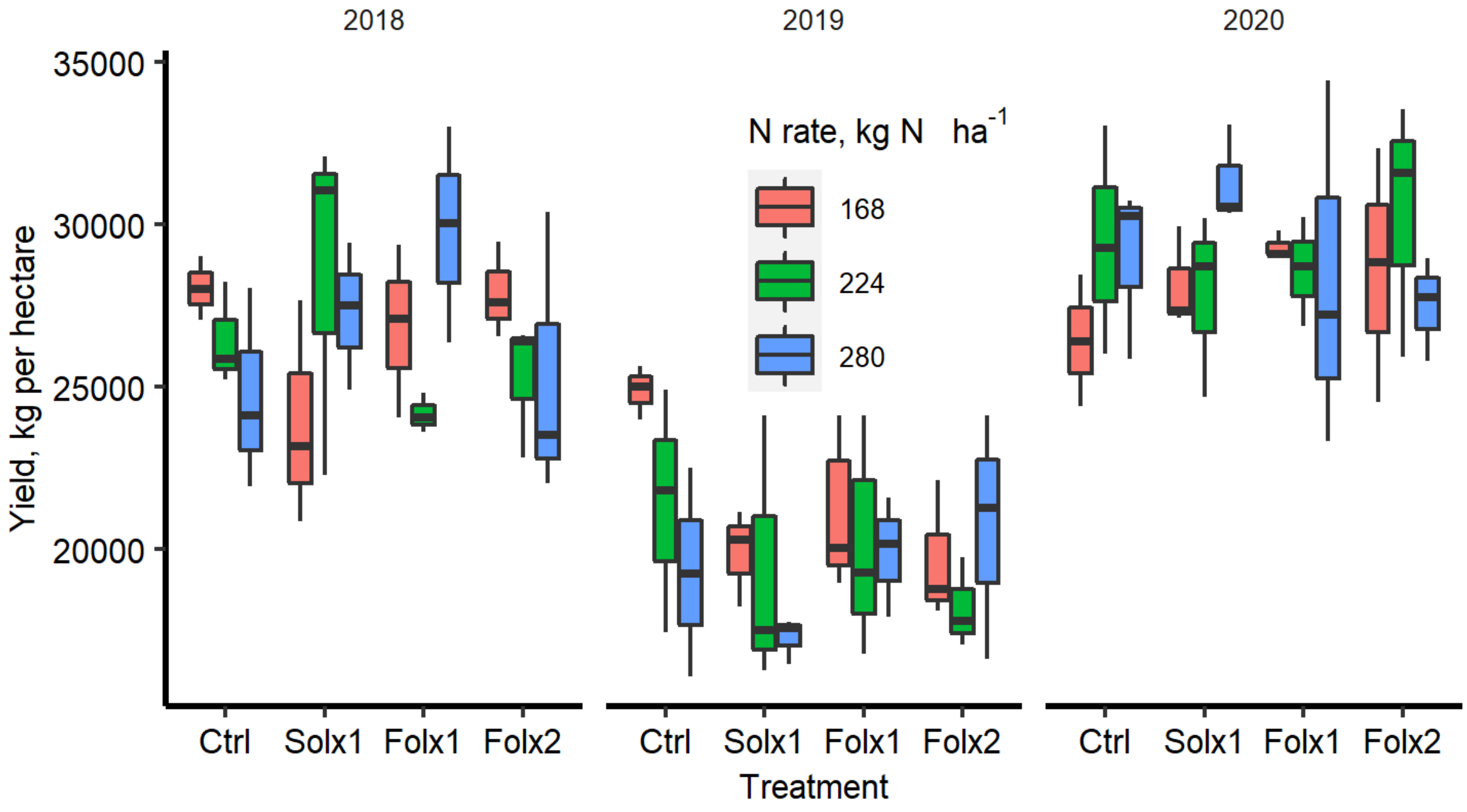
Uthman et al. 2022. Plants, Plants 2022, 11, 638. https://doi.org/10.3390/plants11050638

Yield performance over time a function of fertilization rate



168, 224 and 280 kg N/ha are: 150, 200 and 250 lbs N per acre, respectively

No yield differences as a result of fertilization rate over control.

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Conclusions and take-home messages

- A Mn rate of 8 to 10.3 lbs/ac, for young HLB-affected ‘Valencia’ trees appears to be appropriate.
- An Fe rate of 8.6 to 10.5 lbs/ac for young HLB-affected ‘Bingo’ trees.
- Increases observed in root growth, canopy size and yield over time for trees fertilized with elevated doses of micronutrients.
- Considerations should be made to revise and increase current micronutrient recommendations for HLB-affected trees.
- A nitrogen rate of 200 lbs N per acre still works for the density used, but more validation is needed for high density plantings and varying rootstocks.

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CRDF Citrus Research and Development Foundation, Inc

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Thank You

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