GOOD NUTRITION CAN IMPROVE THE YIELD OF HLB-AFFECTED SWEET ORANGES

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Take home message

- HLB-affected trees have different nutritional requirements than healthy trees
- Soil applied micronutrients are better than foliar
- Soil pH should be carefully monitored, too low or high can have detrimental effects
- Each grove is unique and would benefit from custom nutritional program
  - Different rootstocks have different nutrient uptake

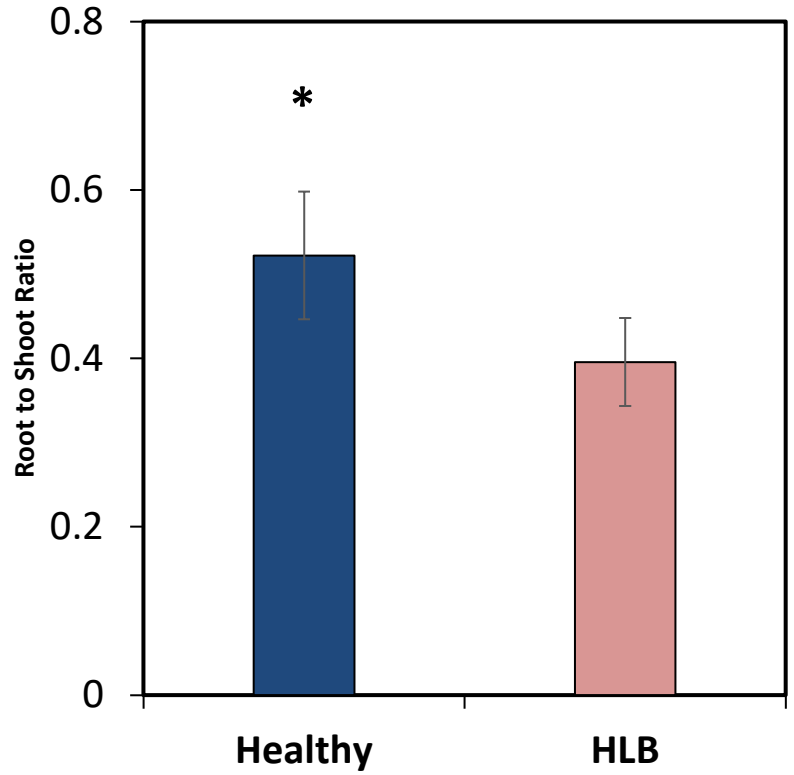
Objective

Effect of controlled release form of mineral nutrients, elevated levels of soil-applied micronutrients, and soil pH amendments (to lower pH).

1. Constant supply of nutrients
2. Soil applied
3. Micronutrients requirement
4. Soil pH amendment

1. Constant Supply of Nutrients

HLB-affected plants are significantly low in root and shoot biomass



Constant supply of fertilizer (as CRF) improves tree growth and yield

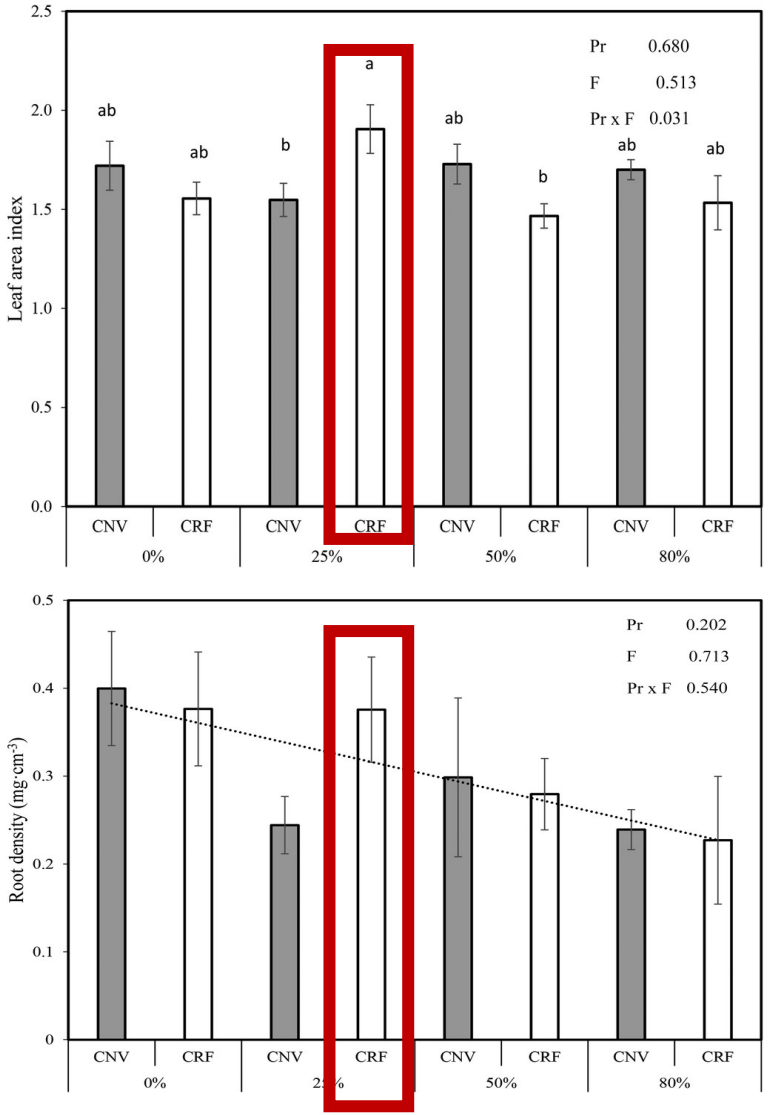


Table 1: Total number of fruit, fruit diameter (inch), and boxes per tree (calculated from yield) of harvested fruit from 4-year-old 'Valquarius'		
	Boxes per tree[x] [mean ± SD]	Calculated boxes per acre (150 trees per acre)
A (Florikote; 14N–4P–10K)	1.42 ± 0.7	210
B (Citriblend; 17N–5P–12K)	1.80 ± 1.0	270
C (Harrell's; 13N–4P–9K)	1.46 ± 0.7	210
D (Citriblend; 18N–6P–11K)	1.25 ± 0.5	187
E (Harrell's; 16N–5P–10K).	1.35 ± 0.7	190

Vashisth and Grosser, 2018

With use of CRF, rate of nutrients applied can be reduced (by 25%)

Vashisth and Livingston, 2019

1. Constant supply of nutrients

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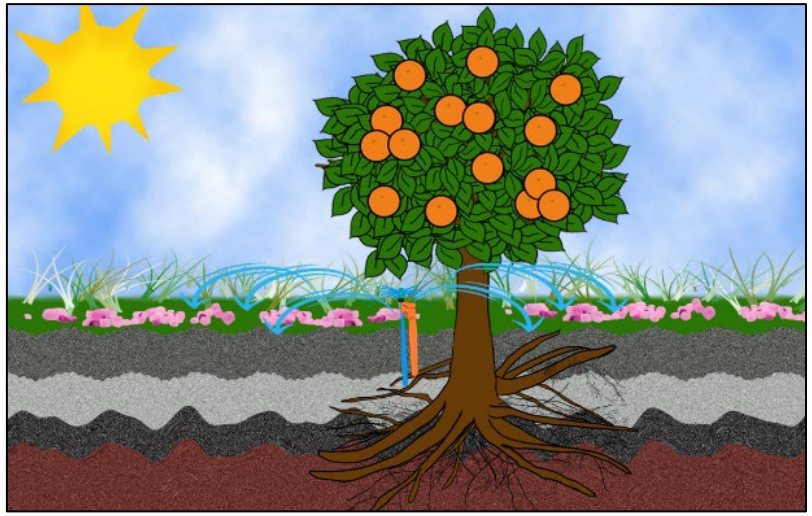
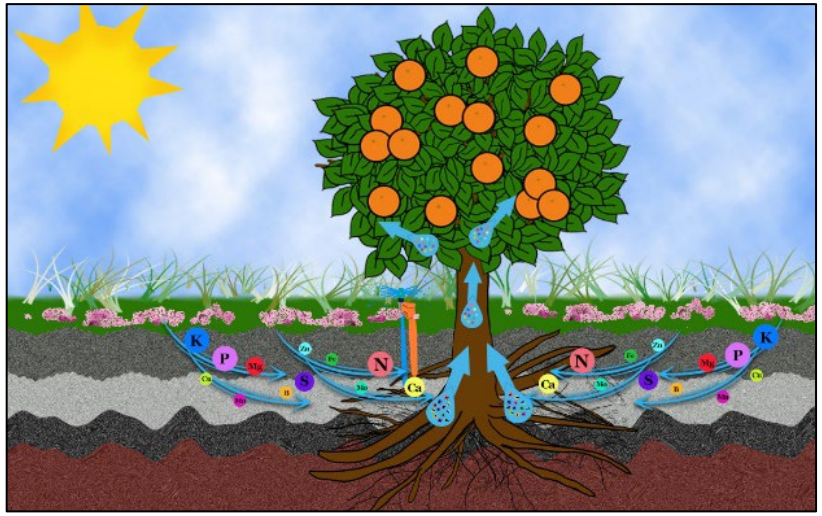
2. Soil-Applied Nutrition Program

- The plant uptakes nutrients when they are in a solution
- During the water uptake by the plant, the dissolved mineral nutrients get taken up by the plant and distributed throughout the canopy
- Mobile and immobile nutrients have equal and uniform distribution to all parts of plant



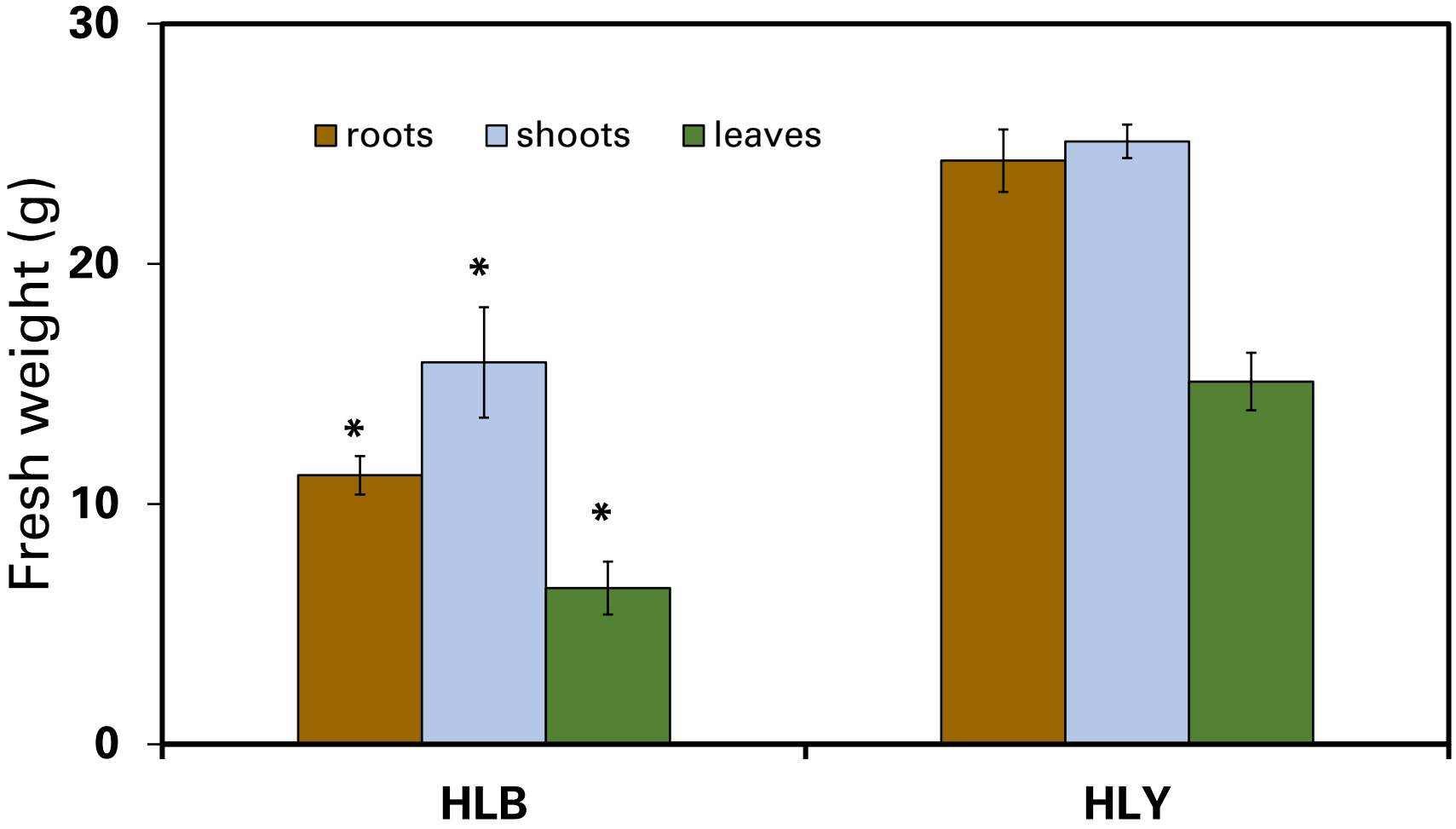


3. Nutritional Needs of HLB-Affected trees

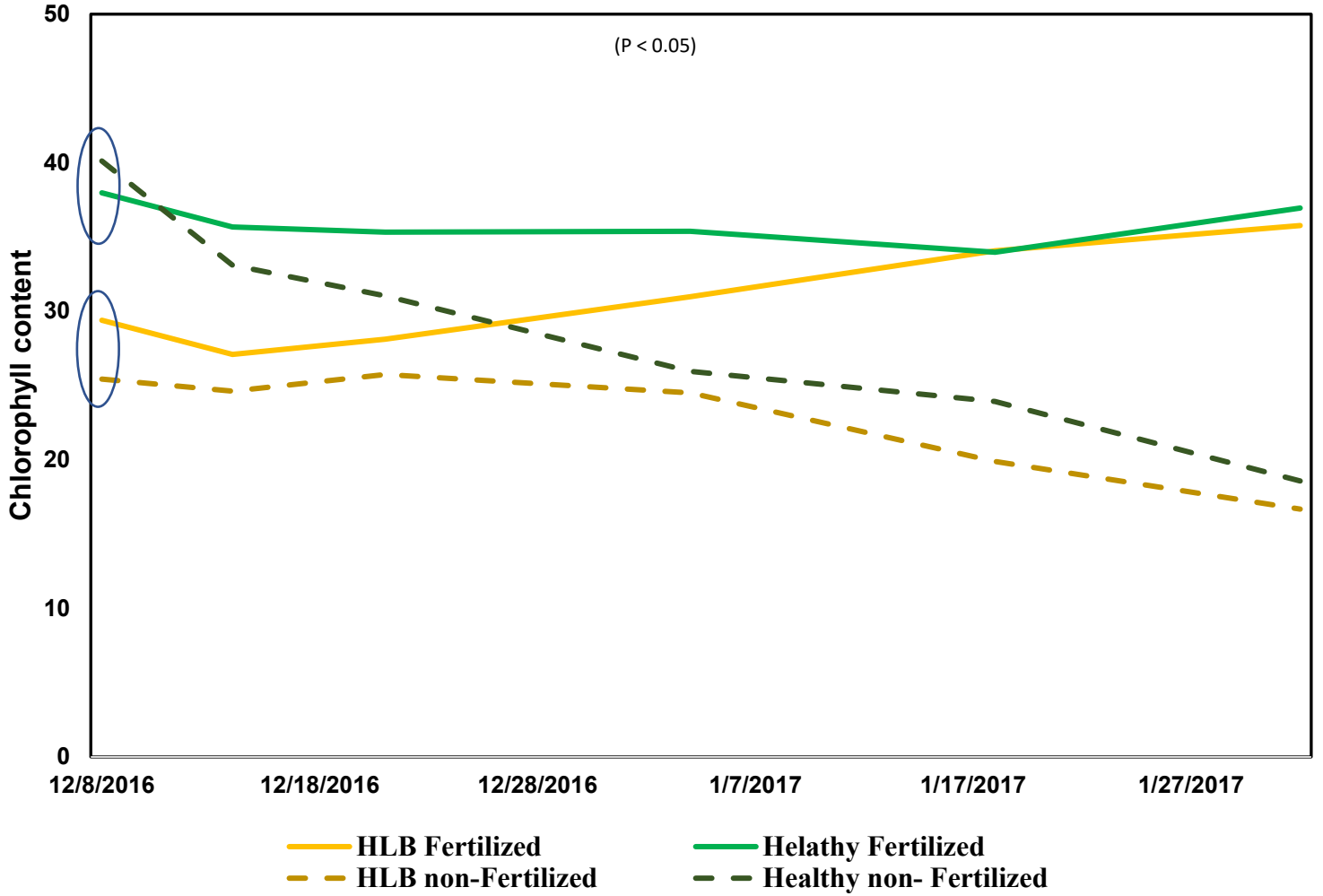
- Same age ‘Midsweet’ grafted on Kuharske rootstock: Healthy (HLY) and HLB-affected
- Plants were deprived from fertilizer for 6 months before experiment
- Hydroponic system with Hoagland solution added at the beginning

Why hydroponic?

HLB-affected plants were significantly low in root and shoot Biomass



Chlorophyll content increased in HLB plants upon fertilization



3. Nutritional needs of HLB-affected trees

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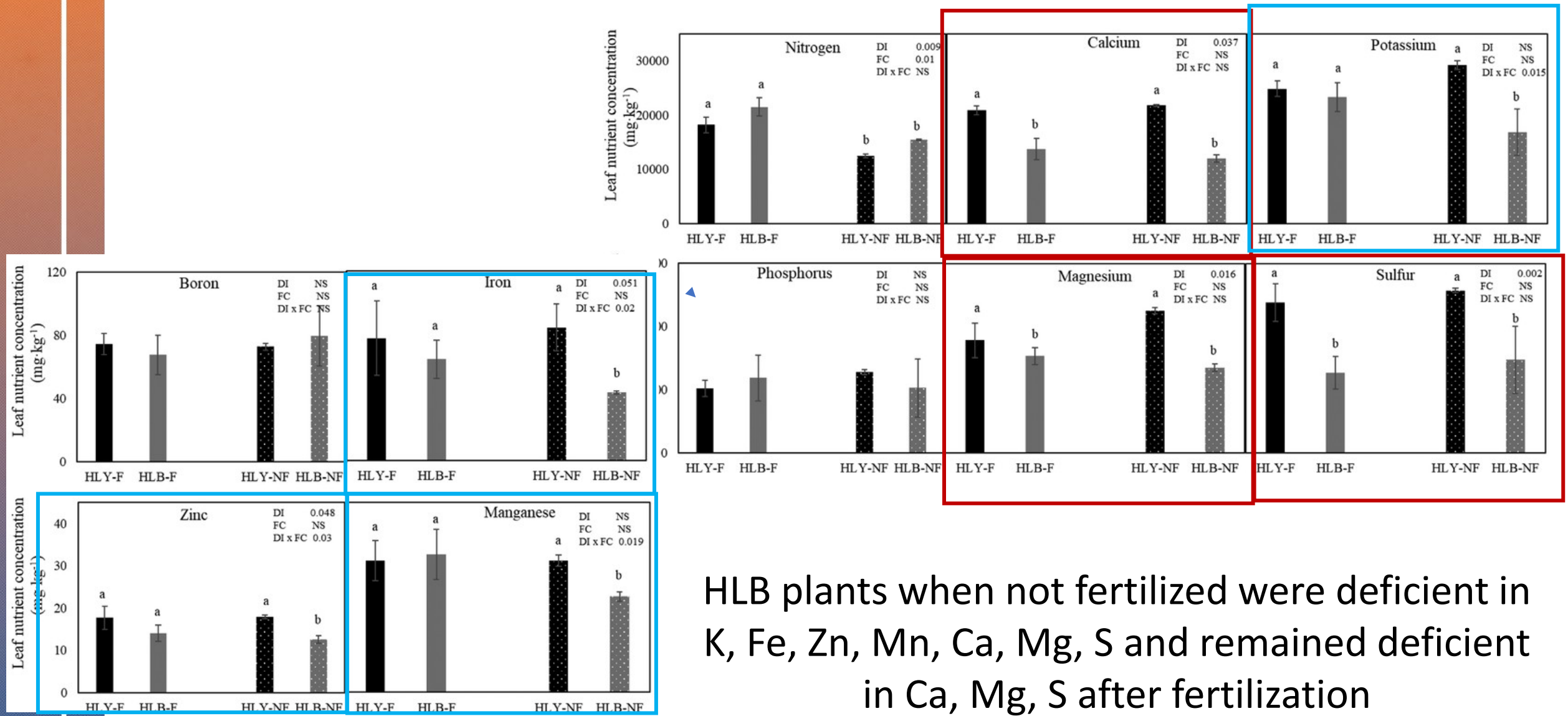

HLB plants when not fertilized were deficient in K, Fe, Zn, Mn, Ca, Mg, S and remained deficient in Ca, Mg, S after fertilization

3. Nutritional needs of HLB-affected trees

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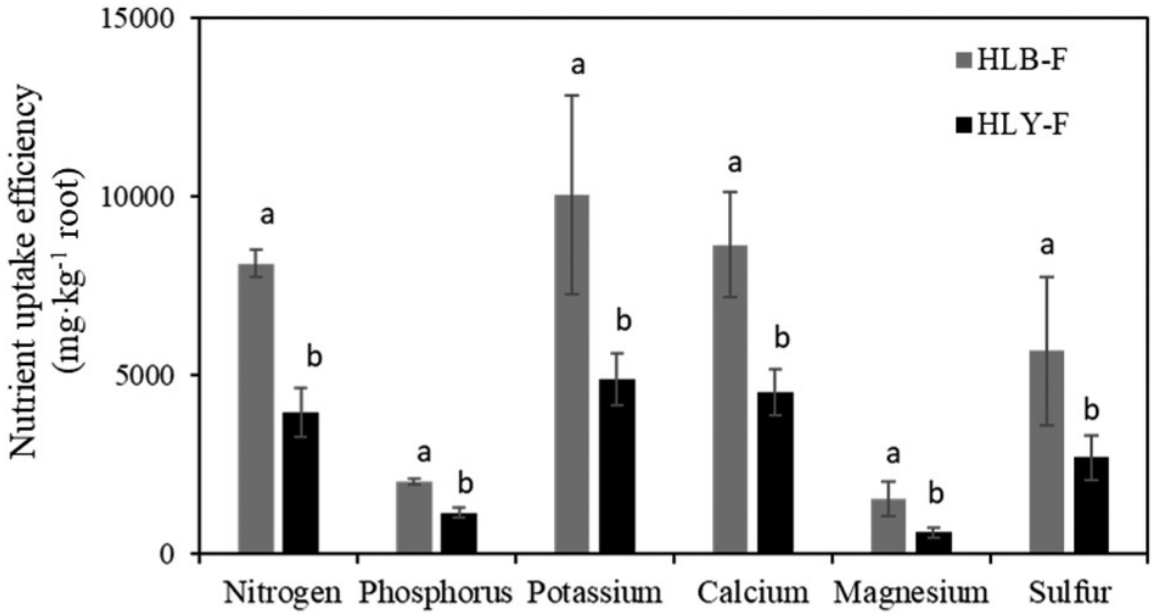
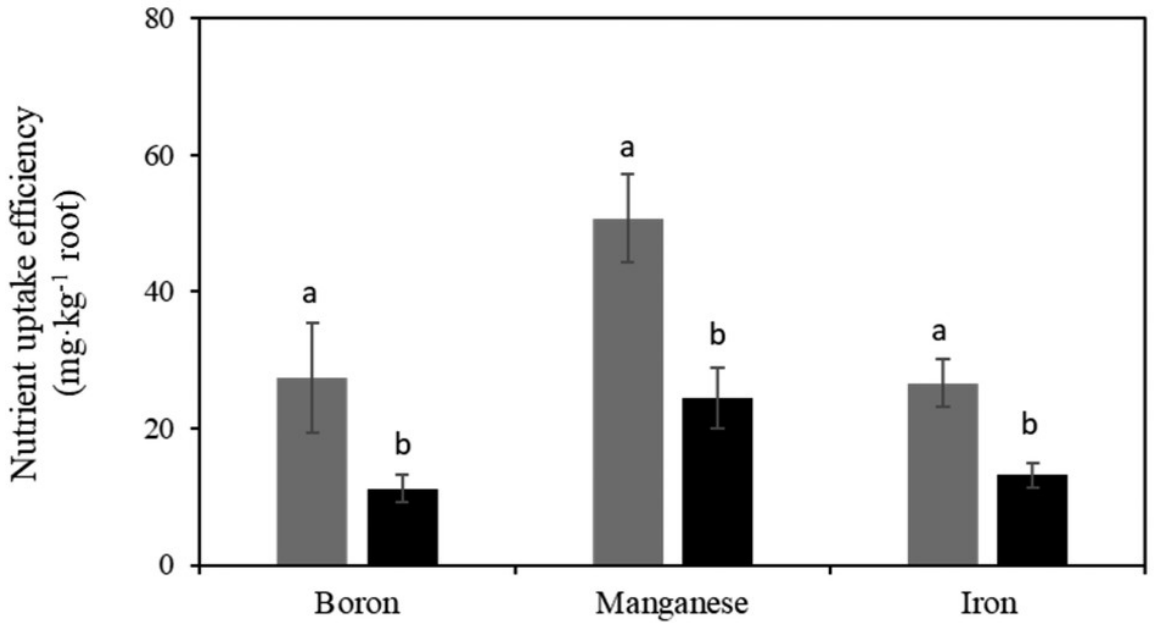
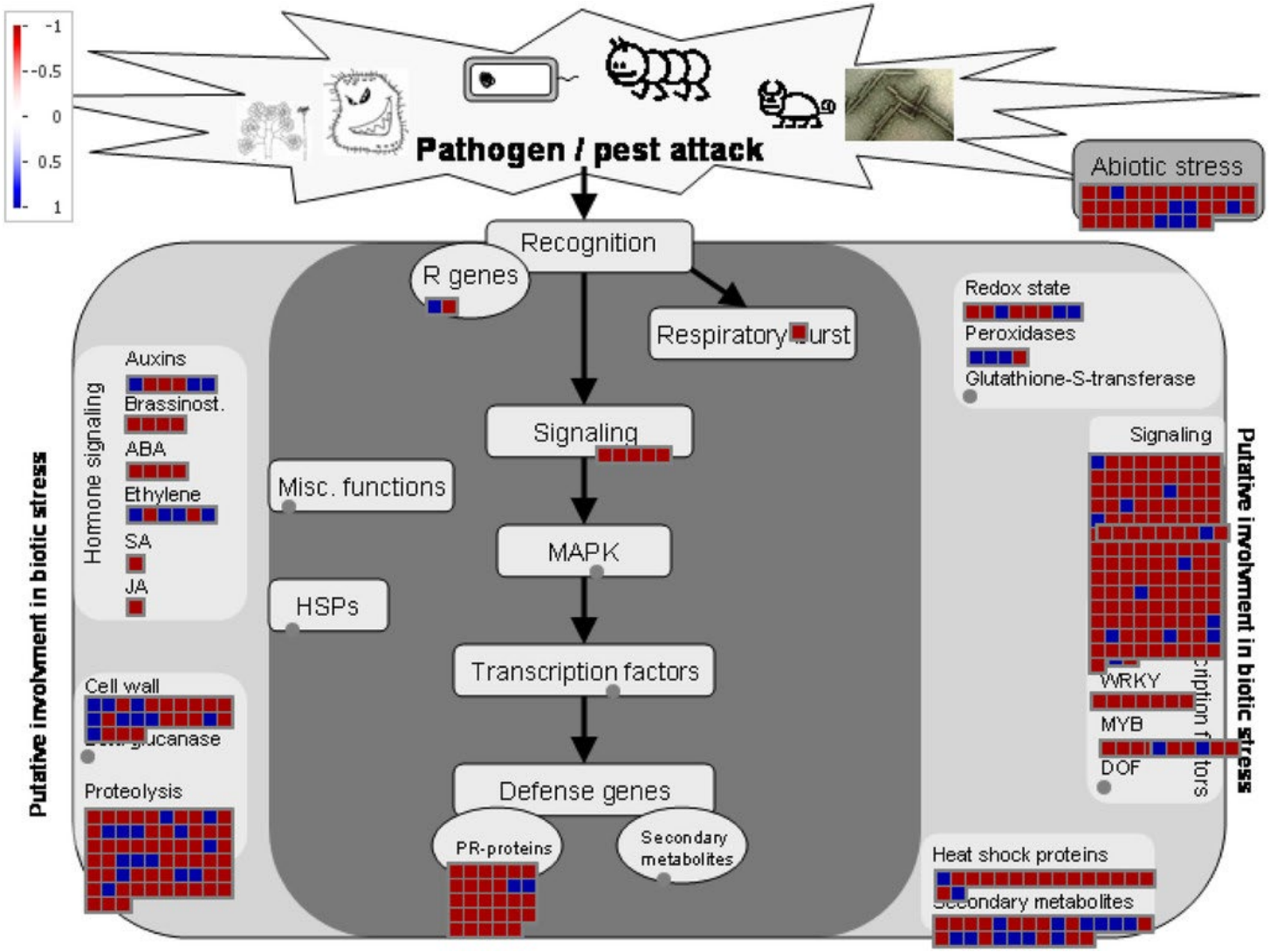
HLB-affected plants were significantly more efficient in nutrient uptake than healthy plants





Anatomical and molecular changes aid in high nutrient uptake efficiency

Upon nutrient availability, several plant biotic and abiotic response pathways were altered



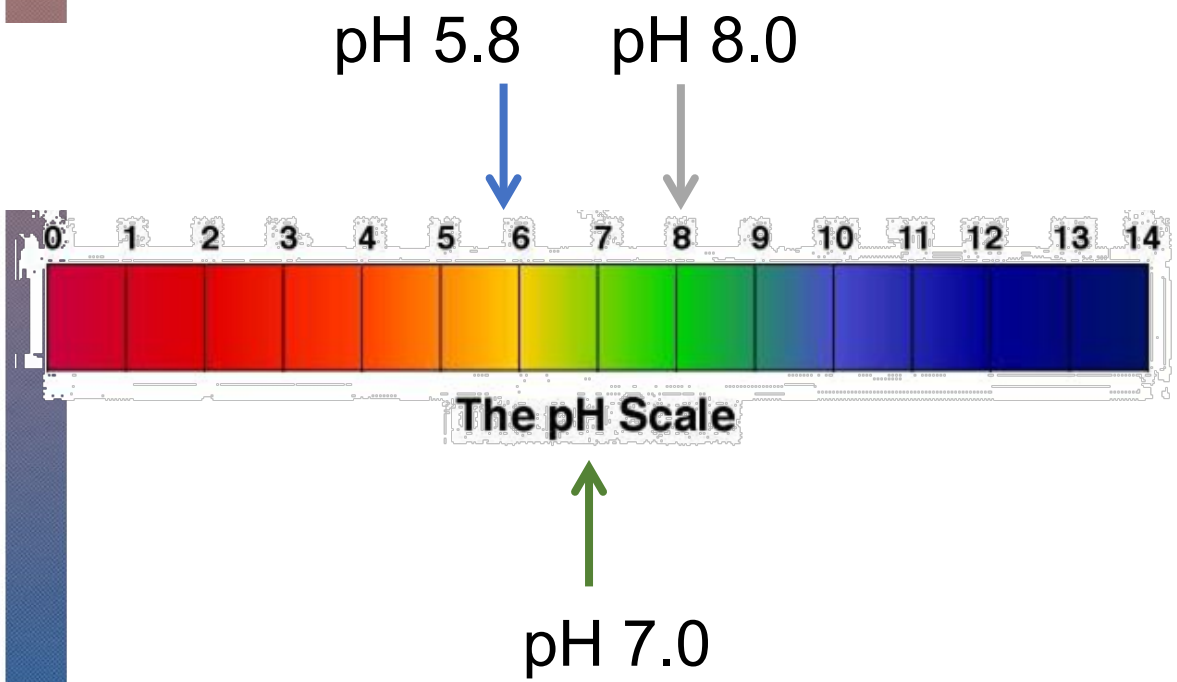
Conclusion

- HLB-affected roots are functional and efficient in nutrient uptake
- HLB-affected trees metabolize nutrients at higher rate than healthy trees
- To improve nutrient uptake efficiency, the existing roots undergo anatomic and transcriptomic changes
- HLB-affected trees should be supplied with constant nutrients at higher rates than what is recommended for healthy trees
- Nutrient availability allow HLB-affected trees to respond to abiotic and biotic stresses

4. Soil pH and HLB tree interaction

- Planting material: ‘Midsweet’ on Kuharske
- Experimental design: CRD (n=8), Factors:

➢pH : 5.8, 7.0 and 8.0



➢ Disease: HLY and HLB

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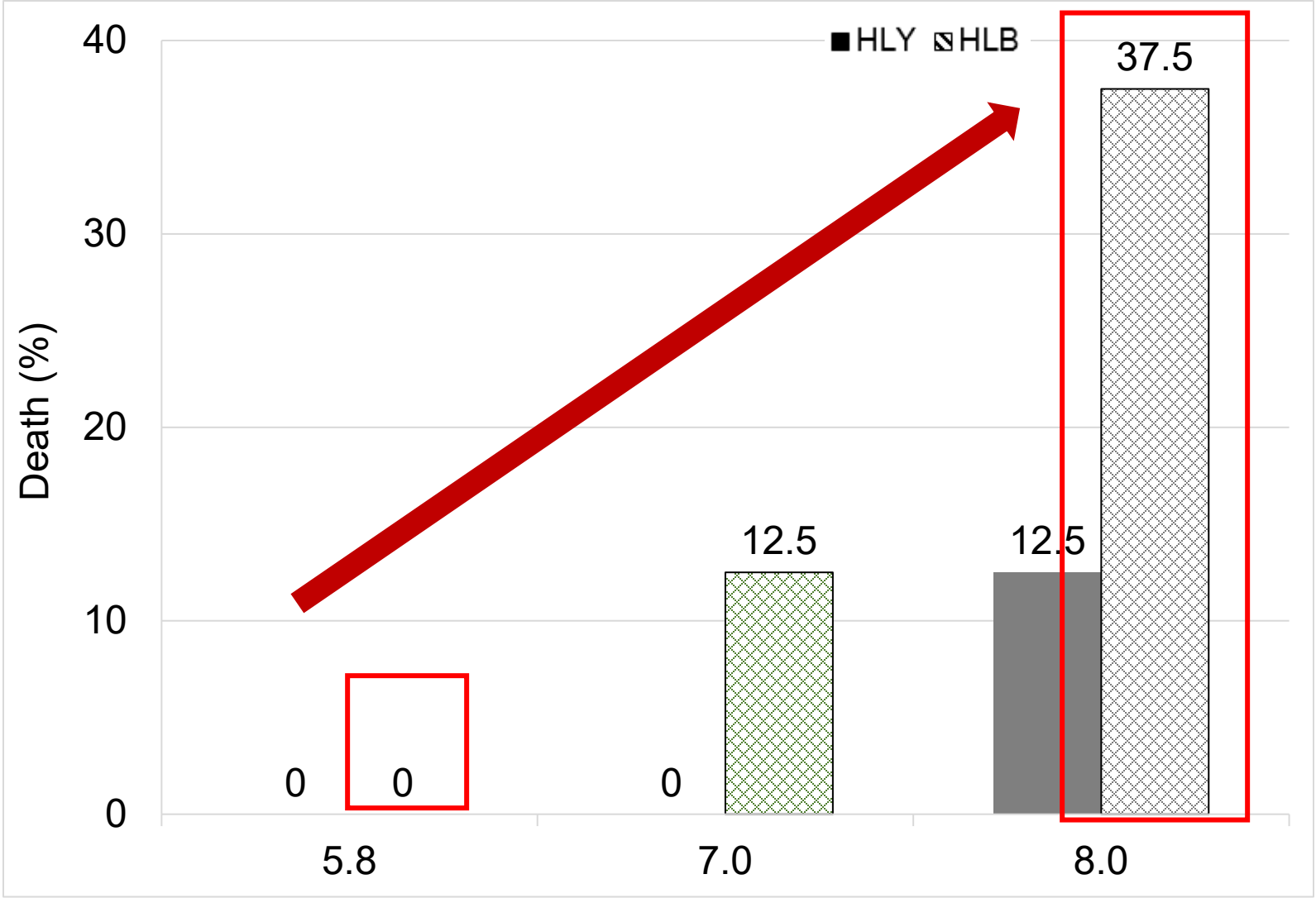
HLB-affected plants under pH 8.0 treatment had the highest death rate



4. Soil pH and HLB tree interaction

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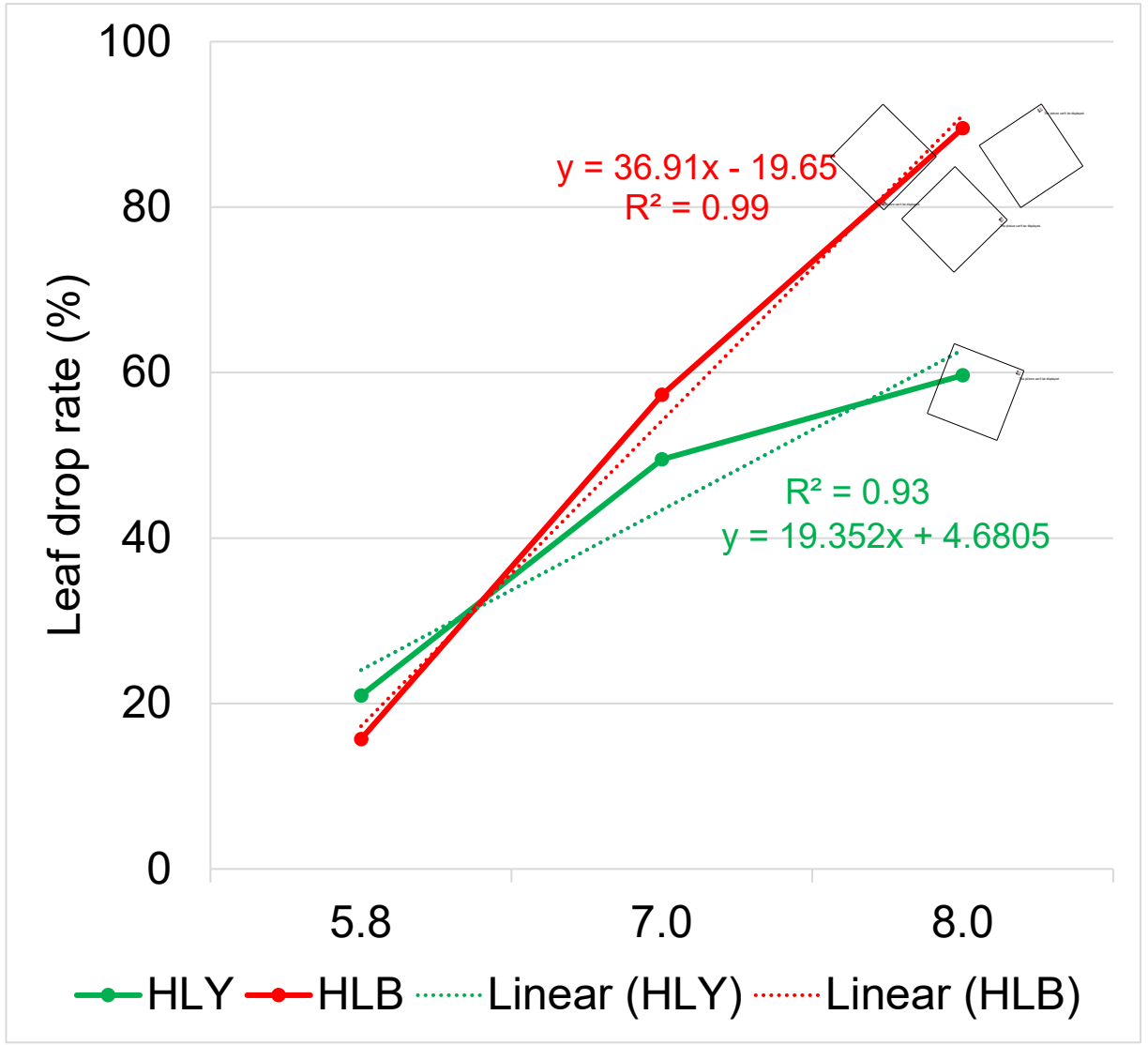
pH 8.0 HLB treatment resulted in heavy leaf drop



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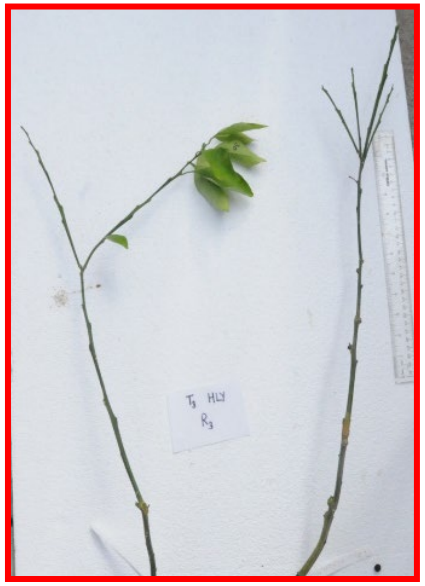
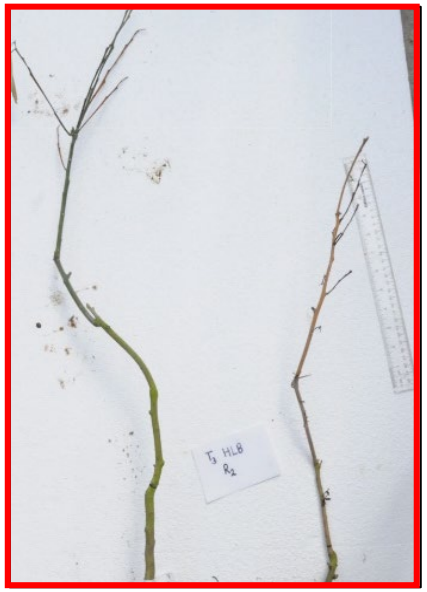
Shoot system at Day 60

HLY:



pH: 5.8 7.0 8.0

HLB:



4. Soil pH and HLB tree interaction

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Root system at Day 60

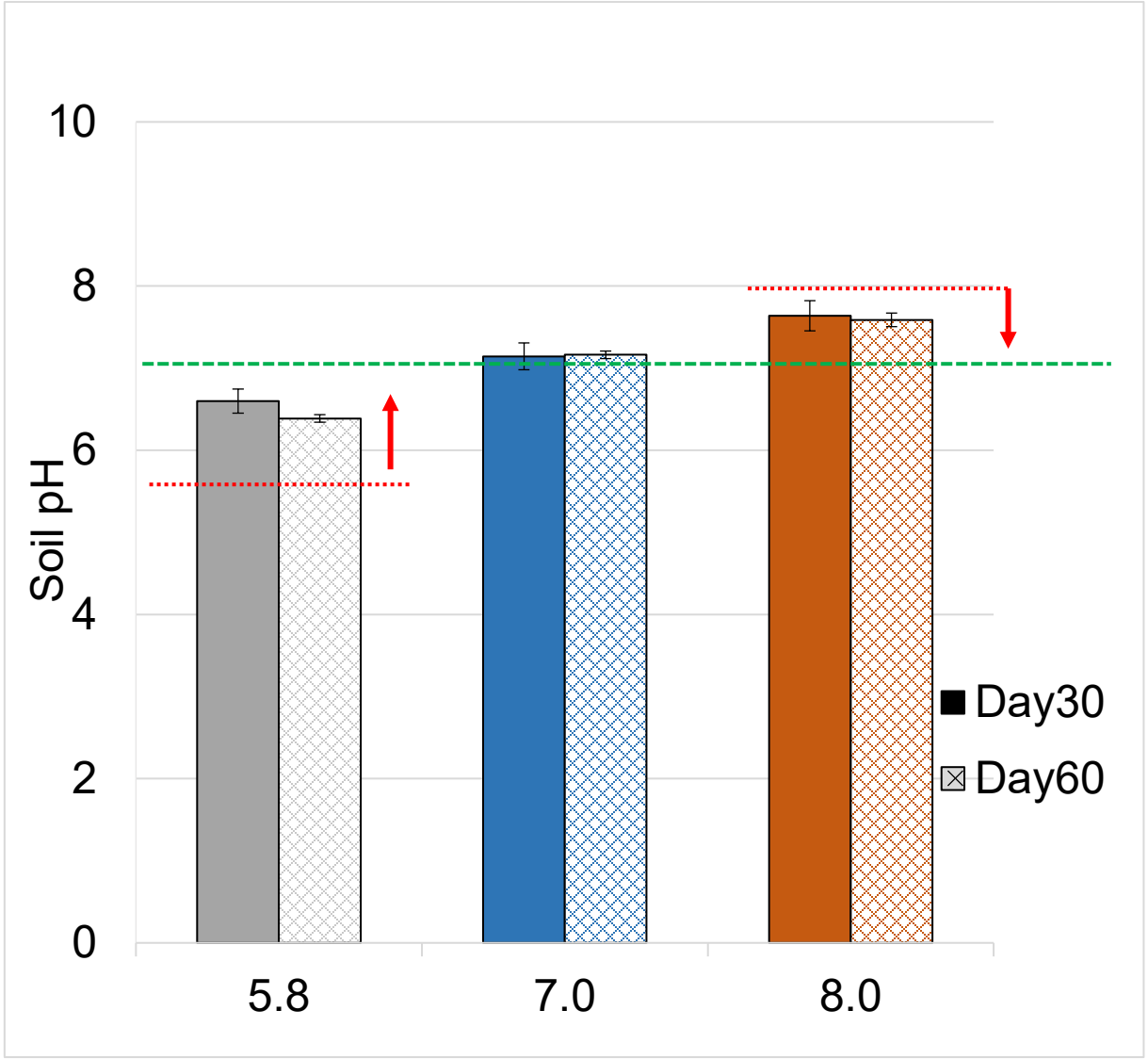
HLY:

pH: 5.8 7.0 8.0

HLB:

4. Soil pH and HLB tree interaction

pH of soil tends to rebound to its original pH



pH 5.8-HLB vs HLY: upregulated genes

- ROS detoxifying processes
- Hormonal regulations
- Growth of root and shoot
- Secondary metabolic process
- Photosynthesis

pH 8.0-HLB vs HLY: upregulated genes

- Cell death
- Defense and immune responses
- Growth and development

pH 5.8-HLB vs HLY: down-regulated genes

- Jasmonic acid related pathways
- Senescence
- Defense and immune responses
- Protein metabolic processes

pH 8.0 HLB plants showed low accumulation of Ca, Mg, and Zn

Nutrient concentration in the leaves										
	N	P	K	Mg	Ca	B	Zn	Mn	Fe	Cu
5.8 HLY	28000	9800	33600	2700	18800	66.40	30.66	65.72	147.81	8.92
5.8 HLB	30900	10600	37700	2600	15800	80.26	35.84	98.27	146.60	8.49
7.0 HLY	27800	5000	27200	2800	15800	55.71	25.09	51.80	137.70	7.89
7.0 HLB	35300	5100	31500	3000	20200	90.82	33.32	110.24	170.15	9.33
8.0 HLY	26500	6200	26100	3400	15500	53.71	27.75	73.54	105.90	7.92
8.0 HLB	31600	2200	20300	1700	9100	45.88	10.73	84.85	98.73	4.08
Optimum	25000-27000	1200-1600	12000-17000	3000-4900	30000-49000	36.0-100	25.0-100	25.0-100	60.0-120	5.00-16.0

Soil results showed highest Zn uptake in pH 8.0 HLB plants

Conclusion

- There is interaction between HLB and soil pH, HLB-plants showed better growth at low pH
- Healthy plants are not significantly benefitted at low pH
- Role of Zn and Mg needs further investigation

Micronutrient Field Trial

- Two locations: Fort Meade and Arcadia
- Valencia/Swingle; 10 to 15 year
- Completely Randomized Block Design
- Trial was initiated in February 2016 to end with 2019 harvest
  - Added 3 more years to have a total of five year yield data, will end with 2022 harvest
  - More treatments were added
- All the fertilizer treatments are applied 3 times a year by hand in the wetted zone

February, July, early October
Split as 45%, 35%, and 20%

About 75% of the fertilizer for year should be applied by Summer

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Treatments (Original 10)

1. Conventional granular fertilizer + foliar
2. Conventional granular fertilizer + Tiger Micronutrient Mix
3. CRF + foliar
4. CRF + Tiger Micronutrient Mix
5. CRF + Tiger Micronutrient Mix + Tiger Mn elevated by 20%
6. CRF + Tiger Micronutrient Mix + Tiger Zn elevated by 20%
7. CRF + Tiger Micronutrient Mix + Tiger Fe elevated by 20%
8. CRF + Tiger Micronutrient Mix + Tiger B elevated by 20%
9. CRF + Tiger Micronutrient Mix + Tiger Mn and B elevated by 20%
10. CRF + Tiger Micronutrient Mix + Tiger Mn and B elevated by 50%

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Rate of Nutrients

- Base applied fertilizer was 12-4-16 with 5% Ca and 3% Mg
  - Nitrogen: CNV: 180 lb/acre and CRF(Harrell's): 150 lb/acre
  - P, K, Ca, Mg were 20% less in CRF treatments
- Tiger Micronutrient mix (Mn-Zn-Fe-B:6-6-3-1); 225 lb/acre
  - Mn: 12 lb/acre
  - Zn: 12 lb/acre
  - Fe: 6 lb/acre
  - B: 2 lb/acre

20% elevated levels on Mn= 14.4 lb/acre

20% elevated levels on Zn= 14.4 lb/acre

20% elevated levels on Fe= 7.2 lb/acre

20% elevated levels on B= 2.4 lb/acre

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Results

- No difference in yield for first two years
- Significant differences in 3rd year
- Canopy volume did not change significantly
- In Arcadia, yield per m^3 of tree was significantly higher for treatment 4, 5, 7, 10
- Overall, treatment (4) CRF+ soil applied micronutrients had consistently high yield at both sites

4. CRF + Tiger Micronutrient Mix
5. CRF + Tiger Micronutrient Mix + Tiger Mn elevated by 20%
7. CRF + Tiger Micronutrient Mix + Tiger Fe elevated by 20%
10. CRF + Tiger Micronutrient Mix + Tiger Mn and B elevated by 50%

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3 Year Cumulative Yield (Boxes per acre)

Fort Meade			Arcadia		
1	QRP +foliar	893	1	QRP +foliar	868
7	CRF+Tiger MM + Fe 20%	913	9	CRF+Tiger MM + Mn+B 20%	1007
8	CRF+Tiger MM +B 20%	981	3	CRF+ foliar	1048
6	CRF+Tiger MM + Zn 20%	1027	2	QRP+ Tiger MM	1055
10	CRF+Tiger MM + Mn+ B 50%	1034	6	CRF+Tiger MM + Zn 20%	1078
5	CRF+Tiger MM + Mn 20%	1039	5	CRF+Tiger MM + Mn 20%	1096
3	CRF+ foliar	1047	10	CRF+Tiger MM + Mn+ B 50%	1194
2	QRP+ Tiger MM	1063	8	CRF+Tiger MM +B 20%	1220
4	CRF+Tiger MM	1076	4	CRF+Tiger MM	1224
9	CRF+Tiger MM + Mn+B 20%	1130	7	CRF+Tiger MM + Fe 20%	1269

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Soil differences should be taken in account

Soil Nutrient Analysis in 2016 (start of experiment)												
	pH	P	K	Mg	Ca	S	B	Zn	Mn	Fe	Cu	CEC
Fort Meade	6.27	936.3	59.75	101.02	2456.8	54.2	0.34	65.27	16.58	61.63	76.12	8.13
Arcadia	5.05	28.5	74.00	81.50	618.5	76.0	0.58	6.52	9.50	28.00	4.01	4.18
State average	6.15	241.22	96.90	181.79	1450.81			40.77	60.79	238.64		

Iron has been found to be low in soil and leaves of southwest growing region- Citrus Nutrition Box Program

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Ranking based on 5 year cumulative yield (boxes per acre)

Fort Meade			Arcadia		
8	CRF+Tiger MM +B 20%	1630	9	CRF+Tiger MM + Mn+B 20%	1347
1	QRP +foliar	1684	1	QRP +foliar	1405
7	CRF+Tiger MM + Fe 20%	1701	2	QRP+ Tiger MM	1529
10	CRF+Tiger MM + Mn+ B 50%	1721	6	CRF+Tiger MM + Zn 20%	1534
3	CRF+ foliar	1766	3	CRF+ foliar	1558
6	CRF+Tiger MM + Zn 20%	1781	5	CRF+Tiger MM + Mn 20%	1574
5	CRF+Tiger MM + Mn 20%	1801	4	CRF+Tiger MM	1705
2	QRP+ Tiger MM	1813	10	CRF+Tiger MM + Mn+ B 50%	1707
4	CRF+Tiger MM	1838	8	CRF+Tiger MM +B 20%	1800
9	CRF+Tiger MM + Mn+B 20%	1979	7	CRF+Tiger MM + Fe 20%	1861

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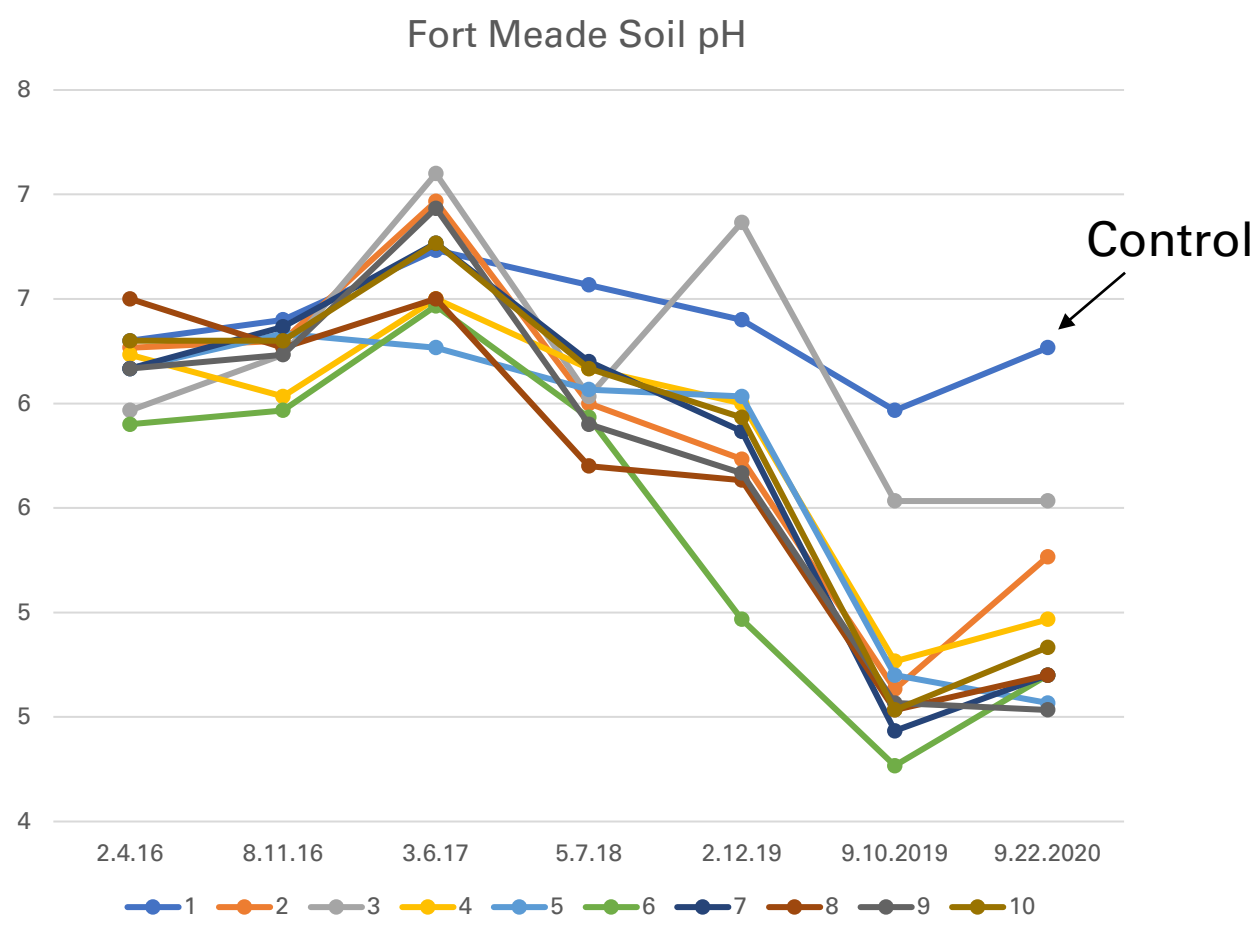
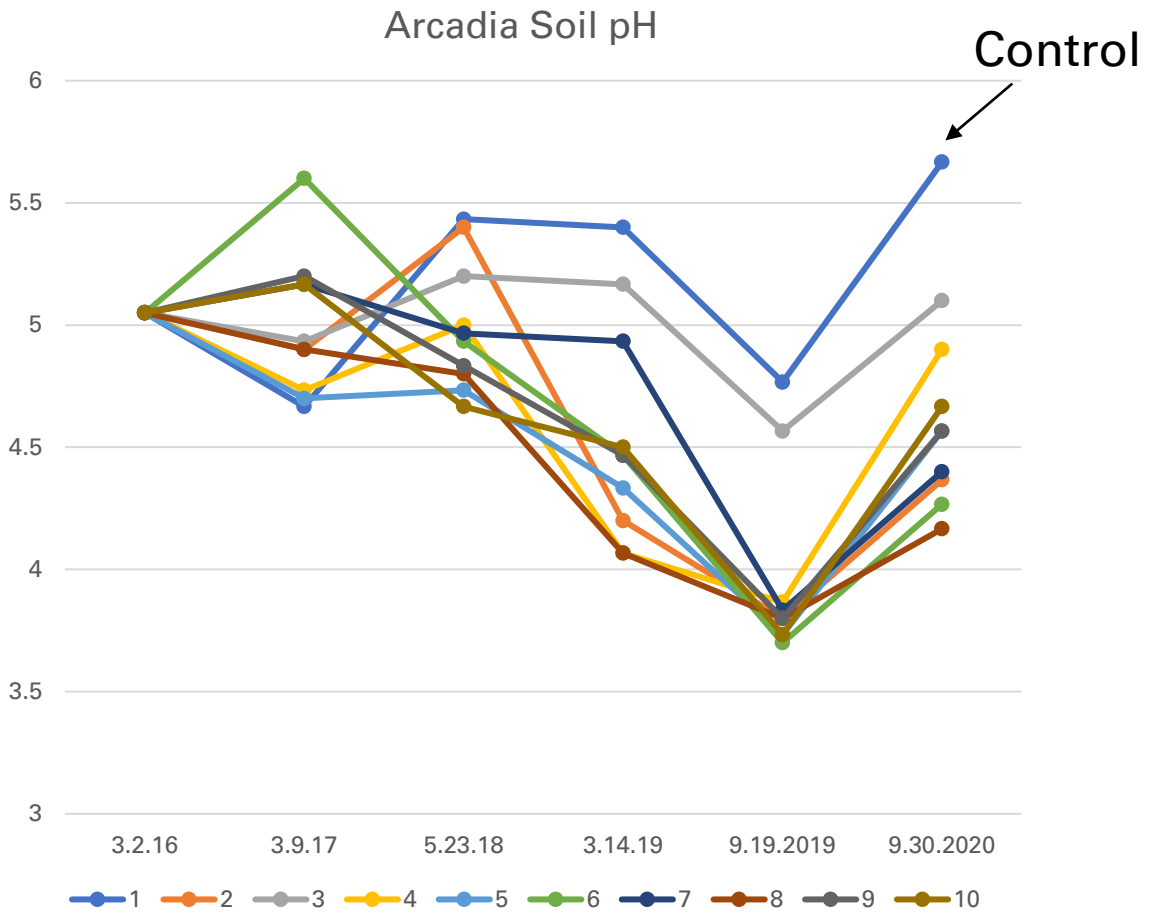
Soil pH dropped with use of Tiger mix

Halted the use of Tiger mix since Fall 2019





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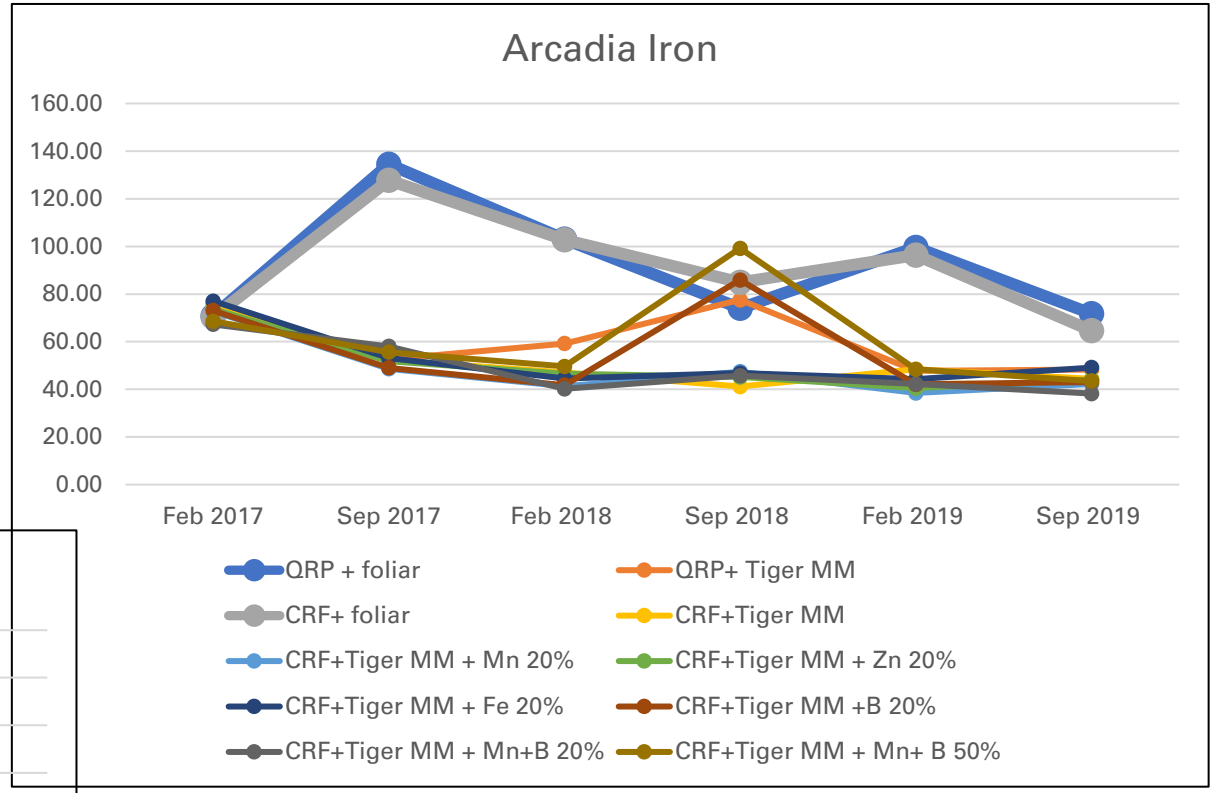
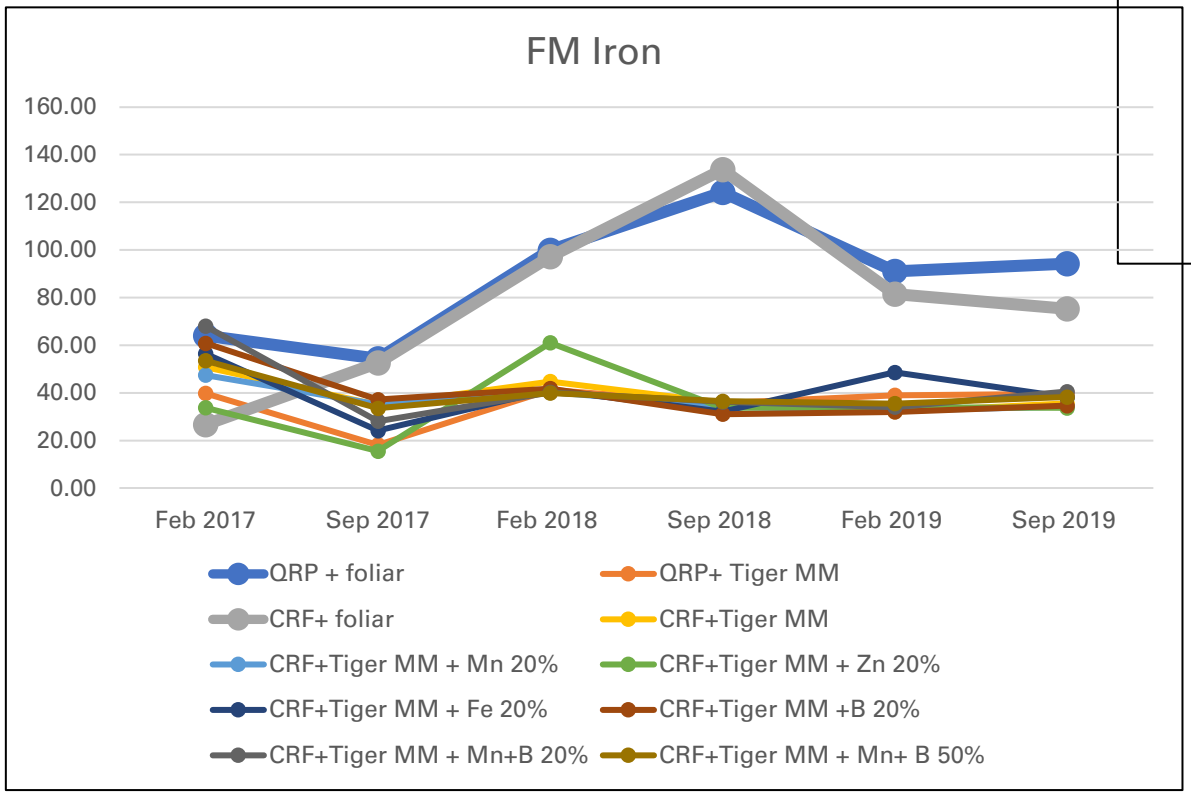
Change from foliar to soil micronutrient may show a drop in number





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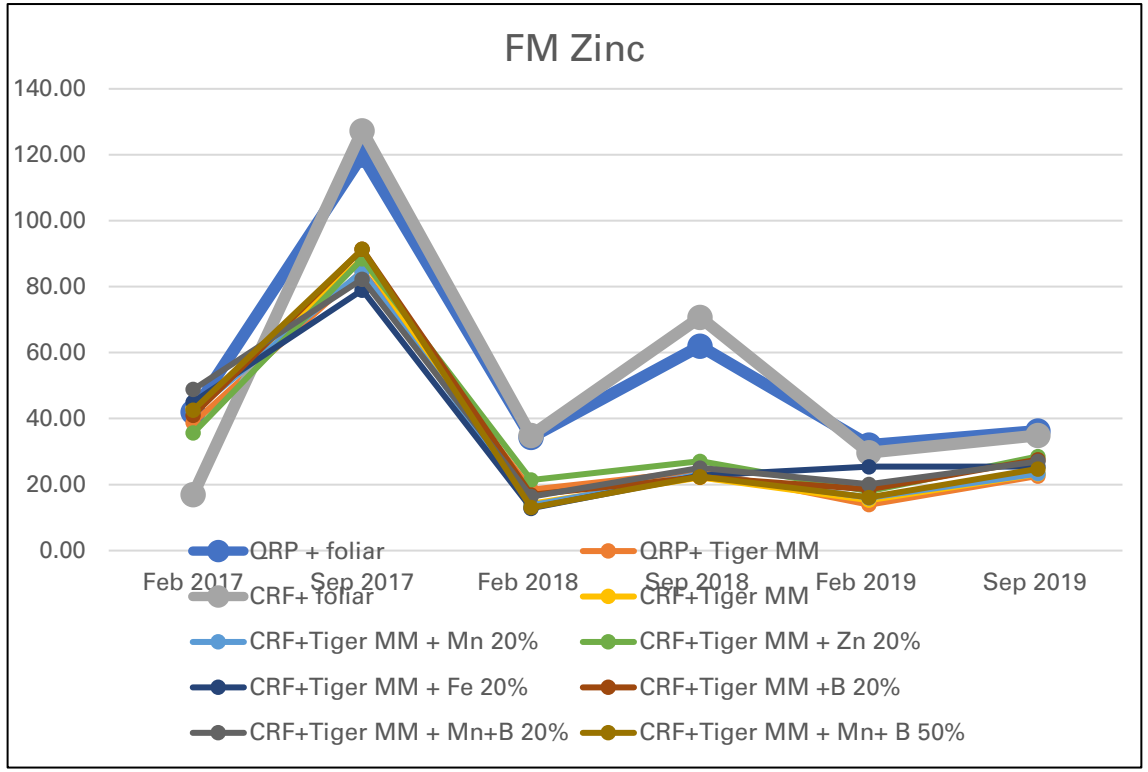

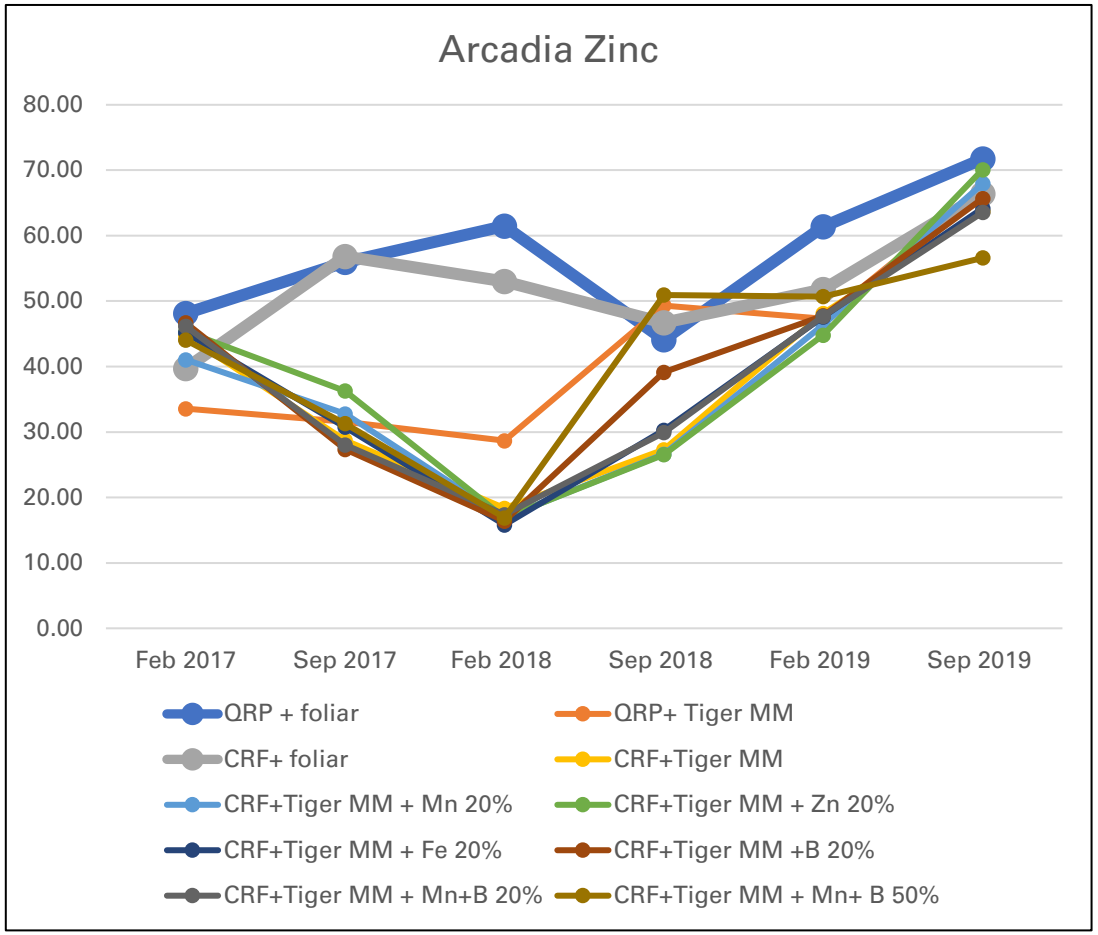

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Relationship between leaf nutrient and other parameters

- Fruit size increase with increase in leaf N, P, K, Mg, S, B, Mn
- Brix increase with increase in leaf N, Mg, S, B, Mn and increase in fruit size
- Acid decreased with increase in leaf N, P, Mg, S, B, Mn and increase in fruit size
- Yield increase with increase in leaf N, Mg and increase in fruit size
  - decrease in leaf Zn

Zn seems to be very important!!!

Multiple studies have been indicating towards role of Zn in managing HLB-trees.

More zinc is required in HLB trees.

New Micronutrient Trial

- 16 more treatments were added in 2020
  - Different rates of micronutrients

1	CRF +Tiger Micronutrients +Mn 50%
2	CRF +Tiger Micronutrients +Zn 50%
3	CRF +Tiger Micronutrients +Fe 50%
4	CRF +Tiger Micronutrients +B 50%
5	CRF +Tiger Micronutrients +Mn + Zn 20%
6	CRF +Tiger Micronutrients +Mn + Fe 20%
7	CRF +Tiger Micronutrients +Zn + Fe 20%
8	CRF +Tiger Micronutrients +Zn + B 20%
9	CRF +Tiger Micronutrients +Fe + B 20%
10	CRF +Tiger Micronutrients +Mn + Zn 50%
11	CRF +Tiger Micronutrients +Mn + Fe 50%
12	CRF +Tiger Micronutrients +Zn + Fe 50%
13	CRF +Tiger Micronutrients +Zn + B 50%
14	CRF +Tiger Micronutrients +Fe + B 50%
15	CRF +Foliar Micronutrients +Tiger 90
16	CRF +Tiger Micronutrients

Cumulative yield-2 years cumulative yield (lbs/tree)

Fort Meade			Arcadia		
7	CRF +TM +Zn + Fe 20%	363	9	CRF +TM +Fe + B 20%	217
1	CRF +TM +Mn 50%	376	8	CRF +TM +Zn + B 20%	279
5	CRF +TM +Mn + Zn 20%	397	1	CRF +TM +Mn 50%	290
11	CRF +TM +Mn + Fe 50%	399	5	CRF +TM +Mn + Zn 20%	301
13	CRF +TM +Zn + B 50%	406	15	CRF +Foliar +Tiger 90	307
15	CRF +Foliar +Tiger 90	406	6	CRF +TM +Mn + Fe 20%	319
3	CRF +TM +Fe 50%	410	12	CRF +TM +Zn + Fe 50%	324
10	CRF +TM +Mn + Zn 50%	424	16	CRF +TM	326
16	CRF +TM	424	3	CRF +TM +Fe 50%	333
4	CRF +TM +B 50%	427	11	CRF +TM +Mn + Fe 50%	337
14	CRF +TM +Fe + B 50%	433	14	CRF +TM +Fe + B 50%	337
12	CRF +TM +Zn + Fe 50%	445	4	CRF +TM +B 50%	338
6	CRF +TM +Mn + Fe 20%	449	10	CRF +TM +Mn + Zn 50%	338
8	CRF +TM +Zn + B 20%	453	2	CRF +TM +Zn 50%	357
2	CRF +TM +Zn 50%	454	13	CRF +TM +Zn + B 50%	387
9	CRF +TM +Fe + B 20%	460	7	CRF +TM +Zn + Fe 20%	387

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How does a rootstock affect nutrient uptake?

Should we consider rootstocks in fertilizer management?

Goal

To study the nutrient uptake in potentially HLB-tolerant rootstocks

- To investigate the differences in nutrient uptake capacity of different rootstocks

Swingle (Commercial Standard) • HLB-susceptible	**UFR-4** • Climbing up charts in bud-wood data • Reported to have good root growth	**UFR-17** • Climbing up charts in bud-wood data • Good performer under HLB
US-896 • Susceptible to HLB • Not a good performer	**46 X 20-04-6** • Suggested by the breeder for its good root attributes	**A+Volk X O-19-11-8** • Past studies on the sibling reported it to have good vigor and HLB tolerance

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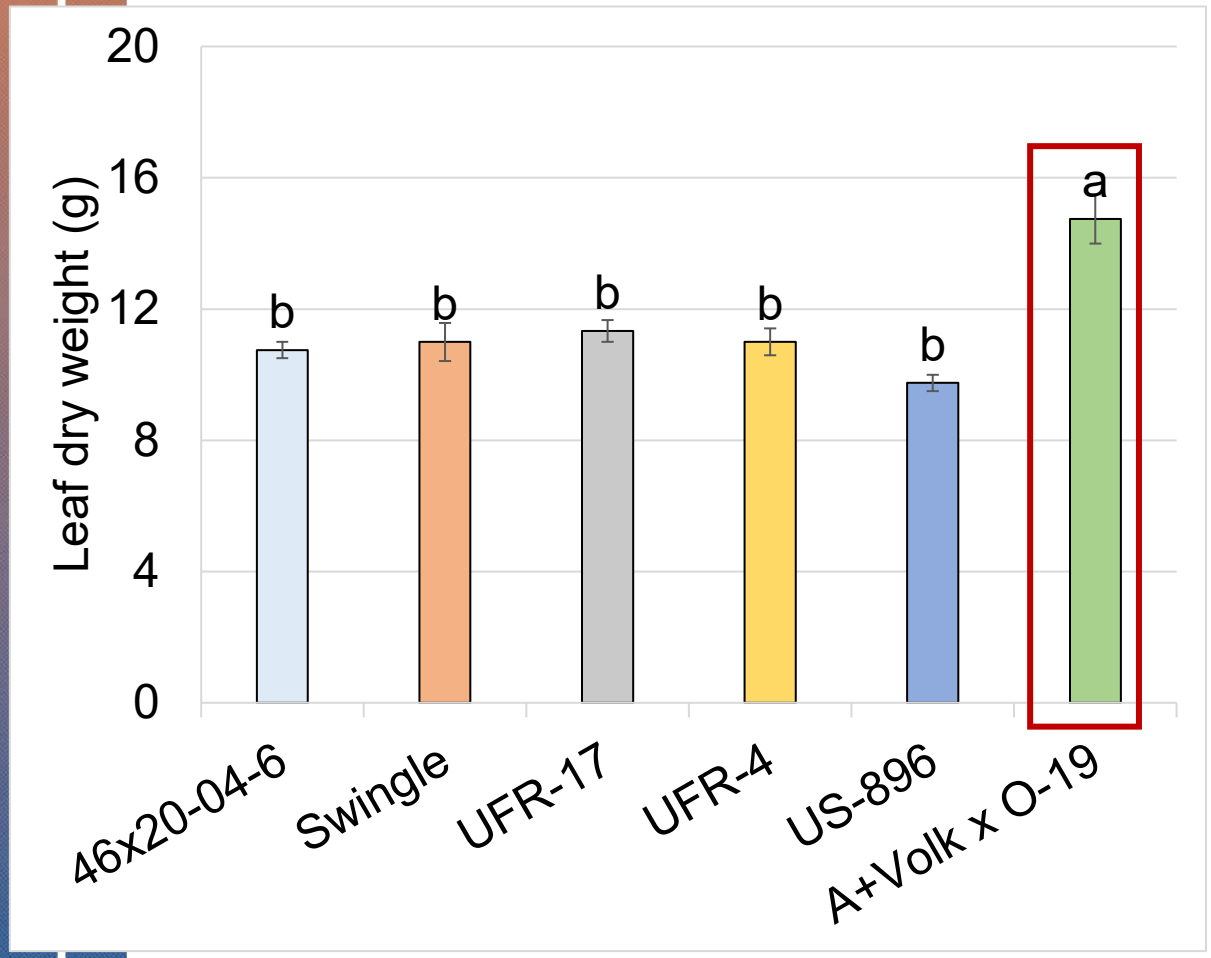
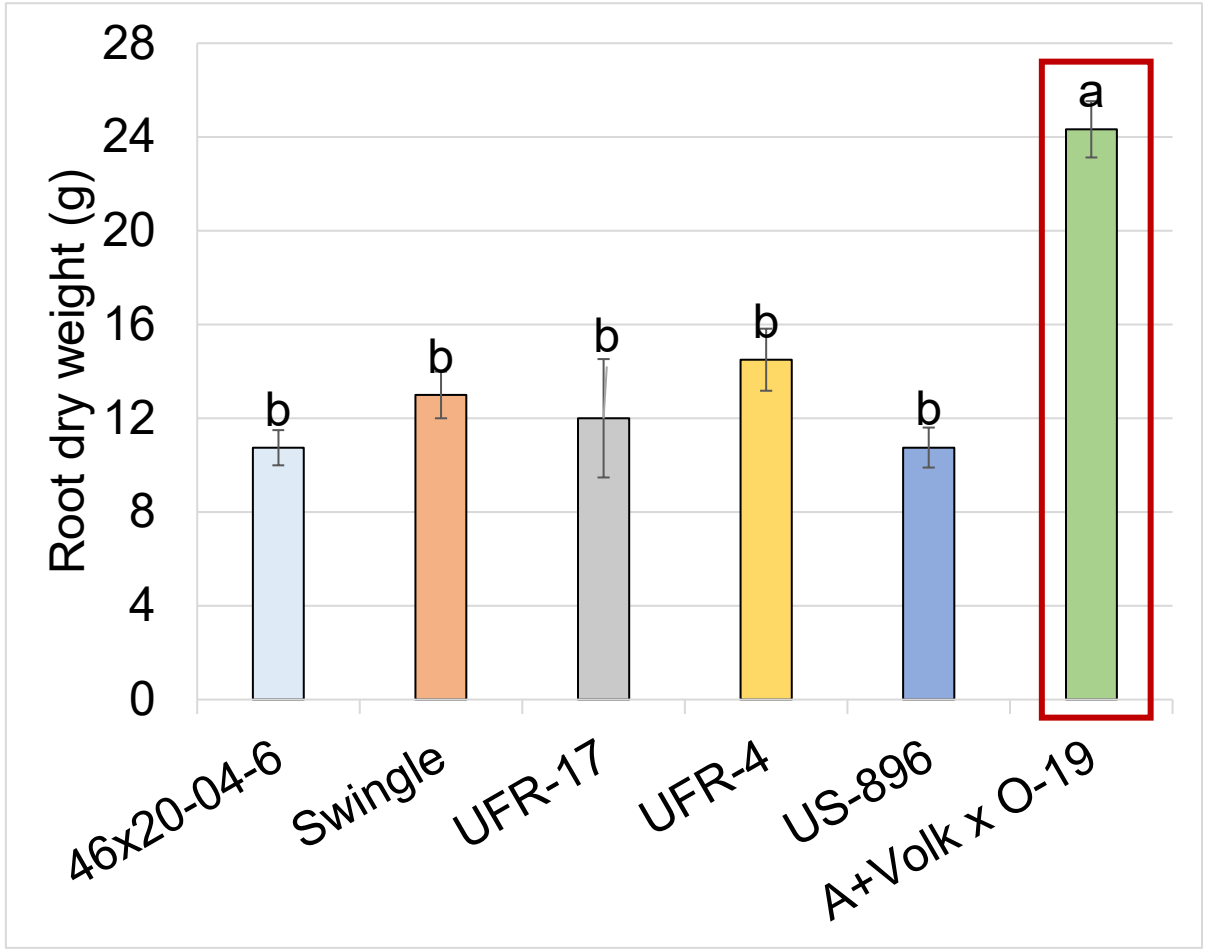
A+Volk X O-19-11-8 had the highest leaf and root biomass, followed by UFR-4 for root biomass





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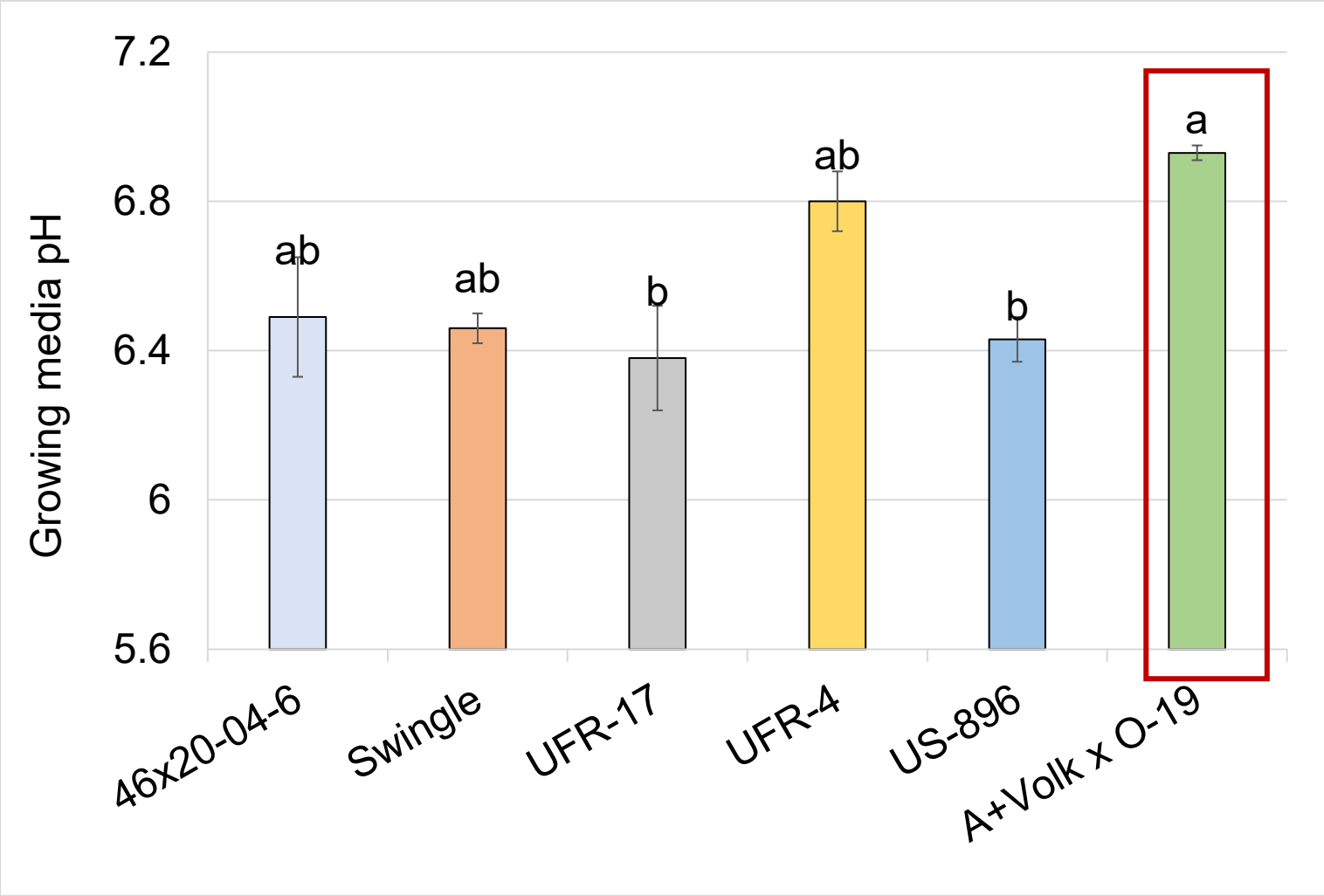
Rootstocks differed in ability to change pH of growing media



A+Volk X O-19-11-8 had the highest increase in pH of the growing media while UFR-17 and US-896 had the least increase by Day 30

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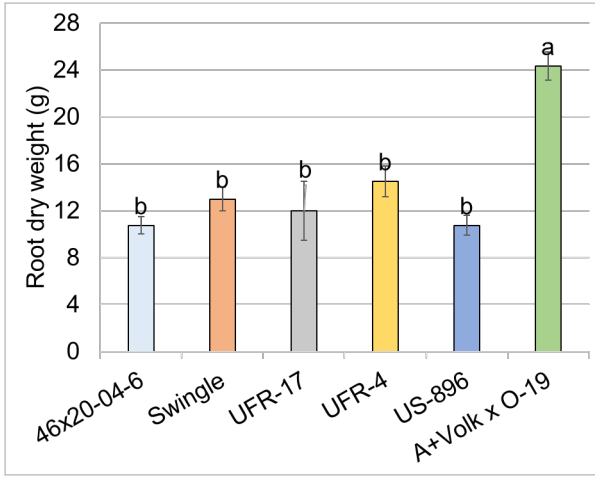
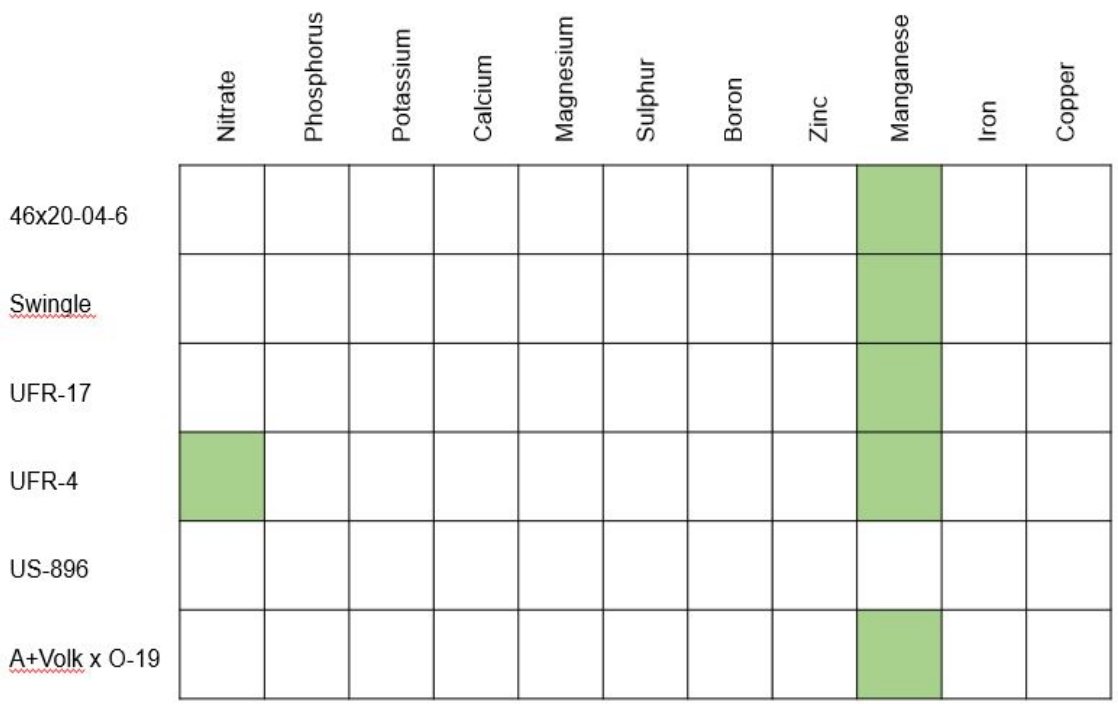
Nutrient Uptake

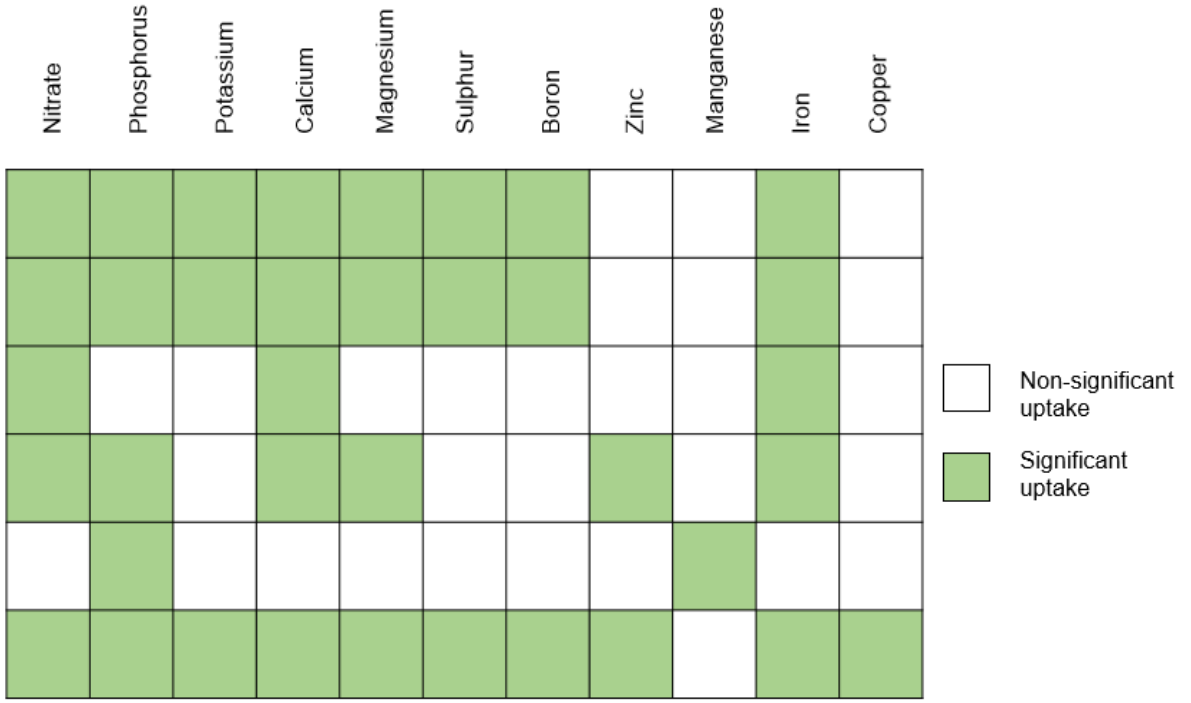
Mn uptake happens immediately following nutrient availability

A + Volk X O-19 has the highest and US-896 has the lowest nutrient uptake potential





Nutrients taken up from Day 0 to Day 15 (Sudden nutrient availability)



Nutrients taken up from Day 15 to Day 30 (Constant nutrient availability)

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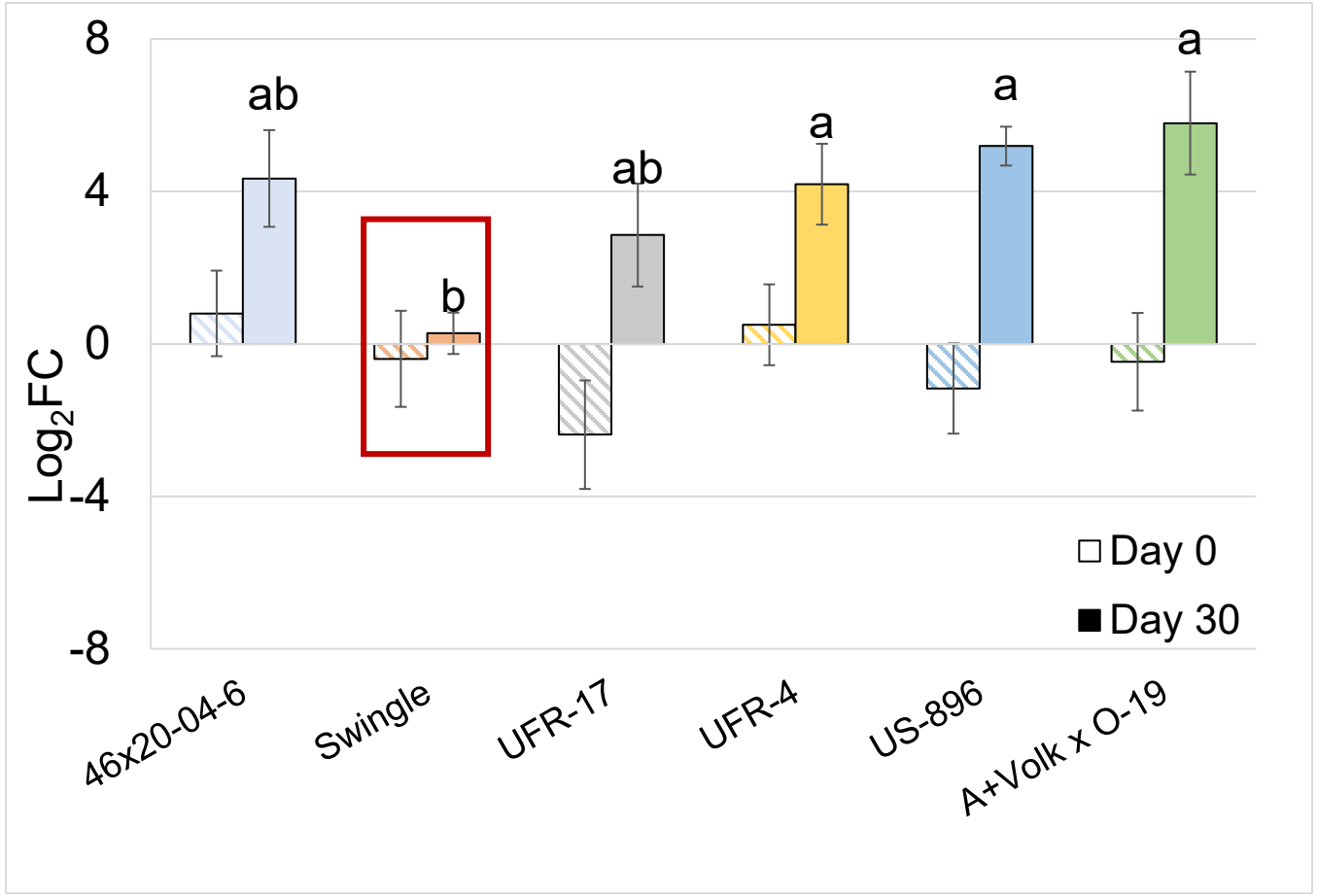
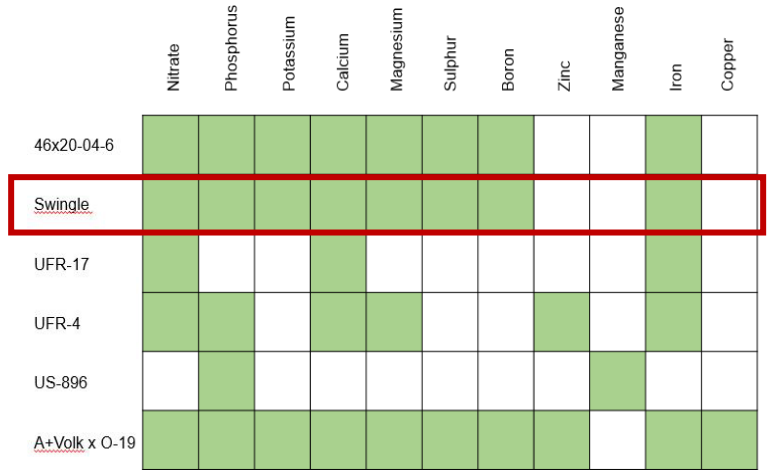
Swingle had the lowest expression of *ZIP5* suggesting the least uptake of Zn by Swingle compared to other rootstocks





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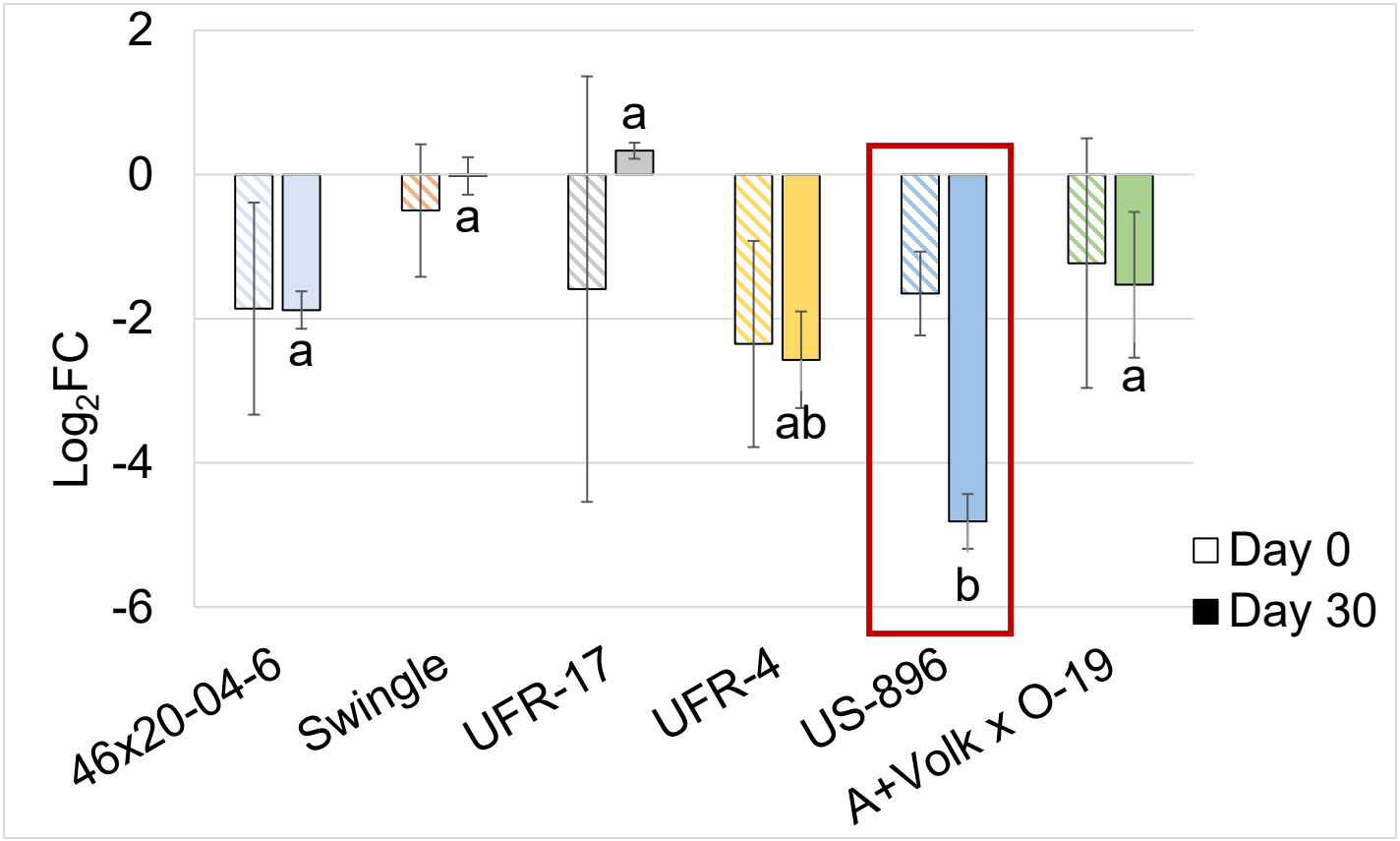
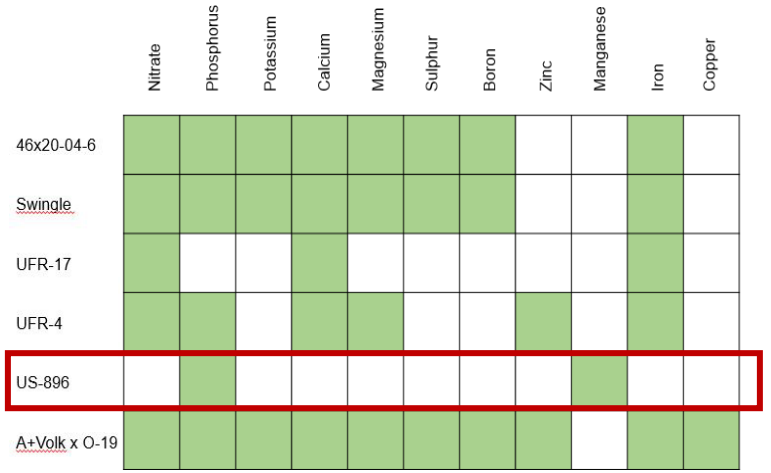
US-896 had the lowest expression of *IRT2* indicating poor Fe homeostasis in US-896 compared to other rootstocks





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Conclusion

- Rootstocks differ in uptake and molecular regulation of transporter genes
- Differences could be due to genetic makeup or intrinsic characteristics of rootstocks, but not biomass
- Swingle has Zn uptake issues, potentially resulting in HLB susceptibility

Summary

- Secondary nutrients and micronutrients are used at higher rates in HLB-affected trees
- Soil applied nutrient are better than foliar micronutrients
- 20% higher than recommended rate of micronutrients can improve productivity of HLB-affected trees
  - Iron and Zinc treatments are performing better in Arcadia location
  - Manganese treatments are performing better in Fort Meade
  - No obvious improvement with 50% increase of micronutrients
- Constant supply of nutrients and soil acidification is beneficial
  - With CRF, the rate of N applied was reduced to150 lb/acre as well as other nutrients
  - Soil pH should be monitored regularly
  - Soil acidification alone is not as helpful, soil applied micronutrients are needed

Summary

- Mg, S, B, Mn, and N improves fruit quality
- Zinc seems to be very important for HLB-affected trees
- Rootstocks should be considered in fertilizer management
- Swingle has lower Zinc uptake and hence poor performance
  - Better Zinc management is needed
- Nutrient efficient rootstocks are in pipeline for release

Suggested rate of soil applied micronutrients:
Mn: 12 to 15 lbs/acre
Zn: 12 to 15 lbs/acre
Fe: 6 to 10 lbs/acre
B: 0.75-1.5 lb/acre

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Thank You!

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