Terra Feed LLC / IFAS – Citra ACS / S Update Report

On September 24, 2015, I returned back to the US-IFAS / Citra experiment station in Citra, Florida to assist with the fifth and final processing of citrus trees. This UF-IFAS / Terra Feed LLC joint experiment was conducted under the direction of Dr. Rao S. Mylavarapu (Professor of Nutrient Management and Director of IFAS ANSERV Labs for the Soil & Water Science Department, UF-IFAS) to evaluate Terra Feed LLC ACS / Elemental S products effects on Valencia / Swingle citrus trees being grown within the their greenhouse facility. Below in Table 1 is a quick review of the current testing procedures for this experiment.

Table 1. Current Treatment Table in Order as they currently appear within the greenhouse in Citra, FL.

Treatment #	Application Products (Added to 16.0 oz. of Water / Pot)	Fertilizer Rate (ml)	ACS Rate (µl)	Sulfur Rate (µl)
T1	5-0-7 Fertilizer + ACS + Elemental Sulfur	20.52 ml	1176 µl	1330 µl
T2	5-0-7 Fertilizer Only	20.52 ml	0.00	0.00
T3	5-0-7 Fertilizer + ACS	20.52 ml	1176 µl	0.00
T4	5-0-7 Fertilizer + Elemental Sulfur	20.52 ml	0.00	1330 µl
T5	Control - (***No Products***)	0.00	0.00	0.00

Based on Treatment #, Application Products are to be added to 1.0 pt. (*16.0 oz. / 473 ml*) of water for *each* potted tree per scheduled application date. Application Products can be mixed together into the same 16 oz. of water for treatments that receive more than one Application Product per Treatment # per potted tree. 1 ml = 1000 µl

Updated Notes:

- ✓ **ACS will be applied 1X / Week (*Every Other Week*) –** (T1, T3)
- ✓ **Elemental Sulfur will be applied 1X / Week (*Every Other Week*) –** (T1, T4)
- ✓ **5-0-7 Fertilizer will be applied 3X / Week (*Each Week*) –** (T1, T2, T3, T4)
- ✓ **CONTROL TREES receive NO FERTILIZER, ACS or SULFUR –** (T5)

Per Dr. Rao S. Mylavarapu's (UF-IFAS experiment director) email sent on September 21, 2015 to Buford Creech (Terra Feed LLC., owner), the September 24, 2015 citrus tree processing at the IFAS-Citra experiment station would be the last one for this joint experiment. Concerning the citrus experiment, Dr. Rao Mylavarapu further stated within this email that "we have recorded all the data that we can with the current set up" following this final processing date. Additionally, Dr. Rao Mylavarapu further communicated in this email that the ACS/S corn study would continue for another two readings (4 weeks).

On September 24, 2015, I carried out a walk-through of the greenhouse prior to the IFAS staff arriving at the station for processing as was done previously for all processing dates. The photos seen below (Photos 1 – 5) are the pictures taken of each Treatment group prior to processing.

Photo 1. T1 (5-0-7 Fertilizer + ACS + Elemental S)

Photo 2. T2 (5-0-7 Fertilizer Only)

Photo 3. T3 (5-0-7 Fertilizer + ACS)

Photo 4. T4 (5-0-7 Fertilizer + Elemental S)

Photo 5. T5 (Control – No Added Products)

Although the soil moisture problem had been corrected prior to the previous processing date on September 10, 2015, it appeared on this processing date that pot moisture levels (seen and felt) were elevated again compared to that seen previously on September 10, 2015 with it appearing similar to that observed back on August 27, 2015. As noted previously on the September 10, 2015 Citra Update Report, excessive irrigation in conjunction with ASC applications (namely T1 and T3) resulted in an anaerobic condition within the pots that can result in stunted root growth. This similar waterlogged condition was seen again for this processing date; however, this excessive irrigation amount did not result in any visible rooting decay, but stunted root growth appeared to occur again as seen in the following Tables and Graphs below .

As was seen on previous processing dates, minor element deficiencies (and macro-deficiency for the T5 Control) were observed again, but with increasing frequency throughout all treated Treatments – including T4 (5-0-7 Fertilizer + Elemental S) this time, which had previously been more resistant to expressing these deficiencies – mainly, that of Fe deficiency. Fe deficiency had been a common and noted problem for T1, T2 and T3 trees on prior processing dates. The following photos illustrate these nutrient deficiencies below.

Photo 6A – D. T1 (*5-0-7 Fertilizer* + *ACS* + *Elemental S*) Fe Deficiencies

A. 

B. 

C. 

D. 

Photo 7A – C. T2 (*5-0-7 Fertilizer Only*) Fe Deficiencies

A. 

B. 

C.

Photo 8A – D. T3 (*5-0-7 Fertilizer* + *ACS*) Fe Deficiencies

A.

B.

C.

D.

Photo 9A – B. T4 (*5-0-7 Fertilizer + Elemental S*) Fe Deficiencies

A.

B.

Photo 10A – D. T5 (*Control – No Added Products*) Nitrogen Deficiencies

A.

B.

C.

D.

Although minor element deficiencies (namely Fe) were observed in all treated Treatments (T1 – T4) as seen in the photos above, there were still a few trees in certain Treatments that exhibited normal growth showing no nutrient deficiencies – mainly Treatments T4 as well as T2 as seen in the following photos below (Photo 11 and 12).

Photo 11. T4 (*5-0-7 Fertilizer + Elemental S*)

Photo 12. T2 (*5-0-7 Fertilizer Only*)

Despite ACS treated trees showing nutrient deficiencies in all remaining trees, Treatment T1 (5-0-7 Fertilizer + ACS + Elemental S) still had the tallest growing trees of all Treatments as seen in Photo 13 below, which shows all trees to be processed on this date, as well as in Photo 14 below which shows the height of the taller T1 tree to be processed for this date. No other Treatment had trees to be processed or remaining that exceeded the height of T1 treated trees.

Photo 13. A Collection of All Treatment Trees to be processed on September 24, 2015

Photo 14. The tallest T1 tree to be processed on September 24, 2015; the IFAS employee standing beside the tree is 5'2" in height and the pot size is 15 gal (15.5" height)

It should be noted that in Photo 14 above, the T1 tree on the right has a large rootstock sprout growing from the 'Swingle' citrumelo rootstock whereas the T1 tree on the left does not; hence, significant tree energy and resources were transferred to this root sprout as opposed to the budded 'Valencia' scion which resulted in less branching of the larger T1 tree compared to the smaller yet more branched T1 tree to the left. Moreover, the rootstock sprout seen on the taller T1 tree exhibits more Fe deficiency symptoms than the 'Valencia' scion of this tree – which is easier to see in Photo 15 below.

Photo 15. Comparing the two T1 (5-0-7 Fertilizer + ACS + Elemental S) trees to be processed with both T2 (5-0-7 Fertilizer Only) trees and one T3 (5-0-7 Fertilizer + ACS) tree

As noted in a research paper titled *Differential tolerance to iron deficiency of citrus rootstocks grown in nutrient solution*, which was published in Scientia Horticulturae, the authors concluded that ‘Swingle’ citrumelo rootstock was more sensitive to Fe deficiency compared to other rootstocks studied in their citrus trial. [1] This publication further states that ‘Swingle’ citrumelo rootstock has a strong susceptibility to Fe deficiency; and, that ‘Swingle’ citrumelo trees require 20 μmol Fe dm^{-3} within the nutrient solution to ensure adequate tree growth. [1] Fe deficiency susceptibility of ‘Swingle’ citrumelo rootstock was also determined by other researchers resourced within this same research paper [1] as well as noted by other researchers in another paper published in England [2] and within literature published by the University of California [3]. As noted by UF-IFAS Extension, Iron (Fe) is one of the 16 essential elements for plant growth and reproduction – which includes the manufacturing process of chlorophyll as well as needed certain enzyme and protein functions such as cytochromes and ferredoxin. [4] Researchers in Spain noted that Fe works as a cofactor for enzymes involved in a wide variety of oxidation-reduction reactions due to its ability to gain and lose electrons and that a reduction of Fe leads directly to a reduction of catalase and peroxidase activities which results in oxidative stress. [5] Additionally, UF-IFAS Extension states that in higher organic based soils (as was the case for the potting soil used for this experiment) "Fe may be present in its reduced state as Fe^{++} in the soil solution or adsorbed onto soil particle surfaces" with organic matter (O.M.) playing a significant role if Fe availability as O.M. acts as a chelating agent via organic acids and complex polymers, thus assisting with Fe availability. [4] However, iron uptake is also dependent upon the plant's ability to actively remove it from a chelating compound in the root zone as well as reducing it from Fe^{+++} to Fe^{++} [4] with the latter form of Fe (ferrous) being soluble in water at any pH; whereas the former (ferric) becomes insoluble at pH level > 3.5. [6] IFAS states that in waterlogged situations, ferric iron (Fe^{+3}) is reduced to the ferrous state (Fe^{+2}) [4]; however, despite elevated organic matter used in the potting soil for this experiment as well as waterlogged conditions that normally assists with Fe solubility, this particular potting soil mix was significantly deficient in soil Fe as seen in Photos 6 – 10 above since 'Swingle' citrumelo rootstock requires at least 20 μmol Fe dm^{-3} within the nutrient solution to ensure adequate tree growth. [1]

It should be noted that the use of ACS (per its label) recommends that this microbe stimulating soil amendment should be used in conjunction with a well-balanced fertility program. Although both T1 and T3 both utilized a liquid fertilizer, this liquid based fertilizer lacked the primary element phosphorous as well as a highly essential (and recommended) micronutrient package. Although soil analysis of this potting mixed did show a high P content for this custom made potting soil, it appears that the lack of a complete micronutrient component in this custom blended potting soil (or as a supplemental additive) was a significant limiting factor for optimum tree growth for those trees utilizing ACS (particularly T1 and T3) as well as T2 and eventually T4 on the last processing date.

[1] Pestana, Maribela; de Varennes, Amarilis; Abad, Javier; and Faria, Eugenio Araujo. (21 July 2004). Differential tolerance to iron deficiency of citrus rootstocks grown in nutrient solution. Scientia Horticulturae 104 (2005) 25–36
http://www.researchgate.net/publication/222541833_Differential_tolerance_to_iron_deficiency_of_citrus_rootstocks_grown_in_nutrient_solution

[2] Muccilli V, Licciardello C, Fontanini D, Cunsolo V, Capocchi A, Saletti R, Torrisi B, Foti S. (2013). Root protein profiles of two citrus rootstocks grown under iron sufficiency/deficiency conditions. Eur J Mass Spectrom (Chichester, Eng). 2013; 19 (4):305-24.
http://www.ncbi.nlm.nih.gov/pubmed/24575629

[3] Crowley, David. Macronutrients: Their Role in Citrus Production. Dept. of Environmental Sciences, University of California, Riverside.
http://www.citrusresearch.org/wp-content/uploads/Crowley_David_Macronutrients_theirrollcitrus.pdf

[4] Hochmuth, George. Iron (Fe) Nutrition of Plants. 2015. Publication #SL353. Department of Soil and Water Science, UF/IFAS Extension, Gainesville, FL
https://edis.ifas.ufl.edu/ss555

[5] Maria Angeles Forner-Giner and Gema Ancillo (2011). Iron Stress in Citrus, Plants and Environment, Dr. Hemanth Vasanthaiah (Ed.), ISBN: 978-953-307-779-6, InTech, Available from: http://www.intechopen.com/books/plants-and-environment/iron-stress-in-citrus
http://cdn.intechopen.com/pdfs-wm/21735.pdf

[6] WPCAMR. Ferrous - ferric iron. 2015. Abandoned Mine Reclamation Clearinghouse, Pennsylvania
http://www.amrclearinghouse.org/Sub/AMDbasics/Ferrous-FerricIron.htm

Citrus tree processing procedures for September 24, 2015 followed similar processes on previous dates when two trees per Treatment Number were processed. Photo 13 above shows these two trees per Treatment to be processed on this date. As was done previously, the initial citrus tree processing steps includes pot numbering (Photo 16A); tree extraction from the 15 gallon pot (Photo 16B); initial hand separation of soil from the root ball (Photo 16C); collecting of soil samples for soil mineral analysis as well as for rhizobia analysis (Photo 16D); rinsing of the root ball (Photo 16E); and, a final shaking of the rinsed tree to assist with removing loose bark from the rinsed root ball (Photo 16F).

Photos 16 A – F. Initial Citrus Tree Processing Steps

A. 

B. 

C. 

D. 

E. 

F. 

Not photographed on this processing date, but also included during the initial citrus tree processing steps for this date, was the collecting of loose roots fragments that broke off the main root ball during the soil extracting and washing processes. These loose root fragments would be added to their respectful root ball prior to weighing each root ball for all trees for all Treatments.

Additionally during this processing date, as was done on August 27, 2015, two additional soil samples were taken from each Treatments' pots to be analyzed by an outside lab. Thus four total soil samples were collected from each Treatment – one for IFAS soil mineral analysis; one for rhizobia analysis to be conducted by IFAS personnel; and, two for outside lab analysis (independent of IFAS). Since each Treatment had two trees processed, the potting soils from each of these two trees were combined as a representative soil sample per their respectful Treatment Number.

The following photos below (Photos 17 – 21) shows each Treatments two root balls with Photo 22 showing all Treatments collectively as a comparison between Treatments.

Photo 17. T5 (Control)

Photo 18. T4 (5-0-7 Fertilizer + Elemental Sulfur)

Photo 19. T3 (5-0-7 Fertilizer + ACS)

Photo 20. T2 (5-0-7 Fertilizer Only)

Photo 21. T1 (5-0-7 Fertilizer + ACS + Elemental Sulfur)

Photo 22. All Treatments ***(From L to R:*** **T5** ***(Control);*** **T4** ***(5-0-7 Fertilizer + Elemental Sulfur);*** **T3** ***(5-0-7 Fertilizer + ACS);*** **T2** ***(5-0-7 Fertilizer Only);*** **T1** ***(5-0-7 Fertilizer + ACS + Elemental Sulfur)***

Surprisingly, there were two Treatments (T2 and T3) that each had an usually small root ball for one of two of their respectful Treatment Number trees which can be seen in Photos 19 and 20 above as well as in Photo 23 below.

Photo 23. T3 – 2 (5-0-7 Fertilizer + ACS)

Like that seen on August 27, 2015 and noted in the report for September 10, 2015, there are two primary reasons for this poor root growth for both of these affected Treatment trees (namely T2 – 1 and T3 – 2):

- Excessive irrigation in conjunction with ASC applications (namely T3); and,
- Excessive irrigation in conjunction with poor tree selection resulting in a poorer quality tree being utilized out of the remaining trees per Treatment (namely T2, but also potentially T3 as well).

IFAS personnel were solely responsible for citrus tree selection for processing from the group of remaining trees per each Treatment. Moreover, IFAS personnel were also responsible for ensuring that irrigation amounts were reduced as was instructed back on August 31, 2015; however, soil moisture conditions were similar to that observed on August 27, 2015 (excessive by touch and sight). It is recommended that a soil moisture meter be utilized for any future experimentation of this type and that soil moisture be properly gauged to the potting soil used as potting soil can vary considerably in soil moisture retention and drainage. It would appear that an anaerobic condition developed within the pots again (particularly T3) resulting in stunted roots – though none were seen in decay or otherwise damaged.

It should be noted that the tree in Photo 23 (T3 – 2) above had an unusually amount of highly decayed soil around its primary roots. This highly decayed soil was not present for any other trees processed on this date for any other Treatments or even its partner tree (T3 – 1). It appeared as though this unusual soil was regurgitated soil, meaning soil one might see from soil passing through the gut of an earthworm (highly digested), though no earthworms were seen in the pot. Moreover, no visible (naked eye) mycelium was observed either which would exclude fungal digestion. It would appear that this unusual "digested" soil may be of microbial origin, namely high bacterial counts, though the type / species is currently unknown to me. It would be interesting to see what IFAS personnel come up with when doing their rhizobia analysis for this particular tree (T3 – 2).

As was done previously, both root length and widths were measured for all trees for each Treatment. Root length consisted of measuring from the top most roots to the length of the longest vertical root; whereas, root width measurements involved measuring the longest roots perpendicular to the stem on both sides of the stem collectively. Table 2 below is a summary of these measurements by tree and by Treatment.

Table 2. Root Lengths and Widths Measurements for each Tree for All Treatments

Valencia / Swingle Root Measurements for September 24, 2015

Treatment Number - Tree Number	Application Type	Root Length (cm)	Root Width (cm)
T5 - 1	Control - (*No Products*)	57.0	87.0
T5 - 2	Control - (*No Products*)	68.0	82.0
T4 - 1	5-0-7 Fertilizer + Elemental Sulfur	57.0	81.0
T4 - 2	5-0-7 Fertilizer + Elemental Sulfur	61.0	109.0
T3 - 1	5-0-7 Fertilizer + ACS	54.0	90.0
T3 - 2	5-0-7 Fertilizer + ACS	60.0	105.0
T2 - 1	5-0-7 Fertilizer Only	54.0	107.0
T2 - 2	5-0-7 Fertilizer Only	59.0	90.0
T1 - 1	5-0-7 Fertilizer + ACS + Elemental Sulfur	66.0	83.0
T1 - 2	5-0-7 Fertilizer + ACS + Elemental Sulfur	71.0	84.0

Following measuring each trees' roots length and width measurements as noted in Table 2 above, the next processing step was to measure the weights in kg of each tree's root ball as well as their respectful scion (shoot). As was done previously on earlier dates, the root ball was cut off right above the top most roots with each portion of the tree (rootstock and scion) weighed separately. When weighing the root balls, any loose roots collected during the washing process were added to their respectful tree prior to measuring their final weights. On this particular day, the scale used for weighing was different from that used previously. This happened because the regularly used scale was not available on this processing date; furthermore, this "new" scale only weighed in grams rather than kg with this "new" scale not being adjustable to kg for this particular model of scale; however, converting units in metrics is a simple process.

The following photos (Photos 24 – 43) show these measurement weights (in grams) for each tree for all Treatments. Table 3 below summarizes these roots and shoots weights into a convenient table for all trees from all Treatments with weight measurements converted to kg.

Photo 24. Control / T5 – 1 Roots

Photo 25. Control / T5 – 1 Shoot

Photo 26. Control / T5 – 2 Roots

Photo 27. Control / T5 – 2 Shoot

Photo 28. (5-0-7 Fertilizer + Elemental Sulfur) / T4 – 1 Roots

Photo 29. (5-0-7 Fertilizer + Elemental Sulfur) / T4 – 1 Shoot

Photo 30. (5-0-7 Fertilizer + Elemental Sulfur) / T4 – 2 Roots

Photo 31. (5-0-7 Fertilizer + Elemental Sulfur) / T4 – 2 Shoot

Photo 32. (5-0-7 Fertilizer + ACS) / T3 – 1 Roots

Photo 33. (5-0-7 Fertilizer + ACS) / T3 – 1 Shoot

Photo 34. (5-0-7 Fertilizer + ACS) / T3 – 2 Roots

Photo 35. (5-0-7 Fertilizer + ACS) / T3 – 2 Shoot

Photo 36. (5-0-7 Fertilizer Only) / T2 – 1 Roots

Photo 37. (5-0-7 Fertilizer Only) / T2 – 1 Shoot

Photo 38. (5-0-7 Fertilizer Only) / T2 – 2 Roots

Photo 39. (5-0-7 Fertilizer Only) / T2 – 2 Shoot

Photo 40. (5-0-7 Fertilizer + ACS + S) / T1 – 1 Roots

Photo 41. (5-0-7 Fertilizer + ACS + S) / T1 – 1 Shoot

Photo 42. (5-0-7 Fertilizer + ACS + S) / T1 – 2 Roots

Photo 43. (5-0-7 Fertilizer + ACS + S) / T1 – 2 Shoot

Table 3. Summary of all Root and Shoot Weights for All Trees for each Treatment

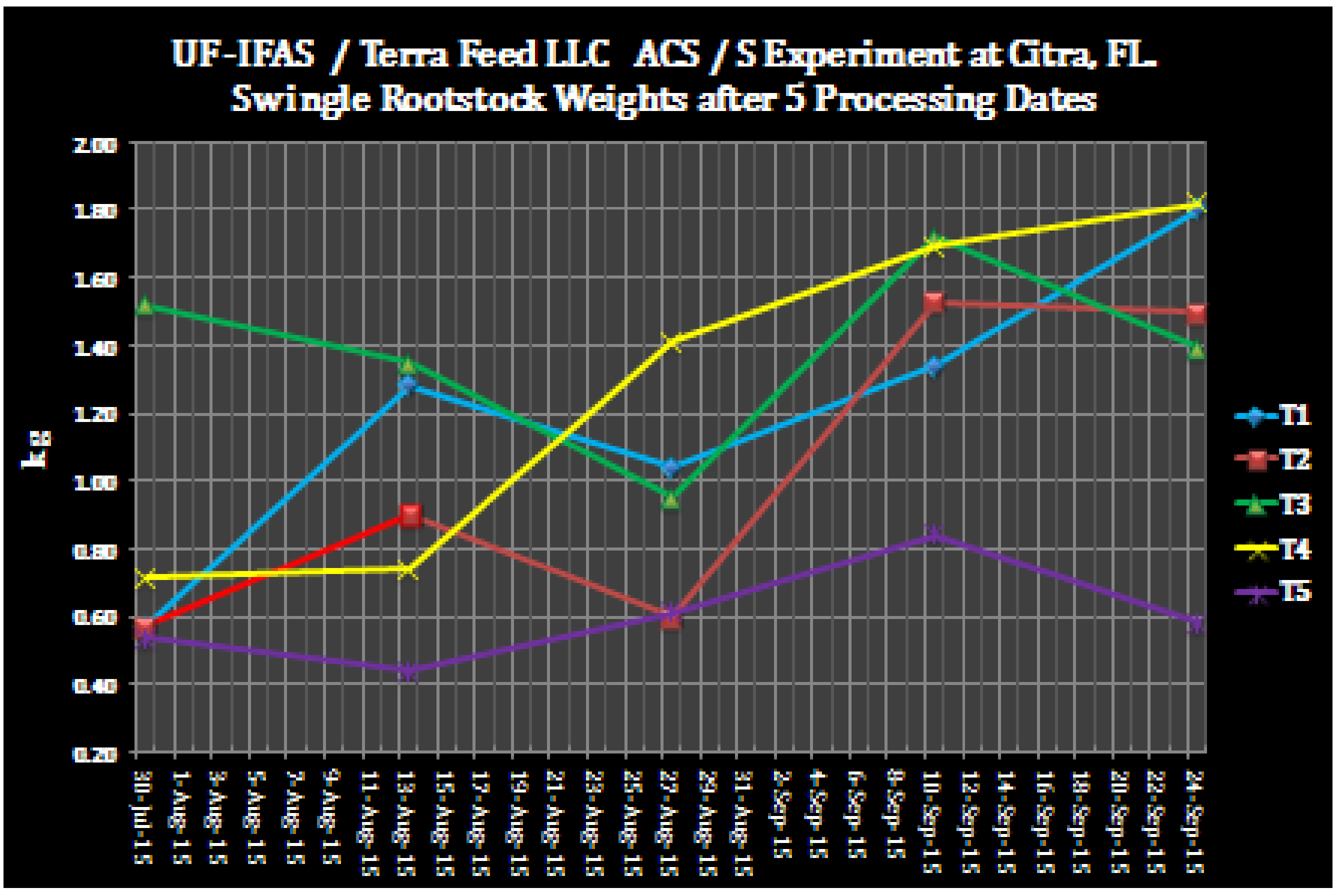
Valencia / Swingle Root and Shoot Weights for September 24, 2015

Treatment Number - Tree Number	Application Type	Root Weight (kg)	Shoot Weight (kg)
T5 - 1	Control - (*No Products*)	0.72	0.15
T5 - 2	Control - (*No Products*)	0.44	0.12
T4 - 1	5-0-7 Fertilizer + Elemental Sulfur	1.79	0.75
T4 - 2	5-0-7 Fertilizer + Elemental Sulfur	1.84	0.75
T3 - 1	5-0-7 Fertilizer + ACS	2.38	0.77
T3 - 2	5-0-7 Fertilizer + ACS	0.40	0.37
T2 - 1	5-0-7 Fertilizer Only	0.91	0.40
T2 - 2	5-0-7 Fertilizer Only	2.09	0.66
T1 - 1	5-0-7 Fertilizer + ACS + Elemental Sulfur	1.13	0.52
T1 - 2	5-0-7 Fertilizer + ACS + Elemental Sulfur	2.48	0.81

Since all previous citrus trees processing dates listed both root and shoot weights in kg rather than grams, all weights for this processing date were easily converted to kg with numerical rounding occurring at the hundredth decimal to match all previous processing dates weight ranges.

Like the summary graphs that appeared in the September 10, 2015 report, both graphs have been revised to reflect the new data collected from this report. Graph 1 below illustrates Swingle rootstock growth for all Treatments over time, and Graph 2 illustrates Valencia Scion Growth over time for all Treatments.

Graph 1. Swingle Rootstock Growth for all Treatments over Time



It is interesting in Graph 1 above that Treatment T1 (5-0-7 Fertilizer + ACS + Elemental Sulfur) continued to increase in root mass since that last processing date on September 10th whereas T3 (5-0-7 Fertilizer + ACS) declined in averaged root mass since the last processing date. As noted above for this final citrus tree processing date of September 24, 2015, potting soil moisture was once again excessive, as was encountered back on August 27, 2015 with both of these processing dates clearly showing a root mass reduction for T3 (5-0-7 Fertilizer + ACS) grown trees; thus, it would appear that the application of ACS (without the Elemental S component) to waterlogged soils would not be recommended based solely on this experiment; however, in it should be noted that this experiment does not directly relate to normal field grown citrus trees in Florida because:

- The experiment occurred in a controlled greenhouse environment were trees were grown in pots as opposed to normal field conditions; hence, soil O_2 limitations were exacerbated with the addition of ACS when the soil conditions became waterlogged in the 15 gal pots;

- This experiment used highly organic potting soil which is not similar to that commonly found in either Ridge or Flatwoods sandy soils where citrus production normally occurs in Florida; moreover, these commonly used sandy soils are usually very limited in organic matter content;

Despite these noted experimental limitations, the information gleaned from this experiment could justify that Florida citrus growers growing on Flatwoods soils should take precautions when applying ACS during the summer rainy / hurricane season which runs from June 1st through November 30th [7] as excessive rainfall periods can lead to significant flooding conditions on these low-lying Flatwoods soils – including those groves that are bedded since standing (non-drained) swell water seeps into raised beds resulting in waterlogged conditions within the beds that could limit soil O_2 concentrations. Terra Feed LLC does not recommend the use of ACS or fertilizer applications during times of excessive rainfall or flooding conditions as the former can exacerbate the limitation of soil O_2 in flooded or semi-flooded (bedded) soils and the addition of the latter leads directly to nutrient leaching problems. Moreover, with ACS usually applied through irrigation systems, irrigation (or fertigation) during excessive rains or flooding normally would not occur when utilizing good management practices. Additionally, based on the results of this experiment, it may prove more beneficial in terms of overall citrus tree health as well as financially practical for Flatwoods growing citrus growers to utilize ACS during dryer spring (particularly early spring) and fall months while transitioning over to the ACS/ Elemental Sulfur combination during wetter summer months since Treatment T1 outperformed T3 during waterlogging conditions during this experiment. Another advantage to making this transition from ACS alone to ACS/S applications during the summer is the fact that ACS/S applications can assist with bicarbonate problems associated with poor irrigation water quality during Florida's high temperature late spring and summer months when irrigation frequency is increased – particularly from May through July.

As for Ridge grown citrus trees such as that found in Lake, Orange, Polk and Highlands Counties, the thick sandy Ridge soils are not affected to significant flooding conditions that would limit soil O_2 concentrations as the majority of these soils are highly permeable; hence, there is no ACS use limitations, complications or precautions for these soil types as those noted above for low-lying Flatwoods soils. Additionally for Ridge grown citrus trees, the use of ACS is significantly beneficial as ACS alone provides a primary carbon source for these organic matter deficient soils; thus, ACS use on these sandy soils allows for higher microbial populations and their beneficial soil mining activities which is also the case for Flatwoods soils too.

Despite this concern for ACS usage during waterlogged soil conditions on Flatwoods soils, the use of Elemental Sulfur sold by Terra Feed LLC (or other potential sources of degradable elemental sulfur such as TIGER 90CR® Sulfur, which is manufactured by Tiger-Sul Products LLC.) has the potential to counteract this negative impact imparted by ACS when used in wet soil environments as seen for Treatment 1 and 4 for this experiment. It should be noted that the finer particle sizes of the Terra Feed LLC Elemental Sulfur product will be more reactive in the soil compared to the slow releasing prilled TIGER 90CR® Sulfur. As seen in Graph 1 above, Treatment T4 (5-0-7 Fertilizer + Elemental Sulfur) performed very well throughout the course of this experiment with a steady increase in 'Swingle' citrumelo rootstock mass over time. Treatment T1 (5-0-7 Fertilizer + ACS + Elemental Sulfur), despite showing a slight slump in root mass from August 13th – August 27th mainly due to wet soil conditions, rebounded nicely after encountering improved soil moisture conditions on September 10th, yet did not regress in averaged root mass on the final processing date of September 24th despite encountering wet soil conditions again as T3 (5-0-7 Fertilizer + ACS) noted above did. Since all factors were the same for these two Treatments (T1 and T3) other than the added Elemental Sulfur in T1, it would appear that the addition of Elemental Sulfur can assist in buffering that damaging effects of ACS usage in water logged soils due to sulfur reducing microbes such as *Desulfobactium*, *Desulfobulbus* and *Desulfotomaculum*, which are obligate anaerobes, or *Thiobacillus thiooxidans* and *T. Ferrooxidans*, which can both reduce Fe^{+3} or Mn^{+4} by using Elemental Sulfur as an electron donor. [8]

As noted in a paper titled <u>*Oxidation of Sulfur in Soils*</u> from California Agriculture, denitrifying bacteria, which usually use organic materials (such as organic matter or ACS), can also utilize sulfur as a substitute energy source. [9] As stated in this paper, the presence of sulfur in the soil delays the oxidation of ammonia to nitrates or a reduction in mineral nitrogen in conjunction with sulfur oxidation with this process occurring only when reduced forms of sulfur are applied such as elemental sulfur or hydrogen sulfide. [9] This paper further notes that as soil moisture increases, so too does nitrate reduction with the rate of sulfur oxidation dependent upon the fertilizer sourcing materials. [9] It is interesting that The Department of Plant Industries – NSW in Australia states that hydrogen sulfide, a by-product of anaerobic waterlogged soils, does the greatest damage to citrus roots; [10]; however, they also mention that the amount of soil organic matter, microorganism present and soil pH contribute to the rate of nutrient imbalances occurring within waterlogged soils, and that the effects of waterlogging can be less severe if water is flowing (i.e. from irrigation) since flowing water assists with moving dissolved O_2 into the root zone while also removing any soil toxins. [10] In the case of this experiment, the soil, although waterlogged at times, was never completed flooded and both irrigation and Treatment fertigations assisted with moving dissolved O_2 into the root zone while also removing any soil toxins. Additionally, it would appear in this experiment that adequate N and Elemental Sulfur were supplied to compensate for the increasing microbial population stimulated by the ACS for Treatment 1; whereas in Treatment 3, the lack of Elemental Sulfur resulted in a reduction of N in the soil that was loss to cell synthesis by soil microbes whose populations were increased by the use of ACS.

[7] National Hurricane Center. 03-Sep-2014. Hurricane Season Dates. NOAA/ National Weather Service. National Centers for Environmental Prediction.
http://www.nhc.noaa.gov/?epac

[8] Inglett, P. W., Reddy, R. K., Corstanje, R. Anaerobic Soils. 2005. University of Florida, Gainesville, FL. Elsevier Ltd. p. 72.
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[9] Martin, J. P. and Ervin, J. O. Oxidation of Sulfur in Soils. Jan. 1954. California Agriculture
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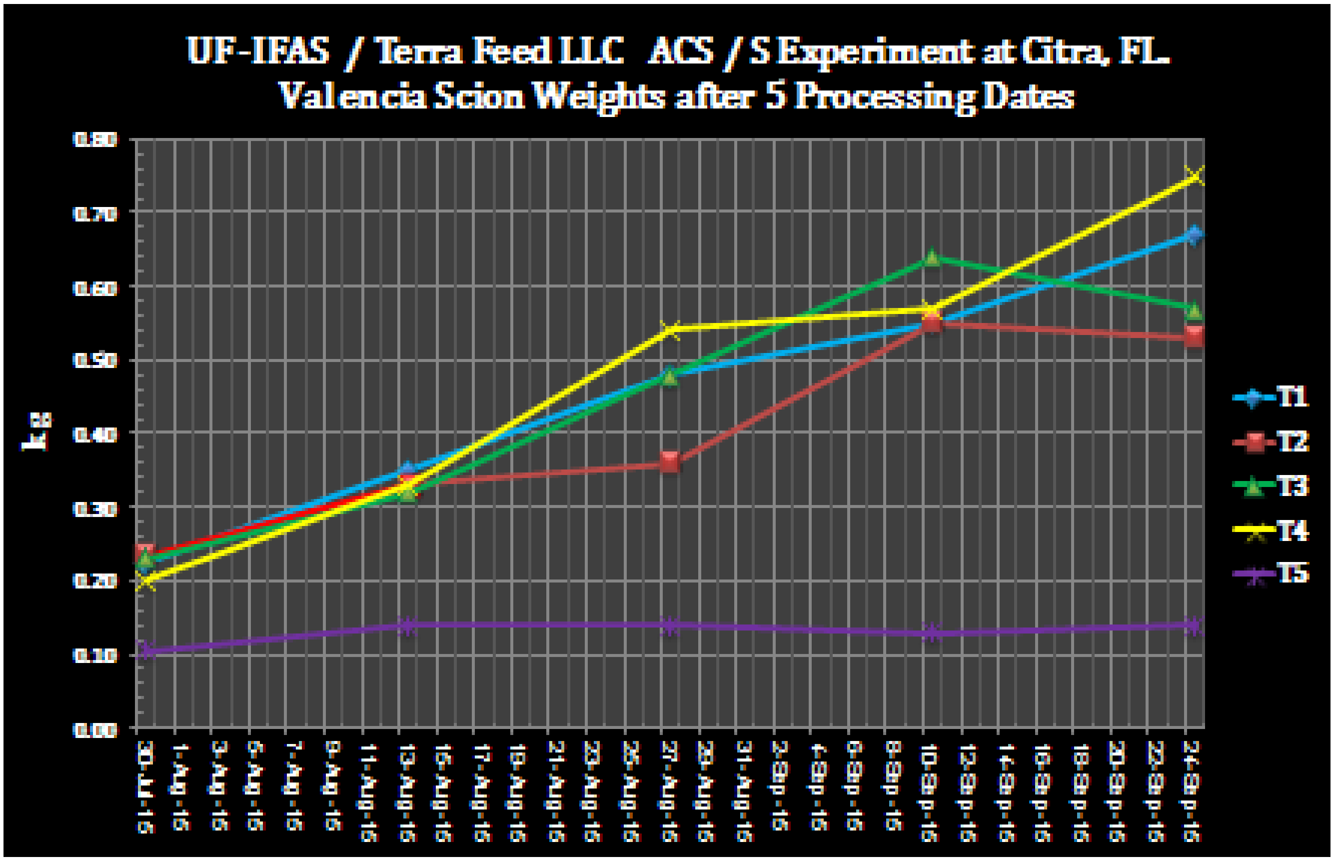
[10] Hardy, Sandra, Barkley, Pat, Creek, Andrew, and Donovan, Nerida. Impacts and Management of Flooding and Waterlogging in Citrus Orchards. March 2012. Department of Plant Industries, NSW, Australia.
Impacts and management of flooding and waterlogging in ...

Table 4 below lists all Treatments averaged root weight(s) by processing date. It should be noted that on the first processing date, July 30, 2015, only one tree was processed per Treatment; whereas on all other processing dates (noted in gray in the table) had two trees processed for the scheduled processing dates listed. On processing dates that had two trees processed per Treatment, the average weight of the two trees was recorded as the representative weight for each respectful Treatment. Table 4 below was used to create Graph 1 above.

Table 4. Summary of 'Swingle' Citrumelo Rootstocks Averaged Weights by Treatment over Time

Treatment	Processing Date	Tree(s) Average Root Weights (kg)
Control		
T5	30-Jul-15	0.54
Avg.	13-Aug-15	0.44
Avg.	27-Aug-15	0.61
Avg.	10-Sep-15	0.84
Avg.	24-Sep-15	0.58
5-0-7 Fertilizer + Elemental Sulfur		
T4	30-Jul-15	0.72
Avg.	13-Aug-15	0.74
Avg.	27-Aug-15	1.41
Avg.	10-Sep-15	1.69
Avg.	24-Sep-15	1.82
5-0-7 Fertilizer + ACS		
T3	30-Jul-15	1.52
Avg.	13-Aug-15	1.35
Avg.	27-Aug-15	0.95
Avg.	10-Sep-15	1.72
Avg.	24-Sep-15	1.39
5-0-7 Fertilizer Only		
T2	30-Jul-15	0.57
Avg.	13-Aug-15	0.90
Avg.	27-Aug-15	0.60
Avg.	10-Sep-15	1.53
Avg.	24-Sep-15	1.50
5-0-7 Fertilizer + ACS + Elemental Sulfur		
T1	30-Jul-15	0.57
Avg.	13-Aug-15	1.28
Avg.	27-Aug-15	1.04
Avg.	10-Sep-15	1.34
Avg.	24-Sep-15	1.80

Graph 2. Valencia Scion Growth over Time



Graph 2 above reflects a significantly different scenario concerning scion tree growth compared to rootstock growth noted above in Graph 1. In this case, all treated Treatments (T1 – T4) continued to increase in growth weight until the last processing date where both T3 (5-0-7 Fertilizer + ACS) and T2 (5-0-7 Fertilizer Only) showed a slight declined in scion weights whereas T1 (5-0-7 Fertilizer + ACS + Elemental Sulfur) and T4 (5-0-7 Fertilizer + Elemental Sulfur) continued to gain scion weight as expected. Unlike 'Swingle' Citrumelo rootstocks weights over time, 'Valencia' scion weights were not dramatically affected by the waterlogged soil conditions noted for the August 27th processing date; however, continued damp soil conditions appeared to have affected those Treatments that lacked the Elemental Sulfur component – namely T3 and T2. Again in this case, like rootstock performance noted above, T4 performed the best among all Treatments with all treated Treatment trees significantly outperforming the T5 Control as expected. Based on Graph 2, T3 scion weight declined in conjunction with rootstock decline for the last processing date; hence, damaged or stunted roots leads directly to stunted scion growth as noted by the Department of Plant Industries – NSW in Australia. [6] It is interesting that the Elemental Sulfur again counteracted the negative effects of waterlogged soil for the scion just has it had done for the rootstocks noted above; thus, as rootstocks continued to increase in weight for Treatments T1 and T4, so too did the Valencia scions weights.

Like Table 4 above, which listed all Treatments average root weight(s) by processing date, a separate table was also assembled to log average scion weight(s) by processing date as seen in Table 5 below. Also, like the root weight table above, excluding the first processing date of July 30, 2015 where only one tree was processed per Treatment, all other processing dates had two trees processed for the scheduled processing dates listed with the averaged weight of the two trees being the representative scion weight for each respectful Treatment for each processing date. Processing dates that had two trees processed are highlight in gray in Table 5 with this table being used to create Graph 2 above.

Table 5. Summary of ‘Valencia’ Scion Averaged Weights by Treatment over Time

Treatment	Processing Date	Tree(s) Average Scion Weight (kg)
Control		
T5	30-Jul-15	0.11
Avg.	13-Aug-15	0.14
Avg.	27-Aug-15	0.14
Avg.	10-Sep-15	0.13
Avg.	24-Sep-15	0.14
5-0-7 Fertilizer + Elemental Sulfur		
T4	30-Jul-15	0.20
Avg.	13-Aug-15	0.33
Avg.	27-Aug-15	0.54
Avg.	10-Sep-15	0.57
Avg.	24-Sep-15	0.75
5-0-7 Fertilizer + ACS		
T3	30-Jul-15	0.23
Avg.	13-Aug-15	0.32
Avg.	27-Aug-15	0.48
Avg.	10-Sep-15	0.64
Avg.	24-Sep-15	0.57
5-0-7 Fertilizer Only		
T2	30-Jul-15	0.24
Avg.	13-Aug-15	0.33
Avg.	27-Aug-15	0.36
Avg.	10-Sep-15	0.55
Avg.	24-Sep-15	0.53
5-0-7 Fertilizer + ACS + Elemental Sulfur		
T1	30-Jul-15	0.23
Avg.	13-Aug-15	0.35
Avg.	27-Aug-15	0.48
Avg.	10-Sep-15	0.55
Avg.	24-Sep-15	0.67

The final processing procedure for September 24, 2015 involved collecting leaf samples for all Treatment trees with the final step occurring after weighing the scions for all trees. Like the soil sampling noted above, two trees were processed per Treatment with the two trees leaves combined as a representative of the Treatment; hence, five total Treatments, five totals leaf samples for lab analysis by IFAS personnel. Only fully expanded leaves near the branch tips were utilized for sampling.