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Opportunities for Optimal Apple Production Management in Arid Conditions

Sam Johnson
Utah State University

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OPPORTUNITIES FOR OPTIMAL APPLE PRODUCTION MANAGEMENT IN ARID CONDITIONS

by

Sam Johnson

A thesis submitted in partial fulfillment
of the requirements for the degree of

MASTERS OF SCIENCE

in

Plant Science

Approved:

Teryl Roper, Ph. D. Major Professor	Brent Black, Ph. D. Committee Member
Grant Cardon, Ph. D. Committee Member	D. Richard Cutler, Ph.D. Interim Vice Provost of Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

2022

ABSTRACT

Opportunities for Optimal Apple Production Management in Arid Conditions

By

Sam Johnson, Master of Science

Utah State University, 2022

Major Professor: Dr. Teryl Roper
Department: Plant, Soils, and Climate

As the Intermountain West urbanizes, high quality agricultural land is being developed for commercial and residential purposes. This pushes agriculture to marginal lands that are frequently salty and apple trees do not tolerate saline soils. Thus, continuing apple production in Utah will require rootstocks that are salt tolerant. The USDA apple rootstock breeding program has produced some rootstocks that are putatively salt tolerant. These apple rootstocks were exposed to saline soil conditions in the greenhouse and in the field with M.9, a widely planted apple rootstock as the control.

In the greenhouse, a near continuous gradient dosing system exposed small apple trees to a gradient of calcium chloride concentrations ranging between an EC_e of one and six. All rootstocks tested showed reduced height, fresh weight, and dry weight with increasing salt concentration. Three orchards were established in 2018. Two locations had salty soil locations: Tintic with a calcium-based salt and Goshen with a sodium-based salt plus a non-salty control at Kaysville. After two years of orchard growth, all tested rootstocks performed best at Kaysville, followed by Tintic and Goshen, suggesting apple rootstocks are most susceptible to sodium based saline soils.

Bitter pit is a calcium related disorder of apples that often develops in storage. Affected apples have sunken dark spots on the peel and are unmarketable. The incidence of bitter pit is not uniform across apple rootstocks because apple rootstocks vary in their ability to partition calcium to fruit. Apples from 14 rootstocks in the 2014 NC-140 planting were examined for bitter pit incidence following storage at 4°C. In general, vigorous rootstocks showed lower peel calcium and a higher incidence of bitter pit following storage.

Tree suckers can potentially harbor disease and insects in orchards. Removing suckers is important but expensive because of the labor required. Finding other cost-effective ways can help growers. Paraquat, fire, naphthalene acetic acid, and urea ammonium nitrate (UAN) were compared along with water for sucker control. UAN provided excellent, but not long lasting, sucker suppression.

(86 Pages)

PUBLIC ABSTRACT

Opportunities for Optimal Apple Production Management in Arid Conditions

Sam Johnson

Apple trees are susceptible to biotic and abiotic stresses in the Intermountain West. The arid climate along with non-ideal soils make apple production challenging. Also, as high-quality agricultural land is developed, crop production gets pushed to land that often is saline. Apple trees grow poorly in saline soils. If apples are going to be grown in Utah, rootstocks must be identified that will tolerate saline soils. The USDA rootstock breeding program produced some rootstocks that may show salt tolerance. This project assessed the salt tolerance of these apple rootstocks in the greenhouse and in the field. Test rootstocks were compared to M.9, a widely planted apple rootstock. In greenhouse tests, a near-continuous gradient dosing system was used to screen 19 apple rootstocks for tolerance to calcium chloride salinity. All of the rootstocks showed a decrease in height, fresh weight, and dry weight as salt concentration increased. Three field test locations were used: Kaysville had minimal salt, Goshen had sodium salt, and Tintic had calcium salt. Over two seasons, field studies showed that sodium salts reduced tree height and trunk cross sectional area more than calcium salts. No rootstock performed significantly better than M.9 in either the field or greenhouse.

Bitter pit is a calcium related disorder of apples that often develops in storage. Affected apples have sunken dark spots on the peel and are unmarketable. The incidence of bitter pit is not uniform across apple rootstocks because apple rootstocks vary in their ability to partition calcium to fruit. Apples from 14 rootstocks in the 2014 NC-140 planting were examined for bitter pit incidence following storage at 4°C. In general, vigorous rootstocks showed lower peel calcium and a higher incidence of bitter pit following storage.

Tree suckers can potentially harbor disease and insects in orchards. Removing suckers is important but expensive because of the labor required. Finding other cost-effective ways can help growers. Paraquat, fire, naphthalene acetic acid, and urea ammonium nitrate (UAN) were compared along with water for sucker control. UAN provided excellent, but not long lasting, sucker suppression.

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Chapter 1

INTRODUCTION TO THE PROBLEM

Irrigation has been used in agriculture for at least 2,500 years (Postel, 1989). Irrigation allows unproductive arid land to become more productive. Irrigation is a vital part of modern agriculture worldwide. The United States contains roughly 396 million acres of crop land with 58 million of those acres irrigated. Thus, irrigated land accounts for nearly 15% of all crop land in the US (National Agricultural Statistical Service, 2019). Arid environments are most commonly irrigated and these dry areas are less prone to disease problems.

However, irrigation water naturally contains soluble salts and these salts are left in the soil as water infiltrates, evaporates, and is transpired by plants, leading to increasing soil salinity (Corwin & Lesch, 2003; Zhemukhov, 2018). Thus, salt concentrations increase in the rooting zone of plants in irrigated agriculture over time. Besides salt that is applied to the soil via irrigation, many soil parent materials naturally contain salts and these are released when weathering occurs. Soil amendments added to improve soil may also contain salts (Kotuby-Amacher, 2000). Organic amendments like animal manure and compost can also add salts, depending on its origin. Care needs to be taken when choosing these amendments. Without care, copious quantities of salt could be added to the soil along with ammendments. Choosing fertilizers with low salt indices can help reduce the amount of salt that is applied to soils each year. Using nitrogen as an example, ammonia has the lowest salt index of 47.1 compared to using UAN which has a salt index of 71.1 (Mortvedt, 2001). Higher concentrations of salts will be applied as fertilizer is banded in the tree row.

Soil salinity leads to crop injury and decreased productivity. When soil salinity increases, soil osmotic potential decreases and the quantity of plant available water is reduced. This limits the ability of plant roots to take up water from the soil (Bernstein, 1975; Mahajan, 2005). Salinity can be toxic for some crops depending on crop tolerance to saline conditions and this can limit plant diversity (Lauchli, 2014). Plants exhibit variability in their ability to withstand saline conditions. Soil salinity is measured and expressed as electrical conductivity (EC) (Corwin & Lesch, 2003). Agronomic crops like barley can tolerate salinity to an EC as high as 17 dS/m and high salinity will only limit the yield by 50%. On the other hand, crops like apples may have a 50% yield reduction at EC values of 4.8 dS/m (Kotuby-Amacher, 2000). Thus, ideal sites for apple production are limited to those with low soil EC.

Productive agricultural land is being developed for non-agricultural uses as worldwide populations increase. The population of Utah has increased by 210% over the last 50 years (National Agricultural Statistical Service, 2019). In Utah, the land area devoted to fruit production has been lost at an average annual rate of 2.5% over the last 8 years (Utah Department of Agriculture and Food, 2017).

In the past, salinity issues have been partially overcome by reclaiming soil by leaching salts through the soil profile and breeding salt tolerant varieties (Shannon, 1997). In some situations, irrigation water can be used to leach salts through the soil profile so they are below the root zone (Kotuby-Amacher, 2000). When genetic variation in salt tolerance exists within a crop species, that trait can be moved through classical plant breeding into breeding lines and then into commercial cultivars. Multiple generations are required to isolate the beneficial gene and to backcross it, allowing for the beneficial trait to be implemented into commercially valuable cultivars (Council for Agricultural Science and Technology, 2017).

Apples (*Malus* x *domestica* Borkh.) are believed to have been domesticated between 4,000 and 10,000 years ago in the Tian Shan Mountains of Central Asia. Apples then moved along the Silk Road to Europe. Over time, apple trees cross pollinated with wild crab apple trees from Siberia (*M. baccata* (L.) Borkh.), Caucasia (*M. orientalis* Uglitz.), and Europe (*M. sylvestris* Mill.) (Duan, 2017). These natural crosses led to hybrid vigor and better-quality apples started to emerge. There is evidence that grafted apples were used in the third millennium BCE in the Middle East (Schlumbaum, 2012). Trees in modern apple orchards are produced by grafting a scion cultivar to a rootstock. Both scion and rootstock are important. The scion produces fruit with specific traits such as flavor, size, sweetness, color, and disease resistance. The rootstock provides size control, precocity, cold hardiness, and the ability to withstand biotic and abiotic stresses. Thus, apple research requires that both scion and rootstock be tested for the various traits they may impart to the mature tree (Crassweller & Shupp, 2018).

Over the past 50 years many apple rootstocks have been produced and released from breeding programs in the United States and abroad. Most have been tested by the multi-state research project NC-140 (Marini, 2016). However, this program is primarily interested in rootstock vigor and climate adaptability. Salt tolerance has not been a part of the NC-140 standard protocols. If genetic variation exists for salt tolerance in the diversity of apple rootstock germplasm, orchards might be planted in locations that are otherwise good quality, but have soil salinity problems. This may include temperate locations in Mexico, South America, Central Asia, and Africa. Potentially, this could help these locations develop apple production that would be beneficial to their economies and their people. What is needed is a quick and accurate method to screen apple rootstock germplasm for tolerance to saline conditions. Many new rootstocks have been developed over the last 45 years and very few of them have been tested for salt tolerance. A new standard is needed to select apple trees that can be grown in Utah's semi-arid, gypsiferous, and calcareous soil and the associated water conditions. With this in place it would be easy to see if genetic diversity exists in apple germplasm that is salt tolerant and could be used for continued breeding and use.

Chapter 2 discusses the development and validation of an automated system used to screen apple rootstocks for tolerance of saline conditions. Chapter 3 presents how putatively salt tolerant apple rootstocks grow in orchard conditions when exposed to ideal growing conditions, soil that is high in calcium salts, or soil that is high in sodium salts.

Chapter 4 looks at how rootstock calcium uptake affects apple storage and bitter pit. Bitter pit was first classified in Germany and called Stippen (Jaeger, 1869). It was later renamed "bitter pit" by Nathan Cobb (Faust, 1968). Bitter pit is when the cells on the outermost part of the fruit begin to break down and decay. Bitter pit can be seen at harvest, more commonly on lighter colored fruit, but is more common after removing fruit from storage. Bitter pit is most commonly found on the calyx end of the fruit (Faust, 1968).

Bitter pit typically develops in storage. This can become a major problem for producers who put an apparently quality crop into cold storage in the fall yet when the crop is removed from storage, much of the fruit is unmarketable. Calcium deficiency in the fruit is the primary cause of bitter pit. Before calcium was found to be the primary cause, conditions like hot dry weather, irregular irrigation, heavy pruning, and thinning were thought to be responsible (Ferguson, 1980).

Trees that have low available calcium have higher levels of bitter pit and trees with higher amounts of available calcium have less incidence of bitter pit (Jemrić, 2016). Foliar sprays have been used to supplement the amount of calcium available to the plant. Calcium applications need to be made at low doses throughout the growing season as calcium uptake through lenticels or the cuticle is low. When using chemicals, growers have to be mindful of what type of calcium to use and when to make applications. If calcium chloride is used, it can limit fruit coloring, thus reducing quality (Cline, 2021).

Apple cultivars vary in their ability to partition calcium to fruit. Often, this is a result of lost xylem function. (Miqueloto, 2015). Rootstocks can also be a contributing factor. Rootstocks that are more vigorous are more likely to result in bitter pit as more calcium is partitioned to vegetative growth instead of fruit.

Chapter 5 looks at a method of controlling root suckers for growers. Crown suckers are shoots that grow from the base of the tree and root suckers can grow away from the base of the tree from shallow roots. Some rootstocks are more likely to produce suckers than others. Suckers create a management problem for growers. If there aren’t many, they can be pruned off during dormant pruning. If they are profuse multiple trips may be needed across the field to manage the suckers. Pruning by hand can be very expensive. Finding other more cost-effective methods of management would be beneficial for intermountain west growers.

Chemical sucker control has been practiced for decades. Naphthalene Acetic Acid (NAA) is widely used to limit the growth of suckers. NAA is a synthetic auxin plant growth regulator that shortens internodes on plants, keeping suckers that grow lower to the ground but not removing them. Multiple contact herbicides are also registered for sucker management (Smith & Gutierrez, 2014). Herbicides vary in effectiveness and can be dangerous to new green tissues. Thus, extra care must be used on new trees. Suckers can also be an access point into the tree for systemic herbicides applied for weed control and can be a place for insect and disease pests to live. We tested a new technique for sucker management using desiccants. Applying urea-ammonium nitrate (UAN) as a foliar spray on the UAN removes water from plant tissue, acting similarly to a contact herbicide but without the potential for tree damage. Along with the reduction is suckers it also provides nitrogen to treated trees.

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Chapter 2

COMPARING APPLE ROOTSTOCKS FOR SALT TOLERANCE USING A LOW VOLUME NEAR-CONTINUOUS GRADIENT DOSING SYSTEM

Abstract

Apples (*Malus x domestica* Borkh.) are a valuable crop that have a low tolerance for saline conditions. This limits where apple trees can be grown. Being able to rapidly test new rootstocks for salt tolerance would hasten the process of rootstock evaluation. Previous field work required substantial time and expense, limiting the number of replicates that could be done. Rapid testing for salt tolerance is needed to select for those traits. A double emitted source (DES) irrigation system was built to impose a gradient of salt concentrations on selected rootstocks to find salt tolerance. This test was run on 19 different apple rootstocks to see if salt tolerance exists. None of the tested rootstocks performed better than the control and all saw reduced growth in response to higher salt concentrations.

Introduction

Crop success is complex and requires genetic, environmental, and management skills to survive along with adaption to abiotic stresses in its living condition (Shannon, 1997). Salinity, nutrient deficiency, drought, and loss of organic soil carbon and microflora are becoming more common in agricultural land, especially land that has been farmed for many years (Rietz, 2003). Tolerance studies have been used for many years to determine crop species and cultivars that can produce high yields under adverse conditions. Before tolerance studies, plants that grew well in a region were collected and seeds were replanted. This limited the diversity of crops that would be grown in an area. Identifying crops adapted to a range of local conditions is a critical part of maintaining global food supplies. Salinity impacts agriculture as it leads to crop injury and decreased productivity. When salinity increases, the osmotic potential of soil decreases and the quantity of plant available water is reduced. This limits the ability of plant roots to take up water from the soil (Bernstein, 1975). When salts dissolve in water, ions like chloride can be taken up and are stored in the leaves until they reach toxic levels and leaf scorch occurs (Bricault, 2021).

Previous salt tolerance studies were time consuming and costly due to the complexity of replications and treatments (Levy, 1999). Aragues et al. (1999) analyzed many types of delivery systems previously used in tolerance studies. The various systems were referenced by many names but Aragues et al. simplified them to three different types of systems: drip irrigation systems, sprinkler applied, and double emitted source. The drip irrigation system consisted of a single line for irrigation into which solution is mixed prior to being injected into the irrigation line and water is controlled by emitters in the line. Sprinkler applied irrigations are done by laying out two or three lines and treatments are mixed in the air. This allows for different levels of treatment across the plots. This method is more commonly done in agronomic crops and can be challenging on tree crops because of size (Frenkel, 1990). The final type is double emitted source (DES) or double drip line systems. These systems require two mainlines. One has a control solution and the other has treatment solution. Drip emitters are then used to create different treatments with a combination of solutions from both lines that are ‘mixed’ in the plant pot (Aragues, 1999). This system is not well suited to field applications as variation in distribution of the salt (or other treatment) can exist spatially. However, in a controlled volume of soil this can be overcome easily with sufficient water (DeMalach 1996; Levy, 1999). Using a DES system, a near continuous gradient dosing system (NCGDS) was created to increase the number of treatments that could be tested at a given time while reducing workload and improving accuracy of the study (Hawks et al, 2009).

The USDA Apple Rootstock Breeding program was initiated in 1968. The objectives of this project are to develop productive and disease resistant apple rootstocks using modern breeding and selection techniques. They are also searching for resistance to abiotic and biotic stresses (Fazio, 2020). The ‘Root2Fruit’ initiative was created to support the work of the USDA apple rootstock breeding program by hastening the pace of apple rootstock evaluation to rapidly get new releases into the hands of apple producers.

The purpose of this phase of the study was to screen rootstocks from the USDA apple rootstock breeding program in a greenhouse for salt tolerance similar to conditions you would find in Utah’s calcareous semi-arid soil conditions.

Methods

A double source drip irrigation system was built in a greenhouse. Logan City culinary water was filtered using an 80-micron filter before entering the system. Stock nutrient solution was made by mixing 1.44 kg Peters Excel 21-5-20 multipurpose fertilizer (ICL, St. Louis, MO), 0.3 grams EDDHA iron, 0.22 kg $MgSO_4$, and 30 L of water. Nutrient solution was injected into the mainline using a commercial injector with a 1:100 dilution (Dosatron D14MZ2; Dosatron, Clearwater, FL). The main supply line was then split. One half was used as the supply line for the control nutrient treatment. A second stock mixture was created mixing 10 L of water with 4.5 kg of calcium chloride, dihydrate (Hi Valley Chemical, Centerville, UT). The second half was sent through a second identical Dosatron which added calcium chloride from the stock solution and then went to the supply lines for treatment. The electrical conductivity (EC) of the salt solution in the line was about 8.1 dS/m. This allowed for one line to be nutrient solution and the other to be nutrient solution mixed with calcium chloride salt. Lines were pressurized at 103 kPa (15 PSI). A diagram of the dosing system is shown in Fig. 2.1

The greenhouse was divided into six zones. Each zone was composed of two lines (nutrient and nutrient plus salt) connected to a main line running perpendicular to the supply lines. Irrigation for each zone was controlled by a solenoid valve for each line, but the two valves were wired together to a sprinkler controller (Hunter X Core controller, Hunter Industires, San Marcos, CA) so that nutrient and nutrient plus salt solution were delivered to the pots in each zone simultaneously. Irrigation was set for an interval of one minute twice a day at 12-hour intervals.

Treatments were established using various combinations of drip emitters installed in each of the two lines. Rain bird Xeri-Bug pressure-compensating emitters (Rain Bird Corp., Tucson, AZ) were used to create the salt gradient among the treatments. The desired total output per pot was 53 L/h or approximately 0.88 L per one-minute irrigation cycle. Eight treatment options were created using combinations of emitters. Three replications of each treatment were randomized within each of the six zones. Emitter combinations and leachate (ECe) are shown in Table 2.1. Calcium chloride was used for salinity treatments in this experiment to mimic soil chemical conditions that are present in highly calcareous soils that are common in the Intermountain West (Kutilek, 2015). Calcium chloride was chosen over sodium chloride because calcium is beneficial for the plant where chloride is not. This allowed for a less harsh environment for the study to see if any salt resistance was present in the putatively salt tolerant rootstocks.

Bare-root apple rootstocks were provided by the USDA Apple Rootsock Breeding Program in Geneva, NY. A total of 19 different rootstocks were tested using this system with M.9 RN29 as a control. Rootstocks were cut to 30 cm and were planted in 10-liter pots in Sunshine Mix #2 (Sungro, Agawam, MA). Rootstocks were grown for 40 days before treatments were imposed. Only one bud was allowed to grow per rootstock. For each rootstock tested, plants were assigned at random to one of eight treatments with three replications. Plants assigned to treatments were randomized across the greenhouse floor. Treatments were laid out in a randomized complete block design. The combination of emitters from the nutrient and the salt lines were placed in the pots and the system was run for 50 days. During the course of the treatment, solute and leachate samples were collected. Nutrient solution or nutrient solution plus salt was collected in a plastic cup and electrical conductivity was immediately measured using a DiST®4 Waterproof EC Tester (Hanna Instruments USA, Smithfield, RI). For each cycle we collected leachate using pot saucers placed under each pot and the EC of the leachate was measured with the same EC meter immediately after collection. In the 2019 growing season, leaf disks were taken using a 200 mm^2 punch. Ten disks were taken from each plant with 5 discs collected from each sampled leaf.

At the end of the treatment, the length of shoot growth from the bud was measured. The top of the plant from bud break was separated from the planted rootstock liner and fresh weight was measured. The roots were washed clean and allowed to air dry before measuring fresh weight. Both roots and tops were dried in a forced air dryer at 60°C for 28 hours, then dry weights were taken. Treatments low (1), medium (4), and high (8) had all of the leaves removed from the dry samples. The dry leaves were ground to 1 mm using a Wiley Mill (Thomas Scientific, NJ). Samples were digested using the Nitric acid/Hydrogen Peroxide Wet Ashing Open Vessel method (Miller, 2013).

Trial rootstocks were compared against M.9 RN29. Plant growth was compared using a linear mixed model. Analyzing the ICP data group means comparisons were conducted using PROC CLIMMIX with Dunnett method to adjust multiplicity.

Results and discussion

Data collected in 2018 showed non-constant variance and thus required a log transformation of the data to make the model assumptions hold and validate model results. Data collected in 2019 showed a constant variance, thus the data were not transformed.

While the treatment system was set up to supply mixtures of nutrient solution and salt solution in discrete amounts related to the mixture of the emitters used, the data were analyzed based on the salt concentration in the leachate solution. During the treatments, the solution going into the pots (solution) and the water leaving the pots (leachate) were collected and compared for each pot. The correlation factor for incoming solution and leachate had an R^2 value of 0.80, indicating a high degree of correlation.

Overall, the slopes of the regression lines modeling the response of rootstocks to increasing salinity were all negative and the slopes of the lines were not significantly different among the rootstocks tested (Figures 2.3-2.5). Figure 2.2 shows the difference between the control M.9 and 84R5P2-062. It appears as if the high salt, treatment 8, on 84R5P2-062 performs as well under high salt conditions as under no salt (normal) conditions. Though it looked this way from the image, the growth was consistent with all rootstocks. Growth of M.9 declined as salinity increased, as expected.

Plant height, was measured from the point of bud break on the rootstock to the tip of the new growth, Plant height was not different for any rootstock relative to salt exposure (Figure 2.4). Vigor of the rootstocks and the amount of growth the plants varied (Table 2.6).

Fresh and dry weights of the roots varied among rootstock, but not in relation to salt exposure. As pot salt concentration increased, both root fresh weight and dry weight decreased. The slopes of the lines were not different among the rootstocks tested (Fig 2.3 & 2.5).

Leaf disks were taken in 2019 and compared among the rootstocks to see if salinity changed specific leaf weight (weight/area). Specific leaf weight (SLW) did not vary among rootstocks or among treatments (data not shown).

The beginning weight of the 30 cm rootstock that was planted had a significant effect on final shoot length, shoot fresh and dry weight, and root fresh and dry weight. When the initial liner weight was large, the growth resulting from that growth was also large and vigorous. Plants with a higher amount of initial reserves grew large plants but still saw the decline in growth in response to the salt concentration.

Shoot length at 40 days varied significantly. Planted rootstocks that had larger shoots from the beginning were more likely to grow large plants. There was still a negative slope of growth relative to salt exposure for these trees.

Leaf samples were taken at plant harvest and twenty-five elements were measured by Induced Coupled Plasma (ICP) analysis and 11 were subjected to statistical analysis to see if mineral composition varied among rootstocks by salt exposure. All of the minerals were examined to see if any correlations occurred between rootstock and treatment to find germplasm that may be more efficient at mineral element uptake. There were no significant differences (Table 2.2). Boron, calcium, potassium, magnesium, potassium, and sulfur were significant when looking at individual tree type concentrations. Calcium, potassium, magnesium, and zinc were all had different concentrations across the treatments (Figure 2.2). Group means comparisons were made to see if significant differences existed in the concentration of each mineral element compared to M.9. Tables 2.3, 2.4, and 2.5 show the results of the comparisons. Most rootstocks performed similarly to M.9. Both higher and lower mineral concentrations can be seen across the different samples ($p<0.05$).

Summary

A near-continuous gradient dosing system was used to screen 19 different apple rootstocks to test for salinity tolerance. All of the rootstocks showed a decrease in growth with an increase in salt concentration. No rootstocks performed significantly better than the control M.9 in this study. As calcium salinity isn’t the only type of salt found in the Intermountain West, continued research needs to be completed looking at sodium salinity and its effects on the rootstocks. From current studies no rootstocks could be suggested as a way to mitigate the effects of saline conditions for growers in the intermountain west.

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Table 2.1 Treatment levels and drip emitter combinations to provide nutrient and nutrient plus salt solutions.

Treatment Level	Emitter Combination[1]		Solute EC_e	Leachate EC_e
	Nutrient L/h	Nutrient + Salt L/h	(dS/m) mean ± SE	(dS/m) mean ± SE
1	53.0	0	1.05 ± .05	.89 ± .04
2	45.4	7.6	1.87 ± .09	1.87 ± .15
3	37.8	15.2	2.91 ± .18	2.55 ± .12
4	30.3	22.7	3.25 ± .12	3.17 ± .11
5	22.7	30.3	3.92 ± .16	4.08 ± .11
6	15.2	37.8	4.69 ± .12	4.65 ± .19
7	7.6	45.4	5.58 ± .08	5.78 ± .17
8	0	53.0	6.22 ± .06	6.60 ± .08

[1] Emitters of noted manufactured-specified flow rates were combined to achieve desired flow rates.

Table 2.2 ICP Mineral analysis of the rootstocks grown in the greenhouse showing significance and interactions.

Overall Significance of Leaf Tissue Mineral Compositions (units are in parts per million: ppm)

Mineral Concentration	Tree Type	Treatment	Interaction Effect
B	x		
Ca	x	x	
Cu			
Fe			
K	x	x	
Mg	x	x	
Mn	x	x	
Na			
P	x		
S	x		
Zn		x	

Significance marked with an x at a α = 0.05.

Table 2.3 – Comparison of the low salt treatment (1) of mineral analysis of greenhouse grown apple rootstocks. Bold text shows concentrations that are significantly different than the M.9 control (all units are parts per million: ppm).

	Treatment 1 - Differences of Tree Types Interactions with Treatment Compared to M.9										
Rootstock	B	Ca	Cu	Fe	K	Mg	Mn	Na	P	S	Zn
4218	0.53	**203.47**	1.52	1.31	329.32	53.92	0.54	0.32	88.66	46.49	0.56
4288	0.52	279.19	1.36	1.50	**342.74**	55.61	0.42	0.45	91.30	45.33	0.50
4809	0.66	280.99	1.11	8.99	423.03	59.17	0.72	0.40	**108.53**	**56.13**	**1.01**
6874	0.55	**222.23**	0.80	1.74	366.04	55.26	0.53	0.39	69.94	42.28	0.64
84R5P2-062	0.49	**215.94**	0.65	1.33	**323.17**	57.47	0.68	0.39	80.65	44.76	0.51
85SA22-12R	**0.78**	**191.79**	0.44	1.16	**279.28**	**39.47**	**1.23**	0.47	75.97	31.24	0.34
85SA22-34R	**0.99**	**208.73**	0.58	1.01	**254.98**	46.71	**0.98**	0.28	71.30	31.02	0.28
85SA22-6R	**1.07**	**262.18**	0.83	4.82	**249.13**	54.52	**1.13**	0.67	92.08	37.28	0.46
85SA22-84R	**0.81**	**217.56**	0.67	1.18	**241.63**	**43.93**	**1.08**	0.33	72.95	32.42	0.33
92(239)20-7	0.59	**213.37**	0.89	1.26	**318.13**	**45.08**	0.40	0.30	61.10	37.77	0.50
M.9	0.52	277.61	0.97	2.17	423.55	58.24	0.59	0.47	71.25	37.17	0.46

Significant at a α = 0.05.

Table 2.4 – Comparison of the medium salt treatment (4) of mineral analysis of greenhouse grown apple rootstocks. Bold text shows concentrations that are significantly different than the M.9 control (units are in parts per million: ppm).

Treatment 4 - Differences of Tree Types Interactions with Treatment Compared to M.9											
Rootstock	B	Ca	Cu	Fe	K	Mg	Mn	Na	P	S	Zn
4218	0.53	224.64	0.82	1.26	302.82	40.59	0.74	0.26	84.37	37.50	0.73
4288	0.48	298.53	1.48	1.63	**281.90**	40.61	0.71	0.35	87.09	**46.43**	0.67
4809	0.51	**326.10**	0.72	1.62	366.07	48.93	0.72	0.36	**113.37**	**52.30**	0.77
6874	0.56	249.34	0.90	1.84	338.02	47.24	0.83	0.72	66.12	**41.58**	0.85
84R5P2-062	0.45	266.60	0.41	1.20	298.09	50.45	0.80	0.23	60.83	38.77	0.56
85SA22-12R	**0.91**	258.93	0.50	0.99	**229.74**	**36.15**	1.15	0.35	77.06	31.05	0.34
85SA22-34R	**0.99**	270.39	0.34	1.06	**231.12**	**34.10**	1.24	0.26	86.62	30.87	0.46
85SA22-6R	**0.92**	280.65	0.40	0.96	**214.62**	**33.71**	1.21	0.32	77.46	29.72	0.40
85SA22-84R	**0.89**	264.37	2.53	7.35	**261.92**	39.73	1.37	0.43	64.64	34.92	0.81
92(239)20-7	0.54	240.92	1.11	1.12	327.76	**36.15**	0.65	0.36	65.77	**44.28**	0.73
M.9	0.48	236.98	0.74	1.23	367.41	49.19	0.88	0.30	69.99	32.36	0.5

Significant at a $\alpha = 0.05$.

Table 2.5 – Comparison of the high salt treatment (8) of mineral analysis of greenhouse grown apple rootstocks. Bold text shows concentrations that are significantly different than the M.9 control (units are in parts per million: ppm).

Treatment 8 - Differences of Tree Types Interactions with Treatment Compared to M.9											
Rootstock	B	Ca	Cu	Fe	K	Mg	Mn	Na	P	S	Zn
4218	0.52	314.22	0.79	1.34	324.86	**36.89**	1.05	0.33	78.74	43.65	0.84
4288	0.50	335.78	1.25	1.61	**295.10**	**37.48**	0.96	0.49	73.73	42.64	0.70
4809	0.46	**365.36**	0.92	1.57	368.37	48.65	1.06	0.42	95.73	46.03	0.83
6874	0.57	319.80	1.12	1.61	336.76	44.80	1.32	0.40	73.74	43.02	1.01
84R5P2-062	0.51	314.18	0.64	1.23	**310.90**	42.09	1.12	0.40	**57.18**	31.51	0.69
85SA22-12R	**0.94**	346.35	0.46	0.99	**209.63**	**36.33**	1.92	0.40	73.33	**27.87**	0.43
85SA22-34R	**0.97**	358.03	0.42	1.03	**229.75**	**35.64**	**2.21**	0.41	88.86	31.05	0.41
85SA22-6R	**1.08**	351.80	0.75	1.09	**212.81**	**30.97**	1.73	0.41	85.34	31.40	0.49
85SA22-84R	**0.92**	344.55	0.41	6.95	**203.60**	44.36	1.89	0.44	72.94	31.12	0.69
92(239)20-7	0.51	286.03	0.75	1.19	**293.94**	**30.60**	0.81	0.37	**58.19**	37.25	1.03
M.9	0.50	277.61	0.95	1.41	386.63	49.94	1.24	0.41	78.16	37.99	0.74

Significant at a α = 0.05.

Table 2.6 – Comparison of rootstock mean growth after 90 days including the entire range of salt exposures. One bud was left to grow on each rootstock with height measurements taken at the point of bud break. Destructive harvest was done to measure the bud growth along with the root growth. Standard error is shown with measurements.

	Rootstock Average Growth		
Rootstock	Mean Length of Shoot Growth ± Standard Error (cm)	Mean Tree Dry Weight ± Standard Error (g)	Mean Root Dry Weight ± Standard Error (g)
4004	79.5±11.3	34.00±12.18	22.50±8.53
4218	79.0±15.9	34.70±17.23	17.00±12.06
4288	115.3±9.2	97.43±9.95	34.00±6.97
4292	78.0±9.2	26.67±9.95	10.67±6.97
4809	82.0±9.2	64.80±9.95	21.67±6.97
5257	102.0±9.2	35.67±9.95	13.33±6.97
6874	92.0±7.1	61.00±7.71	24.60±5.40
84R5P2-062	100.0±7.1	64.58±7.71	35.80±5.40
85SA22-12R	49.3±9.2	17.73±9.95	19.00±6.97
85SA22-34R	46.7±9.2	15.43±9.95	27.00±6.97
85SA22-5R	75.0±11.3	13.00±12.18	13.67±6.97
85SA22-6R	63.7±9.2	22.83±9.95	45.33±6.97
85SA22-84R	54.0±6.5	16.60±7.71	23.00±5.40
92(239)20-7	87.8±6.5	45.55±7.03	19.50±4.93
92650P-4	123.7±9.2	52.33±9.95	18.67±6.97
9265EM-2	53.5±11.3	16.00±12.18	12.50±8.53
G65	91.5±8.0	25.25±8.62	14.00±6.03
M.9	84.3±4.6	45.59±4.97	42.92±3.48

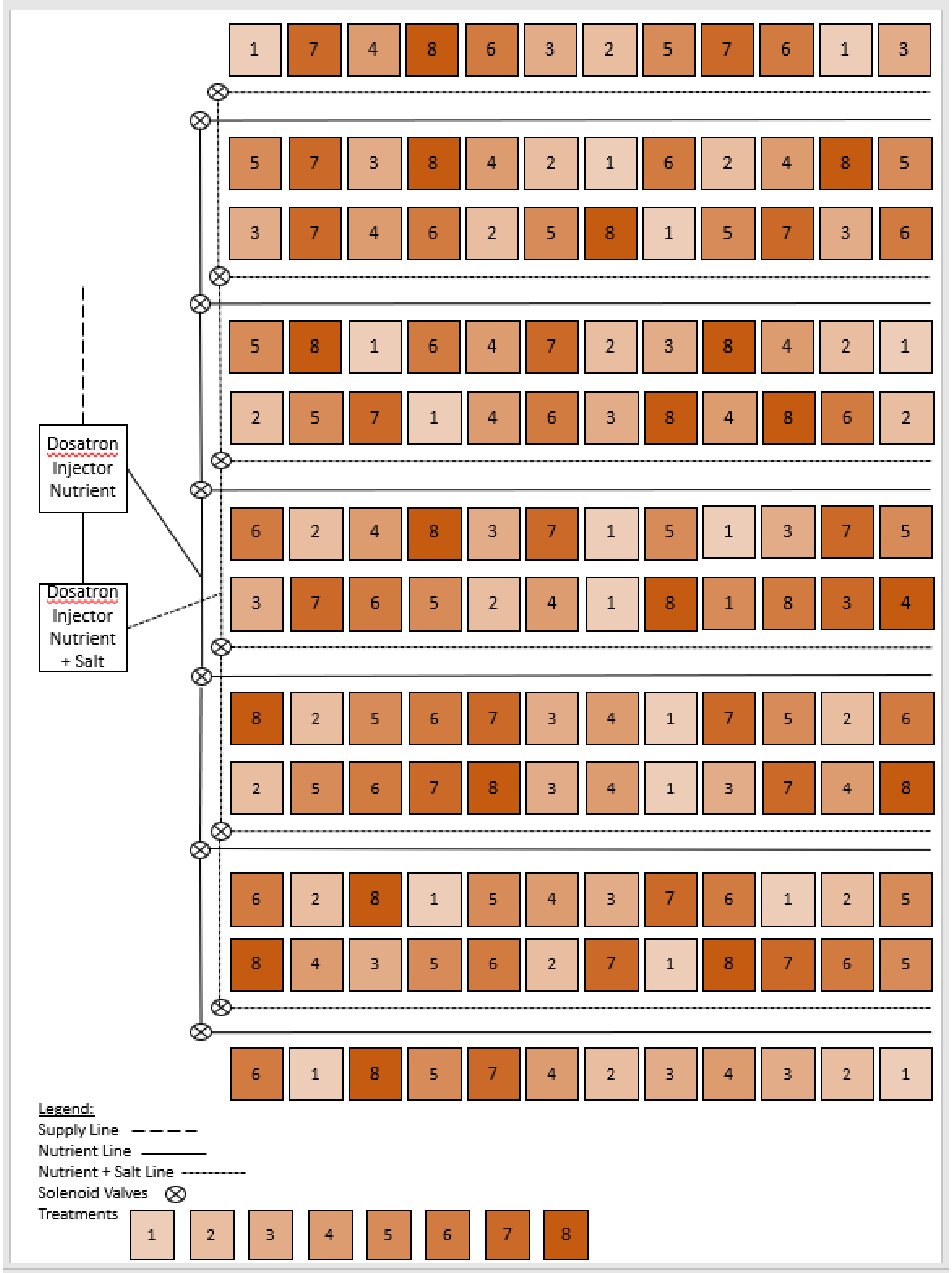

Fig. 2.1 Plumbing schematic for the near-continuous gradient dosing system. All of the levels of treatment received 53 liters per hour irrigation at different nutrient and nutrient + salt levels.

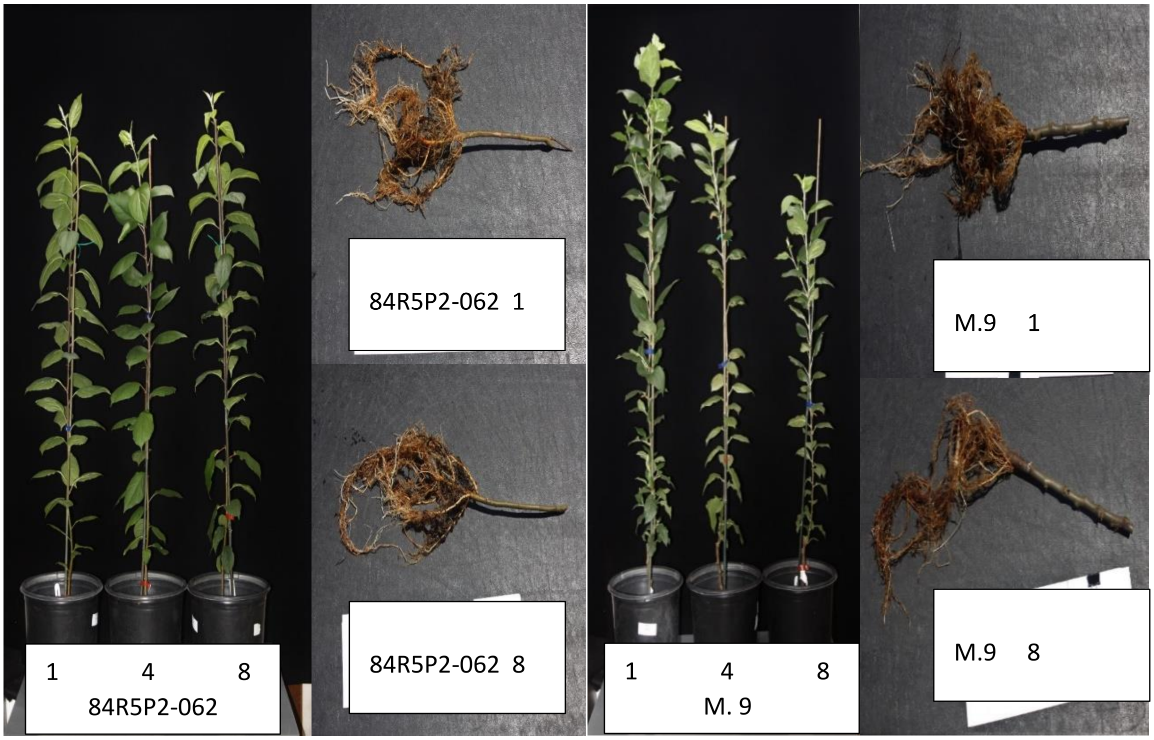

Fig. 2.2 Visual comparison of rootstocks M.9 and 84R5P2-062. Treatment one having only nutrient solution (low salt) and treatment eight having only nutrient solution + salt (high salt).

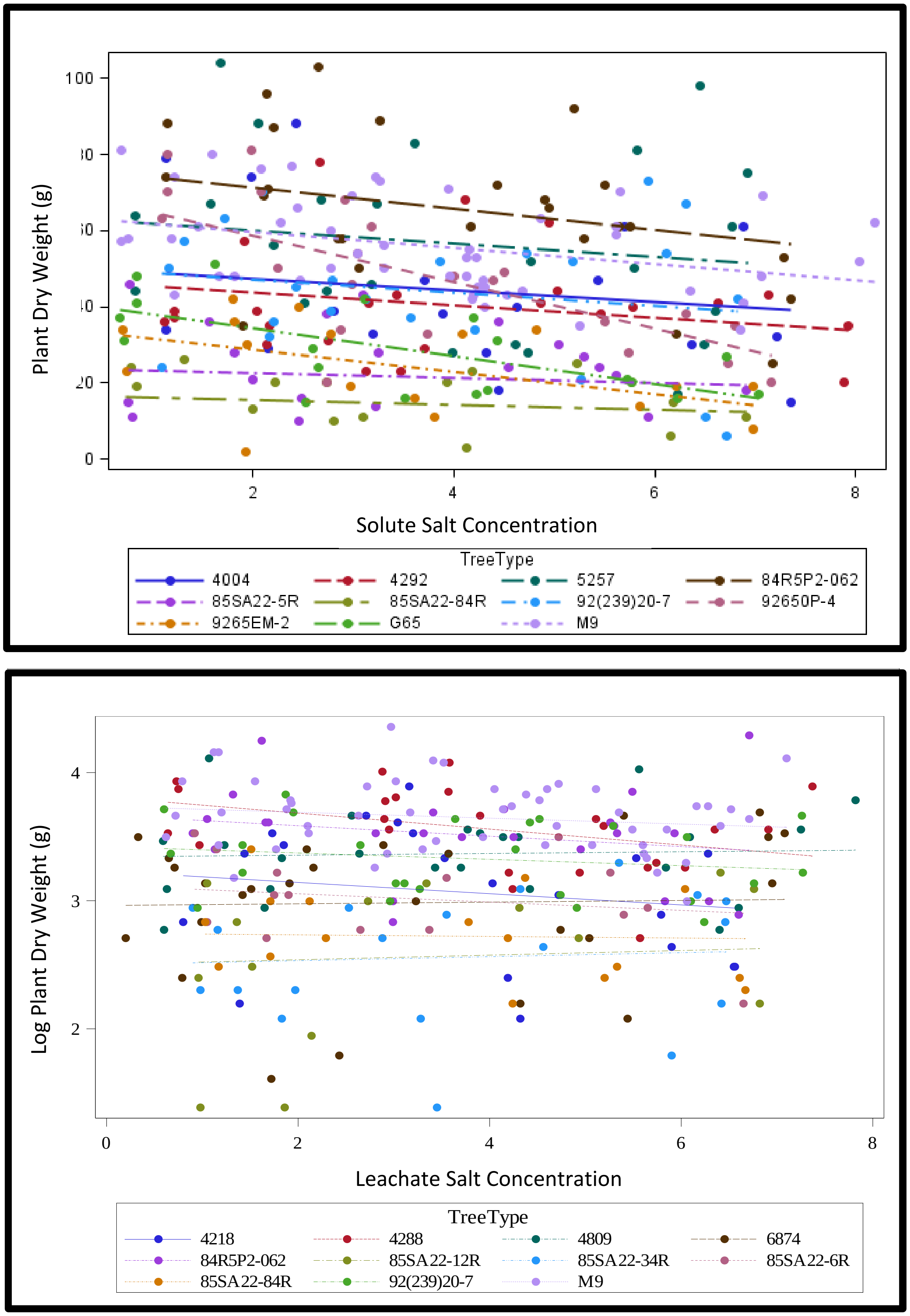

Figure 2.3 – Relationship between plant dry weight and salt exposure for apple rootstocks in a near continuous gradient dosing system. The slopes of the lines for all rootstocks tested are not significantly different. Statistical analysis using linear mixed model in SAS.

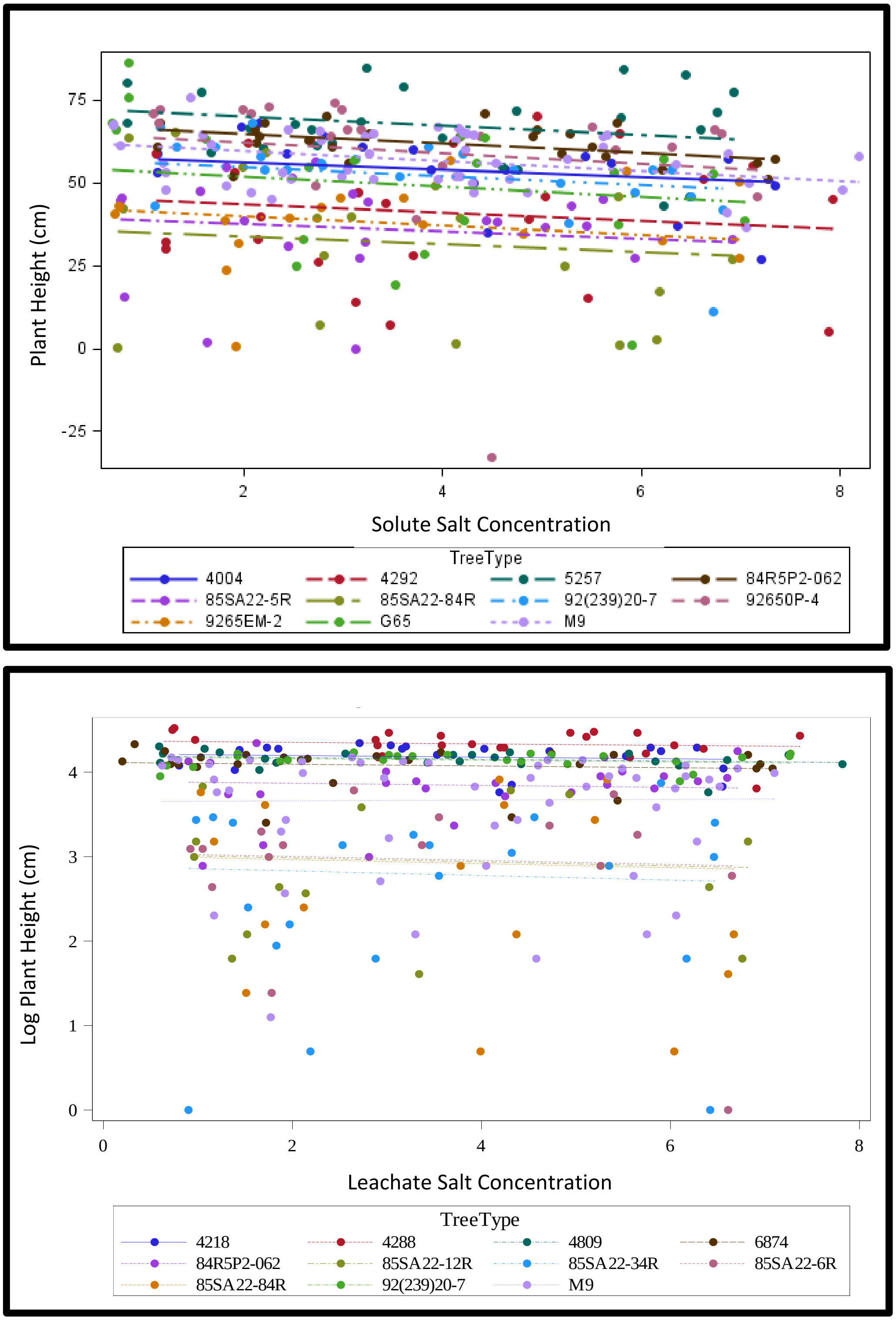

Figure 2.4 – Relationship between plant height and salt exposure for apple rootstocks in a near continuous gradient dosing system. The slopes of the lines for all rootstocks tested are not significantly different. Statistical analysis using linear mixed model in SAS.

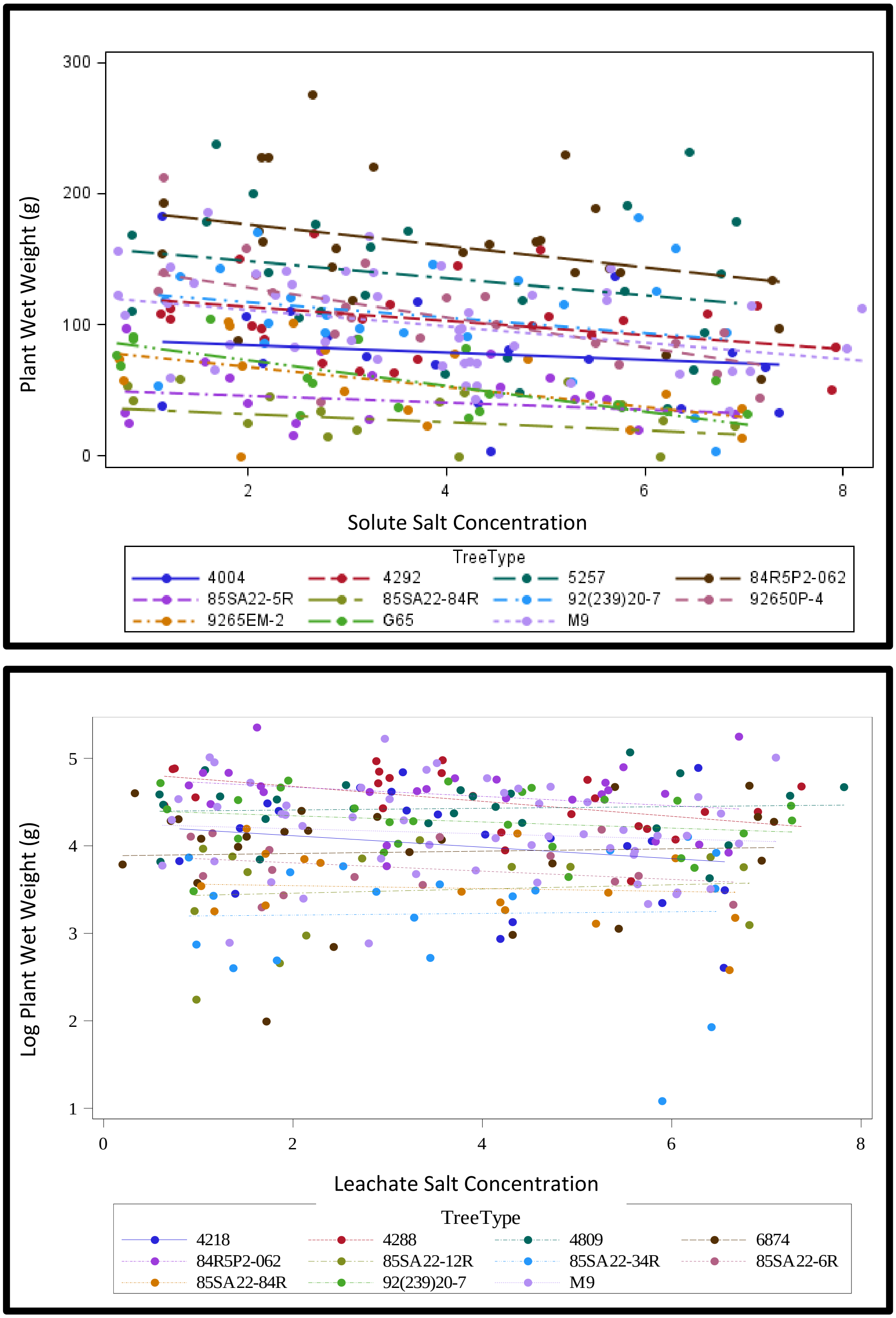

Figure 2.5 – Relationship between plant fresh weight and salt exposure for apple rootstocks in a near continuous gradient dosing system. The slopes of the lines for all rootstocks tested are not significantly different. Statistical analysis using linear mixed model in SAS.

Chapter 3

COMPARING CALCIUM AND SODIUM SALTS ON APPLE ROOTSTOCKS WITH ‘GALA’ SCION IN FIELD CONDITIONS

Abstract

Apple trees have reduced growth when exposed to saline soils. If apple rootstocks existed that could tolerate saline soils, lower quality salty land that is otherwise suitable could be used to produce apples. New rootstocks with putative salt tolerance need to be tested to see how they perform in field situations with soils containing different salt types. Rootstocks from the USDA apple rootstock breeding program were grafted with ‘Gala’ scions and placed in three orchard locations. The orchards were used as treatments: a low salt control site, a calcium-based salt site, and a sodium-based salt site. Trees were grown for two years and growth was monitored. All trees grew similarly when placed in saline environments and trees in salty sites grew significantly less than in the low salt control site. A new method to measure small trees was created by taking images of the trees and counting the number of green pixels in the image. This number was regressed against trunk cross sectional area and found to be accurate and provided another way to measure tree canopy size.

Introduction

Salts limit plant uptake of water from the soil. Saline soils may contain different salt types, but most commonly have high concentrations of sodium or calcium-based salts (Cardon, 2017). Soil spatial variability can be a problem with field studies. The type and concentration of salt can change with soil type in fields (spatial) as well as during the growing season as irrigation water is applied (temporal).

Soil salinity can be created by adding salts to irrigation water, or different sites with naturally occurring salinity can be utilized. Double line-source sprinkler systems have been used to create varying soil salinity on many agronomic crops (Hanks, 1976). Irrigation lines are laid out over an area and different concentrations of salts are injected into them causing gradients of pure water to salt water to be created. Treatments are then mixed in the air. Wind can be a problem on small plots as water doesn’t always fall uniformly. Double line source systems in tree crops pose particular problems. Orchards have larger spacing between plants and watering over or through trees can be challenging after years of growth (Hanks, 1976; Frenkel, 1990). Another method is the double line source drip irrigation. It uses two main drip irrigation lines, one with fresh water and the other with saline water (Hawks et al, 2009). Emitters are placed in each line by individual trees to irrigate with fresh water or water with added salt. Double line source drip systems have limited use in the field studies as the water doesn’t always distribute uniformly in the soil (Aragues, 1999). Another method is using similar soils that naturally have high and low concentrations of salt. Typically, soil is saline from parent material or irrigation that has been applied on the soil over many years (Grattan, 2002; Cardon, 2007). Using these soils can be challenging to work with though as variability can still exist in the soil profile.

Soil salinity must be managed in fields where salt sensitive crops are grown. This is typically done by leaching salts through the soil using large quantities of low salt water. Soil electrical conductivity (EC) cannot be made lower than that of the irrigation water used (USDA-NRCS, n.d.). The amount of water needed to leach salts through the rootzone can be calculated (Cardon, 2007). To reduce soil EC from 3 ds/m to 1.5 ds/m, 15.25 cm of salt free water would need to be applied.

Soil salts are not leached through the root zone with equal ease. Soils that are high in sodium-based salts are more easily leached due to the plus one charge of the sodium ion. Soils that have calcium-based salts are harder to leach with a two plus charge that binds calcium more tightly to soil particles. Higher levels of calcium salt are less detrimental to soils than sodium. When soil sodium levels get too high they can cause soils to lose permeability and structure in a process called dispersion. Improving drainage to allow for excess salts to be removed from the field can also be beneficial (Provin, 2001).

Multi-year research on fruit trees requires a way to accurately measure tree size year after year. Without a surrogate for measuring canopy volume all branches would need to be measured and recorded annually, at great expense. Having a way to measure tree canopy size is critical to understanding growth when comparing among treatments. Trunk cross-sectional area (TCSA) was found to have a linear relationship to the total above-ground weight of apple trees. Thus, measurements of trunk cross sectional area can be used as a proxy for the biomass of the tree. The relationship is accurate as long as there isn’t too much competition or excessive pruning (Westwood, 1970).

Materials and Methods

Apple trees (*Malus x domestica* Borkh) were planted at three different locations in April 2018. Each location represented different soil and water salinity conditions. The USU Kaysville Research Farm (41°01'20.2"N 111°55'52.7"W) was the control site with low soil and water salinity. The Kaysville farm soil is a Kidman Fine Sandy Loam described by the NRCS as a Calcic Haploxeroll. Irrigation water is from snow melt collected in the Wasatch Mountains and distributed via the Weber Basin Water Conservancy District. The orchard site near Goshen, UT (39°55'17.1"N 111°53'00.6"W) has sodium-based soil salinity. The Goshen Farm soil covers both Freedom Silt Loam described by the NRCS as Xeric Haplocalcids and Hiko Stony Sandy Loam described by the NRCS as Xeric Haplocalcids. Irrigation water is from deep wells on site. The irrigation water is acidified via on-site sulfur burners. The Tintic Valley, UT (39°52'26.0"N 112°07'45.8"W) has calcium-based soil salinity. The soil at that location is a Doyce Loam described by the NRCS as a Calcic Argixeroll. Tintic Valley irrigation water is also provided by a deep well on site. The irrigation water is acidified via on-site sulfur burners every third irrigation. Rootstocks were chosen by Dr. Gennaro Fazio (USDA apple rootstock breeder) for their putative salt tolerance. The trial rootstock selections were grafted with ‘Gala’ scions by Willow Drive Nursery (Ephrata, WA). M.9 Nic 29 was used as a control. Trees were planted by hand at the Kaysville location and with a tree planter at Goshen and Tintic. After planting, all trees were examined to ensure graft unions were 10 to 15 cm above the final soil line.

Standard two or three wire trellis was built at each orchard. Depending on soil fertility and tree growth, fertilizer applications were adjusted to encourage appropriate growth. All trees were pruned to a tall spindle. Rainfall between the orchards varied over the two years of study and helps to explain the variation of soil salinity (Tables 3.1 and 3.2). Each orchard was irrigated with microsprinklers per local conditions through the summers. Kaysville was irrigated using Nelson R10 rotary sprinklers. Goshen used Nelson R-2000 rotary sprinklers (Walla Walla, WA). Tintic was irrigated using Olsen Mini-Jet Sprinklers (Santee, CA).

Soil samples were taken in the spring and fall every 12 meters within the tree row. This was done with a standard 1-inch core tool to a depth of 6 inches. Samples within each site were mixed and sent to the Utah State University Analytical Laboratory (USUAL) for analysis. Soil salinity was determined using a soil extract paste. Irrigation water was sampled at the same time as the soil samples. Water samples were brought back to the lab and EC_e was determined using a DiST®4 Waterproof EC Tester (Hanna Instruments USA, Smithfield, RI). This was done twice a year to understand the temporal change in salinity.

Tree Growth was measured at the beginning of each growing season to document the previous year’s growth. At planting in the spring of 2018 initial tree dimensions (height and caliper at 30 cm) were recorded. Caliper was taken on two sides of the trunk and the average of the two numbers was used to calculate the two-dimensional TCSA as a surrogate for above ground biomass (Westwood and Roberts, 1970). Trunk caliper and height measurements were repeated in spring 2019 to measure 2018 growth and in the fall of 2019 after the trees had gone dormant to document growth in 2019.

In July 2019, images of all trees were taken to compare tree growth. A backdrop was constructed with a frame supporting white corrugated plastic. The backdrop was 180 cm x 240 cm. An extension was built for taller trees to ensure the whole tree canopy could be captured in the photograph. Grid lines were drawn on the backdrop at 15cm increments. Pictures were taken from 6 meters away from the tree. Pictures were taken using a Canon T7i with a 24-105 mm lens, using the 24 mm focal length. Images were then compiled and using Turf Analyzer software (http://turfanalyzer.com) green pixels were counted.

SAS was used to compare tree growth at each orchard to the M.9 control. A Two-Way ANOVA model was used with log transformation to normalize the data for change in height and change in TCSA.

Results and discussion

Kaysville soil salinity was very low with an average EC_e levels of 0.963 dS/m. The mean Sodium Adsorption Ratio (SAR) for the 2019 year was 0.475 with a standard error of 0.15 mmol/L. Irrigation EC_e levels were on average. 0.41 dS/m. Tintic soil salinity was 3.14 dS/m with an SAR mean value of 0.71 with a standard error of 0.16. Mean irrigation EC_e was 1.75 dS/m. Goshen soil had an EC_e of 2.49 with a mean irrigation EC_e of 2.51 dS/m. The mean SAR value was 3.575 with a standard error of 0.36. Tables 3.1 and 3.2 show that Goshen had considerable changes in EC_e levels during

2018 and 2019. In 2018, EC levels were as high as 6.12 dS/m. In the following year EC_e dropped to 1.11 dS/m which is similar to Kaysville. Over the course of the year, EC_e began to increase as irrigation was applied. 2019 had higher precipitation than the previous five years (Table 3.3). This additional precipitation leached salts through the rootzone and reduced the EC (Table 3.3).

Kaysville saw minimal change in EC_e as there is very little salt in the profile to be potentially leached with precipitation or added through irrigation. EC at Tintic didn’t change much over the course of the study because of the calcium-based soil salinity at Tintic. Calcium is a divalent cation, which allows for stronger attractions to soil particles, making it harder to dislodge and leach calcium through the profile with precipitation or irrigation. We observed significant differences in EC_e at Goshen over the course of the two years. 2018 was a relatively dry year compared to the last five years (Table 3.3). It required more irrigation, elevating the EC as the irrigation water at Goshen is highly saline. With high snow pack and rain in the last part of 2018 and early 2019, a majority of the sodium had leached through the profile. Sodium is a monovalent cation; thus, it is held less tightly to the soil and is easier to leach below the root zone. During dry years, Goshen will return to high EC and the effects of sodium on the trees will be apparent.

Increase in height and TCSA of all included rootstocks was not significantly different than M.9 within each location (Fig. 3.2). All the trees grew poorly in adverse conditions with a moderate reduction in growth at Tintic and a major reduction in growth at Goshen. Figure 3.1 shows the difference of growth between Kaysville and Goshen. All of the trees performed equal to M.9 at all locations. Overall, apple trees grew better at

Kaysville compared to Tintic or Goshen. Trees at Kaysville grew significantly better than at Tintic which grew significantly better than at Goshen.

Turf Analyzer software was used to count all green pixels on the tree images. The optimal threshold to capture only the green pixels of the trees was determined through multiple tests. Table 3.4 shows the color standards captured by the software. Figure 3.1 shows the pixels counted after each image was processed by the software. The differences in growth between Kaysville (left) and Goshen (right) are clearly visible. Along with a visual image, a pixel count that fell within those standards was generated along with a total pixel count for each entire image. Due to variable numbers of pixels between each picture, a percent green cover was used to normalize the data for comparison. Statistical analysis was done using Statistix 10 data analysis software for researchers (Analytical Software, Tallahassee, FL). Percent green cover was regressed against TCSA measurements and a regression coefficient (R^2) of 0.801 was obtained (Figure 3.3). As tree size increased the accuracy of the pixel count compared to TCSA decreased. This shows that counting the pixels in an image is an effective method to calculate canopy volume of young trees for testing and further confirms the relationship between canopy volume and TCSA (Westwood, 1970).

Summary

None of the tested rootstocks performed different than M.9 when planted in orchards with saline conditions. To date, none of the apple rootstocks used in this research demonstrate tolerance to saline soil conditions beyond the widely planted M.9. Counting pixels to measure tree growth is a useful tool that could be used in the future on smaller less vigorous trees to compare growth year to year. Once trees develop significant canopies there is too much canopy overlap for accurate measurement. As the study continues, over the next two growing seasons the trees' productivity and precocity will become more evident.

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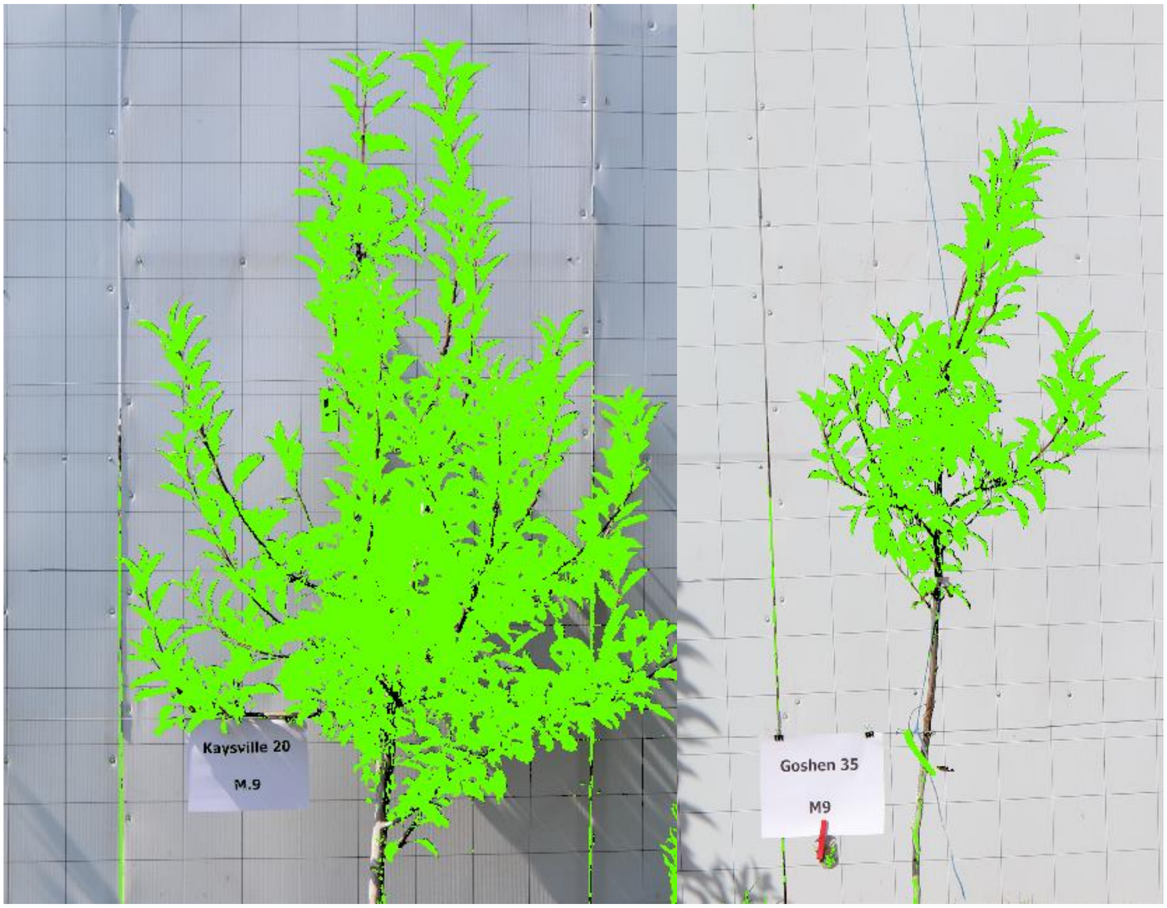

Figure 3.1 Comparison of tree canopy of M.9 rootstock between Kaysville (low salt) and Goshen (high sodium salt). Green areas of the image were identified using Turf Analyzer software.

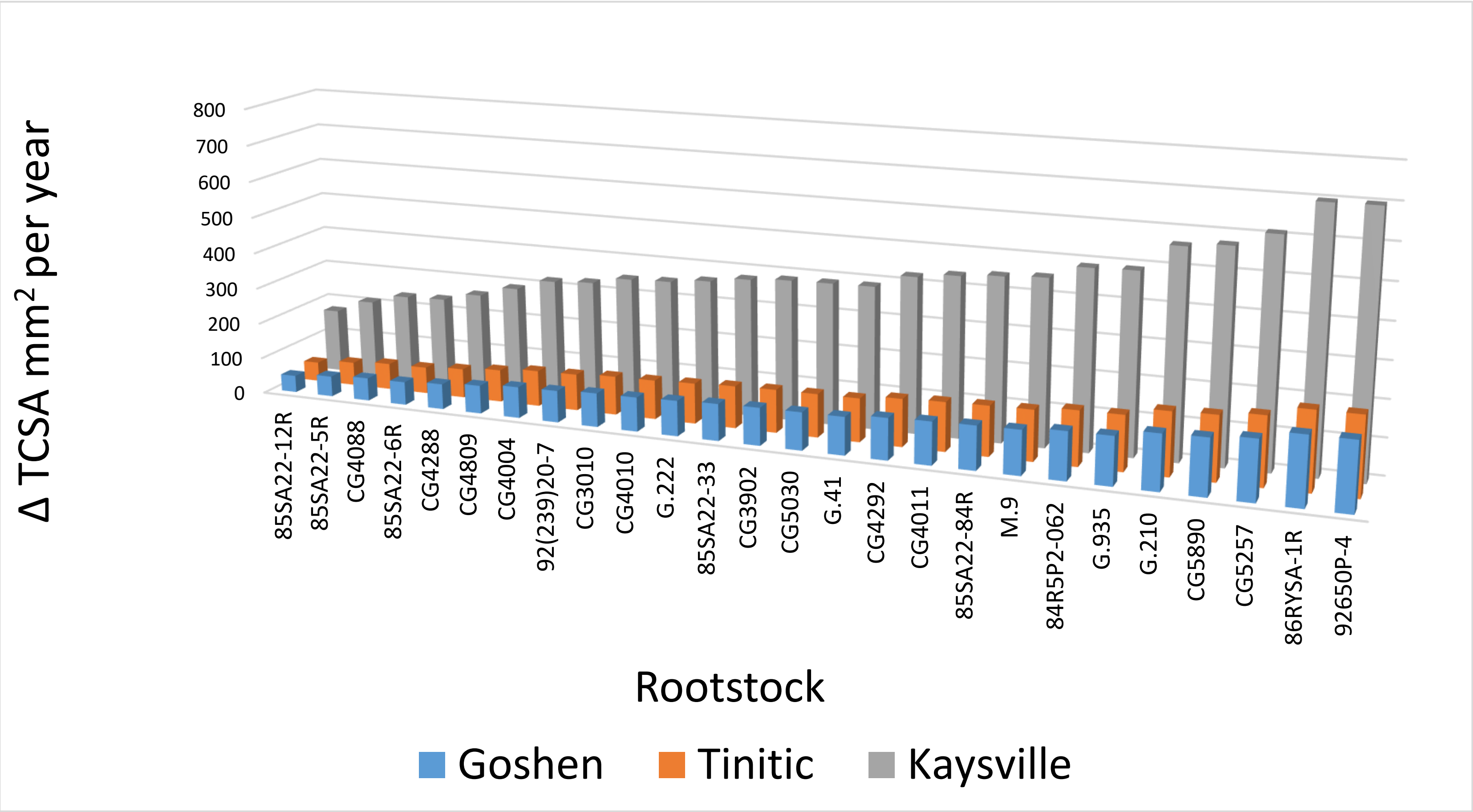

Figure 3.2 Change in trunk cross sectional area (TCSA) from 2019 to 2020 across apple orchards at Kaysville, Goshen, and Tintic Valley, UT. Trees grown at Kaysville show major growth and major increases in TCSA. Trees grown at Tintic and Goshen show reduced growth in comparison. All of the bars are proportionally lower at Tintic and Goshen compared to Kaysville. At any site, no tree grew better than the M.9 control.

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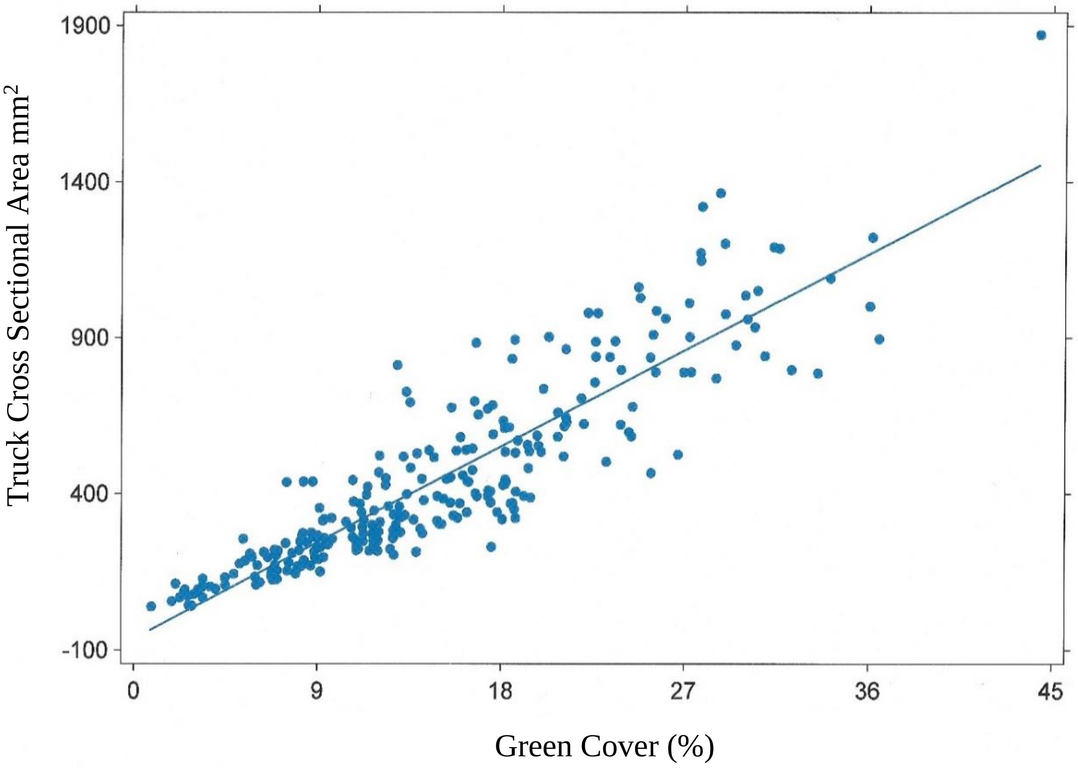

Figure 3.3 Regression line comparing the percent green cover from Turf Analyzer software against trunk cross sectional area (TCSA). The regression coefficient (R^2) of 0.801 was obtained. The correlation is high with small trees but starts to lose strength with larger trees.

Table 3.1 2018 Soil and water measurements for the three treatment locations. Measurements collected from weather stations on site and soil samples analyzed at the USU Analytical Lab.

	Soil Texture	pH	Rainfall 2018 (cm)	Soil Salinity 2018 (dS/m)	Irrigation Salinity 2018 (dS/m)
Kaysville	Sandy Loam	7.4	25.8	1.12	0.56
Tintic	Loam	7.6	22.6	3.04	2.02
Goshen	Loam	7.8	27.6	6.12	2.50

Table 3.2 2019 Soil and water measurements for the three treatment locations. Measurements collected from weather stations on site and soil samples analyzed at the USU Analytical Laboratory.

	Rainfall 2019 (cm)	Irrigation Salinity 2019 Spring (dS/m)	Irrigation Salinity 2019 Fall (dS/m)	Soil Salinity 2019 Spring (dS/m)	Soil Salinity 2019 Fall (dS/m)	SAR[1] Spring (mmol/L)	SAR[1] Fall (mmol/L)
Kaysville	55.1561	0.14	0.53	1.05	0.72	0.26	0.69
Tintic	38.8874	1.65	1.58	3.00	3.38	0.48	0.94
Goshen	33.51022	2.60	2.45	1.11	2.49	3.06	4.09

[1] SAR is the sodium adsorption ratio which shows the amount of sodium in the soil relative to other salts.

Table 3.3 Yearly precipitation at the three orchard sites in Utah over 5 years compared to average rainfall. Data collected from the Utah Climate Center using weather stations found at each orchard.

	2015 Rainfall CM	2016 Rainfall CM	2017 Rainfall CM	2018 Rainfall CM	2019 Rainfall CM	5 Year Average Rainfall CM
Kaysville	51.6	49.8	41.3	25.8	55.2	44.7
Tintic	30.9	26.9	23.4	22.7	38.9	28.6
Goshen	24.8	24.7	29.1	27.7	33.5	27.9

Table. 3.4 Settings used in the Turf Analyzer program to select only the green of the tree leaves.

Threshold information:					
Low hue:	32	Low saturation:	10	Low brightness:	0
High hue:	170	High saturation:	100	High brightness:	100
Shadow Threshold information:					
Shadow low hue:	0	Shadow low saturation:	0	Shadow low brightness:	0
Shadow high hue:	360	Shadow high saturation:	100	Shadow high brightness:	23
Quality Rating Settings:					
Min Color Rating:	1	Max Color Rating:	9	Color Weight:	1
Min Cover Rating:	1	Max Cover Rating:	9	Cover Weight:	1
Min Density Rating:	1	Max Density Rating:	9	Density Weight:	1
Min Uniformity Rating:	1	Max Uniformity Rating:	9	Uniformity Weight:	1

Chapter 4

COMPARING BITTER PIT INCIDENCE ON STORED APPLES FROM TREES ON DIFFERENT ROOTSTOCKS

Abstract

Fruit with low calcium concentrations are more susceptible to bitter pit developing while in storage. Apple cultivars vary in their susceptibility to bitter pit. ‘Fuji’, an apple cultivar highly susceptible to bitter pit, was grafted to fourteen rootstocks to see if the incidence of bitter pit was correlated with fruit peel calcium concentration and to see if rootstock affected either variable. Ten apples were harvested one week before total harvest and the peel removed and tested for mineral concentration. The rest of the apples were harvested and a half bushel box from each rootstock was placed in refrigerated storage for three months. After storage, apples were analyzed for incidence of bitter pit and post-storage quality. Apple trees with less vigor had lower incidence of bitter pit while more vigorous trees had higher incidence of bitter pit.

Introduction

Bitter pit is the physiological breakdown of cells immediately under the peel of apples (Cline, 2000). It was first reported in Germany and was called Stippen (Jaeger, 1869). It was also known as “Baldwin Spot” and “Blotchy Spot” until 1895 when Nathan Cobb renamed it “bitter pit” in Australia and the name stuck (Faust, 1968). Bitter pit is the most common corking disorder of apples. It can be seen at harvest, but is more commonly found after apples have been stored. Affected apples start with slightly off colored round spots and in storage the cortex tissue degrades. On the peel this appears as sunken dark brown to black spots as the cells immediately below the peel deteriorate. Bitter pit is typically found in greater abundance on the calyx end of fruit (Faust, 1968).

Bitter pit is an abiotic disorder that affects apples at full maturity, both at harvest and in storage. Because it develops in storage, growers typically can’t sort out affected fruit prior to storage and they incur the cost of storing unmarketable fruit. Fruit calcium deficiency is the primary cause for bitter pit. Before low fruit calcium was identified as the cause in the development of bitter pit in apples, it was believed to be caused by conditions like hot dry weather, irregular irrigation, heavy pruning and thinning, and excess nitrogen (Ferguson, 1989). All of these factors affect calcium uptake, but are indirect contributors to the development of bitter pit.

Foliar calcium sprays have been used to reduce the severity of bitter pit in apples. The most accurate way to test fruit calcium is to analyze the peel on the calyx end. Depending on the length of storage, ratios of different minerals are critical (Cline, 2020). To increase fruit calcium by spraying trees with supplemental calcium requires multiple applications as calcium absorption through the cuticle or lenticels into fruit is low. Typically, calcium chloride is used, but calcium nitrate can also be used. Calcium applications typically start in mid-July and finish in August (Faust, 1968; Cline, 2020).

Apple cultivars vary in their susceptibility to develop bitter pit. Cultivars like ‘Golden Delicious’, ‘Fuji’, and ‘Honeycrisp’ are highly susceptible (Jemrić, 2016). Cultivars differ in the fruit growth stage achieved when xylem function is lost. (Miqueloto, 2015). Ca^{2+} ions are transported through the xylem and this partially explains why different scion types have different susceptibility to bitter pit (Saure, 1996). Rootstocks also play a significant role in bitter pit development as the uptake of calcium is known to vary among apple rootstocks. Rootstocks that produce moderate to vigorous scion growth are more likely to produce apples with bitter pit (Jemrić, 2016). Fruit that is underripe is more likely to have low calcium concentration, thus increasing the chance of bitter pit.

Materials and Methods

Apple trees (*Malus* x *domestica* Borkh.) were planted at the Utah State University (USU) Kaysville research farm (41°01'20"N 111°55'50"W, 1334 m elevation) in April 2014 as part of the NC-140 multi-state project. Fourteen rootstocks were grafted with ‘Fuji’ scions with 10 replications. Trees were planted 1.8 m apart in rows spaced 6 m in a completely randomized block design. Trees were cared for using standard horticultural practices and following the NC-140 planting protocols. Trees were trained to a tall spindle and banded with 22.6 kg of nitrogen per acre. Micronutrients were applied to the foliage in the fall. Immediately after petal fall Amid-Thin W (VALENT, Walnut Creek, CA) was applied to thin the apples. Pest management was as needed based on degree day models and trap catches. Irrigation was applied with Nelson R-10 Rotary Sprinklers (Walla Walla, WA). Full bloom occurred on April 30th, 2018 and fruit were harvested on October 15th, 2018. Trunk cross-sectional area (TCSA) was measured at the end of October 2018.

The study objective was to see if rootstocks cause variation in fruit peel calcium concentration. One week before harvest, ten fruit were collected from each rootstock.

Two apples that were representative of the fruit on the tree were collected from each of the first five replicates of each rootstock. Apples were weighed and set aside for fruit peel mineral analysis. Fruit were triple washed using distilled water and surfactant. Peel was removed from the calyx end of the fruit using an Apple Peeler Corer Slicer (VKP Brands, Orem, UT; Figure 4.1). Peel was collected and placed in a bag and dried for one week at 60°C in a forced air-drying room. Peel samples were then sent to Cornell University (Geneva, NY) to be ground and digested for mineral analysis. Mineral analysis was done using techniques similar to Gomez (2020).

Forty apples were harvested from each study tree. Fewer apples were collected if the tree didn’t have enough fruit or if they were extra-large and didn’t fit in a storage box. All of the remaining apples were then harvested and counted along with an overall weight of fruit harvested including dropped and unmarketable fruit. Before the apples were put in storage they were visually rated for incidence of bitter pit. Apples were stored under refrigeration at 4°C for three months at Mountainland Fruit (Santaquin, UT). After storage, fruit from each box were visually rated by a single person for incidence of bitter pit. Ten representative fruit per box were peeled on the blush and opposite side. Fruit firmness was measured using an 8mm tip on a FR-5120 Penetrometer (Lutron Electronics, Taipei, Taiwan). Juice generated from measuring firmness was collected in a weigh boat and soluble solids was measured using a PAL-1 refractometer (ATAGO, Tokyo, Japan). After all apples from a rootstock were finished the equipment was cleaned with wipers. All data were statistically analyzed using linear mixed models in SAS.

Results and Discussion

Bitter pit incidence varied widely across the rootstocks. Figure 4.2 shows the range of bitter pit severity from mild on the left to extensive damage on the right. The incidence of bitter pit was expressed as a percentage of stored apples evaluated.

Previous research suggests that calcium is a major contributor to the incidence of bitter pit (Ferguson, 1989), and our results are consistent with this finding. Trees that had higher fruit calcium concentrations had lower incidence of bitter pit (Table 4.1). Fruit peel calcium concentrations of the Vineland rootstocks and M.26 were significantly lower than the other rootstocks in this trial and these trees had a higher incidence of bitter pit. However, V.1 didn’t follow this pattern. (Table 4.1). While our fruit peel mineral analysis included data for calcium, potassium, magnesium, and nitrogen, only fruit peel calcium concentration contributed to predicting the incidence of bitter pit. Potassium, magnesium, and nitrogen were not related to the incidence of bitter pit (data not shown). Rootstock did not affect fruit firmness, soluble solids, total yield per tree (kg), or fruit per tree (crop load).

Tree size described as trunk cross sectional area (TCSA) varied widely across the rootstocks used in this trial (Table 4.2). The Vineland rootstocks were the largest. The Geneva rootstocks, where the description begins with G, were generally smaller. M.26 and M.9 were included as standards with M.9 being smaller and M.26 being larger. B.10 is a smaller rootstock. On average, the Geneva rootstocks, M.9 and B.10 trees had less bitter pit than larger trees. M.26 had more bitter pit than expected based on TCSA. The Vineland rootstocks were variable. V.1 had a lower incidence of bitter pit than V.5, V.6, or V.7, but the V.5, V.6, and V.7 had the highest incidence of bitter pit and were the most vigorous rootstocks in the trial.

Mean weight of fruit varied by rootstock. G.41 and G.935 had lower yield than V.5 and V.6. Otherwise, yields were similar among the rootstocks.

Smaller trees generally had higher fruit peel calcium and the larger trees had the lowest fruit peel calcium. The Vineland rootstocks and M.26 had the lowest fruit peel calcium (Table 4.1). By definition, vigorous trees produce more vegetative growth. Calcium moves in the xylem and with greater leaf area, more water is transpired through leaves and relatively less is transpired through fruit, leading to lower fruit calcium and higher incidence of bitter pit (Jemrić, 2016).

Summary

The incidence of bitter pit is not uniform across apple rootstocks in this trial. Fruit from smaller, less vigorous, trees exhibited less bitter pit and had higher concentrations of fruit peel calcium. Larger, more vigorous rootstocks partition more available calcium to vegetative growth instead of fruit. If a larger tree is needed to correct agronomic conditions (replant or infertile site) or with a low vigor scion, avoiding shortages of nutrients, water, and ensuring fruit number relative to the diameter of the trunk (thinning) are the best ways to avoid bitter pit. Lastly, different scion cultivars can be used to avoid having bitter pit. ‘Fuji’ and ‘Honeycrisp’ produce large apples and thus have higher susceptibility to bitter pit compared to smaller fruiting cultivars like ‘Gala’ and ‘Delicious’.

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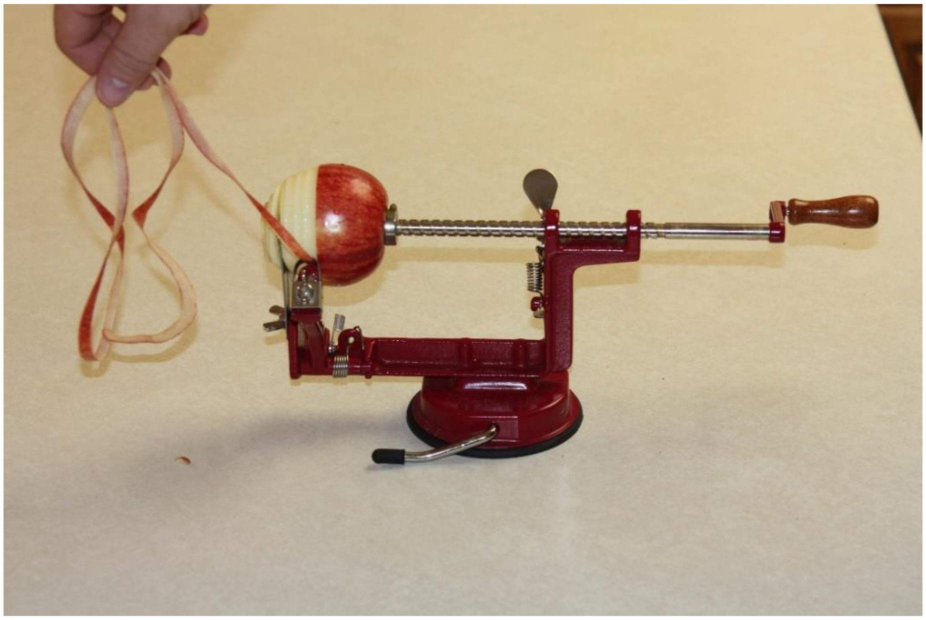

Figure 4.1 – Apple Peeler-Slicer removing the peel from the calyx end of an apple. Peel samples were analyzed for mineral concentrations.

Figure 4.2 –The range of bitter Pit severity on ‘Fuji’ apples after 3 months of storage (Jan. 2019). Bitter pit only effects the first few layers of cells and can range from minor indentations and discoloration to major damage to the fruit peel, making the fruit unmarketable.

Table 4.1 – Yield, fruit number and fruit characteristics of apples from various rootstocks after storage for three months at 2°C. Statistical comparison for all variables recorded after 3 months of storage on 'Fuji' apples after being stored for 3 months.

Root Stock	Mean Bitter Pit (%)	Mean Firmness (N)	Mean Soluable Solids (Brix)	Mean Total Yield (Kg)	Mean Total # of Fruit per Tree (Cropload)	Mean Weight of Fruit (g)	Mean Fruit Peel Ca%	Mean TCSA cm^2
G.11	3.9% abc*	34.95 a	15.4 a	33.65 a	195.7 a	194.01 abcd	0.06 abc	30.0 f
G.202	1.7% bc	33.77 a	14.6 a	27.22 a	196.8 a	174.63 bcd	0.08 a	31.1 ef
B.10	1.1% c	33.46 a	14.8 a	34.55 a	192.6 a	179.63 bcd	0.07 ab	31.3 def
G.214	2.0% bc	34.38 a	15.6 a	30.28 a	176.2 a	190.94 abcd	0.07 a	32.3 def
G.935	1.0% c	33.33 a	14.4 a	34.61 a	206.3 a	172.44 cd	0.07 ab	33.8 def
M.9	2.5% abc	32.54 a	14.4 a	34.49 a	197.9 a	184.64 abcd	0.07 ab	38.0 cdef
G.41	5.8% abc	34.73 a	14.8 a	38.79 a	231.5 a	171.27 d	0.06 abc	38.2 cdef
G.30	2.1% bc	33.47 a	14.6 a	35.79 a	219.2 a	182.27 bcd	0.06 abc	40.1 cdef
G.969	3.0% abc	34.31 a	15.6 a	36.85 a	186.9 a	202.37 abcd	0.06 abc	40.7 cde
M.26	8.8% abc	35.28 a	15.3 a	31.74 a	178.3 a	196.38 abcd	0.04 abcd	41.3 cd
V.1	2.4% abc	32.38 a	14.3 a	38.67 a	208.9 a	197.91 abcd	0.05 abcd	45.5 bc
V.7	11.1% ab	33.95 a	15.3 a	41.62 a	226.6 a	207.28 abc	0.03 d	55.6 b
V.5	15.3% a	34.92 a	15.5 a	27.25 a	145.9 a	220.32 a	0.04 bcd	67.5 a
V.6	15.6% a	34.53 a	15.2 a	28.06 a	152.7 a	209.18 ab	0.04 cd	68.4 a

*Numbers within a column followed by the same letter are not different at α = 0.05 level. Multiplicity is adjusted to Tukey-Kramer's method.

Chapter 5

Managing Suckers Around Fruit Trees

Abstract

Many types of fruit trees produce suckers around the base of the tree. Crown suckers arise in the area immediately surrounding the tree trunk (Photo 5.1), and root suckers can arise from roots further away from the trunk. Not only are suckers around trees unsightly, but they can also harbor insect pests like wooly apple aphid and provide points of entry for diseases like fire blight. If suckers are profuse, they interfere with in-row weed management and can absorb systemic herbicides such as glyphosate. Some rootstocks used for fruit trees such as M.7 for apples and Mazzard for cherries are genetically predisposed to produce suckers. M.9 clone RN-29 is more inclined to sucker than other M.9 clones. In some cases, sucker growth is a symptom of partial incompatibility between the rootstock and scion. Suckers can also result from injury to the crown, such as extreme cold or mechanical damage. Whatever the cause, managing suckers takes time and expense. This fact sheet reviews mechanical and chemical control methods to manage suckers surrounding fruit trees.

Introduction

Many types of fruit trees produce suckers around the base of the tree. Crown suckers arise in the area immediately surrounding the tree trunk, and root suckers can arise from roots further away from the trunk. Not only are suckers around trees unsightly, but they can also harbor insect pests like wooly apple aphid and provide points of entry for disease like fire blight. If suckers are profuse, they interfere with in-row weed management and can absorb systemic herbicides such as glyphosate.

Some rootstocks used for fruit trees such as M.7 for apples and Mazzard for cherries are genetically predisposed to produce suckers. M.9 clone RN-29 is more incline to sucker than other M.9 clones. In some cases, sucker growth is a symptom of partial incompatibility between the rootstock and scion. Suckers can also result from injury to the crown such as extreme cold or mechanical damage. Whatever the cause, managing suckers takes time and expense. Sucker management falls into two general categories: mechanical and chemical. Each approach has merit depending on the orchard situation.

Mechanical Control

When only a few suckers are present, they are often removed during dormant pruning. In severe cases, using sickle bar mowers or gas-powered hedge shears can remove suckers. However, mechanically removing suckers in some situations can cause multiple new shoots to arise from cutting a single sucker, making the problem worse. Expensive and labor-intensive, mechanical control may be required more than once a year.

Related to mechanical control is control by heat. In a Utah State University (USU) trial, burning suckers with a propane torch provided reasonable control that lasted several weeks. This may present an effective approach for a few suckers here and there. Treating an entire block with a torch would require very slow drive speeds, consuming a substantial amount of propane. Without care, irrigation tubing could be damaged.

Chemical Control

Chemically controlling suckers can be effective and is less labor-intensive than mechanical control. A single operator can treat many acres in a day. Chemical controls for suckers can be grouped into three categories: plant growth regulators, herbicides, and desiccants.

Plant Growth Regulators. Commercial fruit growers have long used a synthetic auxin, Naphthalene Acetic Acid (NAA), to reduce the growth of suckers. This is the same plant growth regulator (PGR) used to thin fruit, but the timing and concentration are very different. Because NAA will cause a thinning response, application must be delayed until a month after petal fall. This allows time for the fruit to set and become less sensitive to NAA. Nevertheless, the application should be made at a low pressure (10-20 psi) using nozzles that produce large droplets to reduce drift. A specific formulation of NAA (Tre-Hold A-112™) is registered for this use. For apples, a 0.5% to 1% solution of NAA should reduce the growth of root suckers.

Herbicides. Some specific contact herbicides are registered for managing suckers on fruit trees. While registered for sucker suppression or control, they are still herbicides and can damage trees, especially young trees, where the bark is green and not yet corky. Therefore, take care not treat tree trunks during application. Install trunk wraps on young trees before applying herbicide products. Contact herbicides have the added advantage of providing some control for weeds emerging after spring herbicide applications.

General application principles for herbicides to manage suckers include spraying only during calm winds, using low pressure and large droplet size. Low drift nozzles are preferred. The use of off-center nozzles may lead to overspray on trunks. For these contact herbicides, good coverage of the sucker foliage is essential. Spray sufficient water to wet the leaves thoroughly. Treating when suckers are still young and succulent and not woody achieves the best result.

Paraquat (Gramoxone^{TM}) is a caustic, non-systemic, post-emergent herbicide that burns green vegetation. Paraquat is rapidly absorbed by green plant tissues and reacts with photosynthesis to produce superoxides that kill plant cells. Paraquat is highly toxic to humans. Paraquat is a restricted-use pesticide that can only be mixed and applied by certified pesticide applicators. It provides good burn-down of suckers at higher rates.

Glufosinate (Rely 280^{TM}, Cheetah^{TM}) is another contact herbicide registered for sucker management. It is the slowest acting of the herbicide products included in this fact sheet. It can take 20-25 days to reach the level of control provided by the other herbicides in 10-14 days.

Carfentrazone-ethyl (Aim EC) is register for sucker control in fruit trees. Aim must be applied using a hooded sprayer to minimize the opportunity for drift. Also, it must be mixed with an appropriate rate of a nonionic surfactant or crop oil concentrate. Although Aim is effective at controlling green and non-woody suckers, the opportunity for injury from drift makes this a less desirable choice.

Pyraflufen-ethyl (Venue) is a contact herbicide providing post-emergent control of a range of broadleaf weeds. It also has a supplemental label for controlling suckers in fruit trees. It is fast-acting and effective at the 4 fluid ounces per acre rate. Cherry suckers are more susceptible to Venue than apple. Applications rates can be found on Table 5.2.

Desiccants. Recently, we became aware of a material used elsewhere for sucker control in tree fruits and nuts. The liquid fertilizer Urea Ammonium Nitrate (UAN) is a powerful desiccant. It is not registered as a pesticide. Growers can purchase it in co-op agronomy centers in the Intermountain West. When sprayed on suckers in the spring, it desiccates the succulent foliage and stunts growth. Since it is 32% nitrogen by weight, it also provides additional nitrogen when applied for sucker control.

In 2019, we conducted a trial assessing UAN for sucker control. The trial was conducted on a block of ‘Gala’ on EMLA.7 rootstocks at the Kaysville Research Farm in Kaysville, Utah. The trees were planted in 2006 and had a long history of extensive root suckering. In the early spring, we cut off all the existing suckers with hedge shears. That ensured sucker regrowth and made the various treatments uniform in not having suckers present when we began the trial. Treatments were assigned to trees in five orchard rows in a completely randomized design with four replications. Applications were made on four dates in 2019: April 30, May 3, May 9, and May 20. The first treatments were made when initial sucker growth ranged between three and six inches. Treatments were water (control), 1% NAA, Paraquat, UAN, and burning with a propane torch. NAA and Paraquat were mixed immediately before use. All liquid treatments were applied with a one-gallon pump up sprayer, and the suckers were sprayed to runoff. When we burned with a propane torch, we burned the area under the tree until all the suckers were devoid of leaves.

We evaluated the treatments on May 9, June 10, and July 1, 2019. We photographed each single tree plot and gave a control rating between 1 (no control) and 5 (complete control).

Figure 5.1 shows the results of the study. Water was the control and provided no control across evaluation dates. Paraquat provided good initial control, but this was short-lived. Also, it offered better control with the latest treatment date. NAA delivered better control with the latest treatment date. NAA delivered better and longer-lived sucker control, although the results were somewhat variable. Even by July 1, we still observed some control from the April 30 NAA treatment. UAN also provided better control with later treatment dates. The May 20 treatment still provided acceptable control by July 1. UAN produced the Longest-lasting control. In general, later treatments provided longer-lasting control in the period we evaluated.

Based on this research, we conclude that UAN is an acceptable material for sucker management in the late spring though early summer. It offered better control than Paraquat and control equal to NAA. Paraquat, NAA and UAN are easily applied with a boom sprayer in a commercial setting. Paraquat has the added advantage of also suppressing early weed growth. UAN has the added advantage of providing some nitrogen as well as suppressing early weed growth.

Table 5.1 displays the estimated cost of sucker control products on a per-acre basis. The lowest cost product is Paraquat, followed by UAN and NAA. The cost of application labor, fuel, and depreciation are not included in these costs. However, applying UAN at a rate of 20 gallons per treated acre provided about 20 pounds of nitrogen per projected acre, thus offsetting nitrogen that would otherwise be applied.

In apple orchards, not all rootstocks are equally prone to suckers. We recommend avoiding planting apple trees on M.7 rootstocks. Also, when nursery trees are “high-budded” so the root system can be planted slightly lower, this can reduce the amount of suckering. However, this approach can be overdone. Avoiding mechanically damaging rootstocks can also prevent suckering.

Disclaimer

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Plant growth regulators are classified as pesticides by the U.S. Environmental Protection Agency. You are responsible for using pesticides according to the manufacturer’s current label directions. Follow directions exactly to protect people and the environment from pesticide exposure. Failure to do so violates the Law

This information is provided as an educational tool to inform growers what materials are legal to apply and what is effective. No implication is intended that Utah State University recommends the use of any materials.

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Smith, T.J., & Guterrez, E. (2014). Evaluation of Venue, Gramoxone, Aim, and Rely herbicides for root and crown sucker control in apple and cherry. Massachusetts Fruit Notes 79:1-4.

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This Chapter has been published as a Utah State University Extension Fact Sheet. (see appendix)

Johnson, Samuel; Roper, Teryl; and Dai, Xin, "Managing Suckers Around Fruit Trees" (2020). *All Current Publications.* Paper 2144. https://digitalcommons.usu.edu/extension_curall/2144

Table 5.1 – Cost[a] per Treated Acre of Various Sucker Control products on an Orchard area Basis, Based on a Six-Foot Treated Area per Tree Row. Based on 2019 Chemical Prices.

Products	**20-foot row spacing**	**15-foot row spacing**	**10-foot row spacing**
UAN	$10.50	$14.00	$21.00
Paraquat	$3	$4	$6
1% NAA	$15	$20	$30
Rely	$11	$15	$23
Aim	$5	$7.50	$10
Venue	$7	$9	$14

[a] Based on 2019 chemical prices

Table 5.2 - Use Patterns for Herbicides Registered for Sucker Control in Tree Fruits.

Generic Name **Trade Name**	**Rate/acre**	**Applications/Year**	**REI (hours)**
Paraquat Gramoxone	2.5 to 4 pints	3	12
Glufosinate Rely, Cheetah	48 to 56 fluid ounces	2	12
Carfentrazone-ethyl Aim	2 fluid ounces		12
Pyrafulfen-ethyl Venue	3 to 4 fluid ounces	3	12

Note. Check product labels for specific use information.

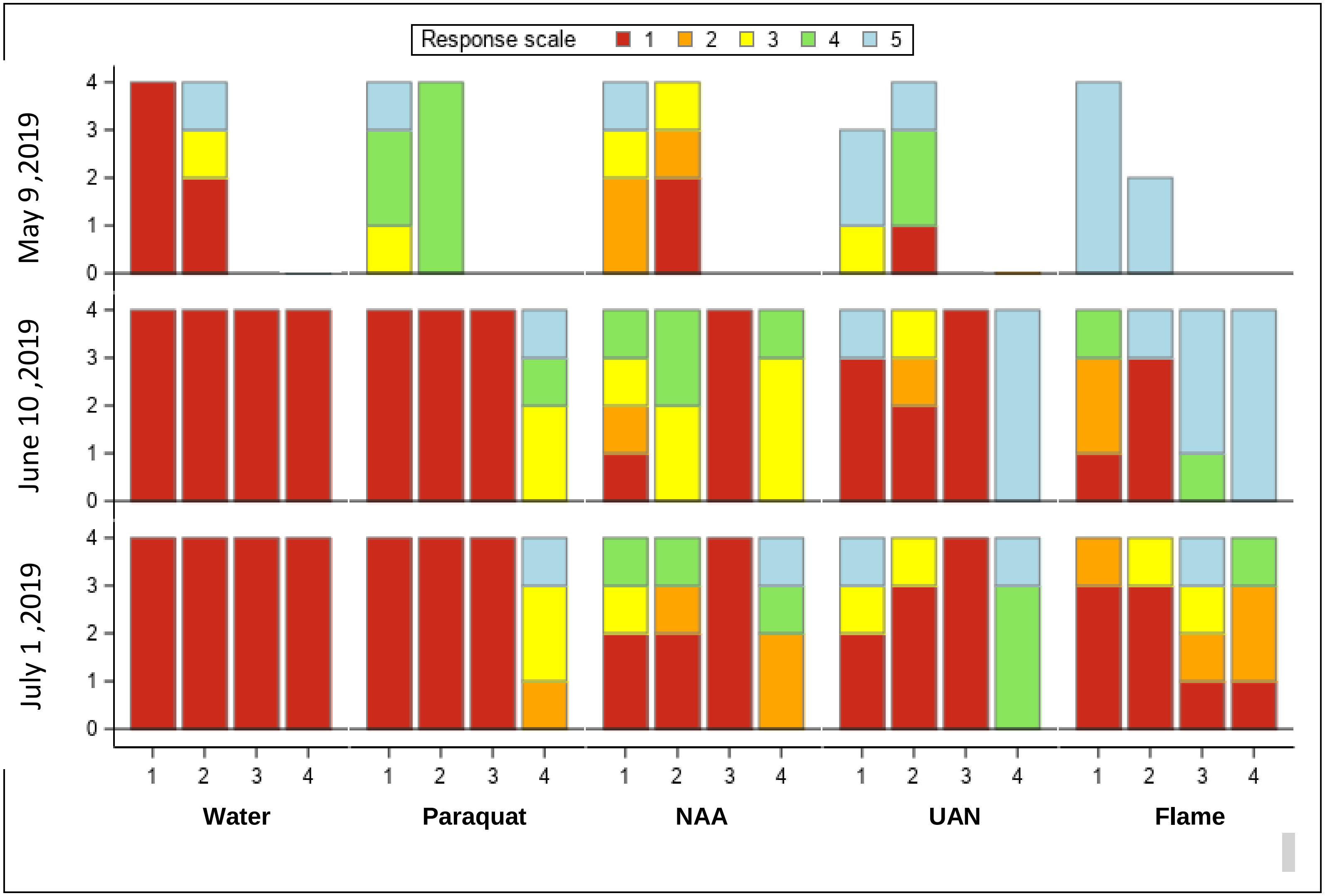

Figure 5.1 - Degree of sucker control by five treatments with four application dates and three evaluation dates in Utah, 2019. Treated trees were ‘Gala’ on M.7 rootstocks planted in 2006.

Figure 5.2 - This young apple tree has profuse suckers around the crown of the tree. Left unmanaged, the suckers will grow up into the lower parts of the tree. Photo by Teryl Roper

Figure 5.3 - Apple Trees with profuse suckering one week after Treatment with UAN in Kaysville, Utah. The treatment desiccated the foliage. Photo by Samuel Johnson.

Chapter 6

CONCLUSION AND SUMMARY

A near-continuous gradient dosing system was used to screen 19 different apple rootstocks to test for salinity tolerance. All of the rootstocks showed a decrease in growth with an increase in salt concentration. No rootstock performed significantly better than the M.9 control in this study.

None of the tested rootstocks performed different than M.9 when planted in orchards with saline conditions during the first 2 seasons. To date, none of the apple rootstocks used in this research demonstrate tolerance to saline soil conditions beyond the widely planted M.9. Counting pixels to measure tree growth is a useful tool that could be used in the future on smaller less vigorous trees to compare growth year to year. Once trees develop significant canopies there is too much canopy overlap for accurate measurement. As the study continues, over the next two growing seasons the trees' productivity and precocity will become more evident.

The incidence of bitter pit is not uniform across apple rootstocks. Fruit from smaller, less vigorous, trees show less bitter pit and have higher concentrations of fruit peel calcium. Larger, more vigorous rootstocks partition more of the available calcium to the shoots instead of fruit. If a larger tree is needed to correct horticultural conditions (replant or infertile site) or with a low vigor scion, avoiding shortages of nutrients, water, and adjusting fruit number relative to the diameter of the trunk (thinning) are the best ways to avoid bitter pit. Lastly, different scion cultivars can be used to avoid having bitter pit. ‘Fuji’ and ‘Honeycrisp’ produce large apples and have higher susceptibility to bitter pit compared to smaller fruiting cultivars like ‘Gala’ and ‘Delicious’.

With the high cost of manually removing suckers finding an alternative is very beneficial. UAN had the greatest control on suckers on M.7 rootstock apples. The best control was when applications were applied at the end of May allowing for adequate growth before they were removed.

Chapter 7

Appendix A

Horticulture

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November 2020

Managing Suckers Around Fruit Trees

Samuel Johnson *and* ***Teryl Roper****, Utah State University Department of Plants, Soils, and Climate;* ***Xin Dai****, Utah Agricultural Experiment Station*

Many types of fruit trees produce suckers around the base of the tree. Crown suckers arise in the area immediately surrounding the tree trunk (Photo 1), and root suckers can arise from roots further away from the trunk. Not only are suckers around trees unsightly, but they can also harbor insect pests like wooly apple aphid and provide points of entry for diseases like fire blight. If suckers are profuse, they interfere with in-row weed management and can absorb systemic herbicides such as glyphosate.

Some rootstocks used for fruit trees such as M.7 for apples and Mazzard for cherries are genetically predisposed to produce suckers. M.9 clone RN-29 is more inclined to sucker than other M.9 clones. In some cases, sucker growth is a symptom of partial incompatibility between the rootstock and scion. Suckers can also result from injury to the crown, such as extreme cold or mechanical damage. Whatever the cause, managing suckers takes time and expense.

Photo 1. *This young apple tree has profuse suckers around the crown of the tree. Left unmanaged, the suckers will grow up into the lower parts of the tree. Photo by Teryl Roper.*

Sucker management falls into two general categories: mechanical and chemical. Each approach has merit depending on the orchard situation.

Mechanical Control

When only a few suckers are present, they are often removed during dormant pruning. In severe cases, using sickle bar mowers or gas-powered hedge shears can remove suckers. However, mechanically removing suckers in some situations can cause multiple new shoots to arise from cutting a single sucker, making the problem worse. Expensive and labor-intensive, mechanical control may be required more than once per year.

Related to mechanical control is control by heat. In a Utah State University (USU) trial, burning suckers with a propane torch provided reasonable control that lasted several weeks. This may present an effective approach for a few suckers here and there. Treating an entire block with a torch would require very slow drive speeds, consuming a substantial amount of propane. Without care, damage could occur to irrigation tubing.

Chemical Control

Chemically controlling suckers can be effective and is less labor-intensive than mechanical control. A single operator can treat many acres in a day. Chemical controls for suckers can be grouped into three categories: plant growth regulators, herbicides, and desiccants.

Plant Growth Regulators. Commercial fruit growers have long used a synthetic auxin, Naphthalene Acetic Acid (NAA), to reduce the growth of suckers. This is the same plant growth regulator (PGR) used to thin fruit, but the timing and concentration are very different. Because NAA will cause a thinning response, application must be delayed until a month after petal fall. This allows time for the fruit to set and become less sensitive to NAA. Nevertheless, the application should be made at a low pressure (10-20 psi) using nozzles that produce large droplets to reduce drift. A specific formulation of NAA (Tre-Hold A-112™) is registered for this use. For apples, a 0.5% to 1% solution of NAA should reduce the growth of root suckers.

Herbicides. Some specific contact herbicides are registered for managing suckers on fruit trees. While registered for sucker suppression or control, they are still herbicides and can damage trees, especially young trees, where the bark is green and not yet corky. Therefore, take care to not treat tree trunks during application. Install trunk wraps on young trees before applying herbicide products. Contact herbicides have the added advantage of providing some control for weeds emerging after spring herbicide applications.

General application principles for herbicides to manage suckers include spraying only during calm winds, and using low pressure and large droplet size. Low drift nozzles are preferred. The use of off-center nozzles may lead to overspray on trunks. For these contact herbicides, good coverage of the sucker foliage is essential. Thus, spray sufficient water to wet the leaves thoroughly. Treating when suckers are still young and succulent and not woody achieves the best result.

Paraquat (Gramoxone™) is a caustic, non-systemic, post-emergent herbicide that burns green vegetation. Paraquat is rapidly absorbed by green plant tissues and reacts with photosynthesis to produce superoxides that kill plant cells. Highly toxic to humans, Paraquat is a restricted-use pesticide that can only be mixed and applied by certified pesticide applicators. It provides good burn-down of suckers at the higher rates.

Glufosinate (Rely 280™, Cheetah™) is another contact herbicide registered for sucker management. It is the slowest acting of the herbicide products included in this fact sheet. It can take 20-25 days to reach the level of control provided by the other herbicides in 10-14 days.

Carfentrazone-ethyl (Aim EC) is registered for sucker control in fruit trees. Aim must be applied using a hooded sprayer to minimize the opportunity for drift. Also, it must be mixed with an appropriate rate of a nonionic surfactant or crop oil concentrate. Although Aim is effective at controlling green and non-woody suckers, the opportunity for injury from drift makes this a less desirable choice.

Pyraflufen-ethyl (Venue) is a contact herbicide providing post-emergent control of a range of broadleaf weeds. It also has a supplemental label for controlling suckers in fruit trees. It is fast-acting and effective at the 4 fluid ounces per acre rate. Cherry suckers are more susceptible to Venue than apple.

Table 1. *Use Patterns for Herbicides Registered for Sucker Control in Tree Fruits*

Generic name Trade name	Rate/acre	Applications/year	Restricted-entry interval (REI) (hours)
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Photo 2. *Apple trees with profuse suckering one week after treatment with UAN in Kaysville, Utah. The treatment desiccated the foliage. Photo by Samuel Johnson.*

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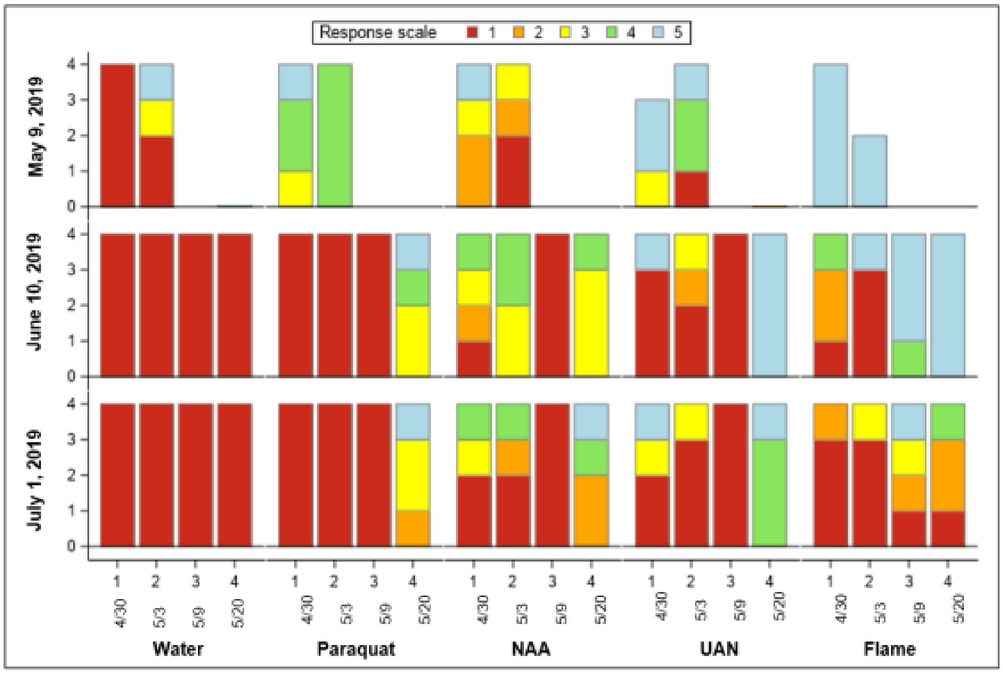

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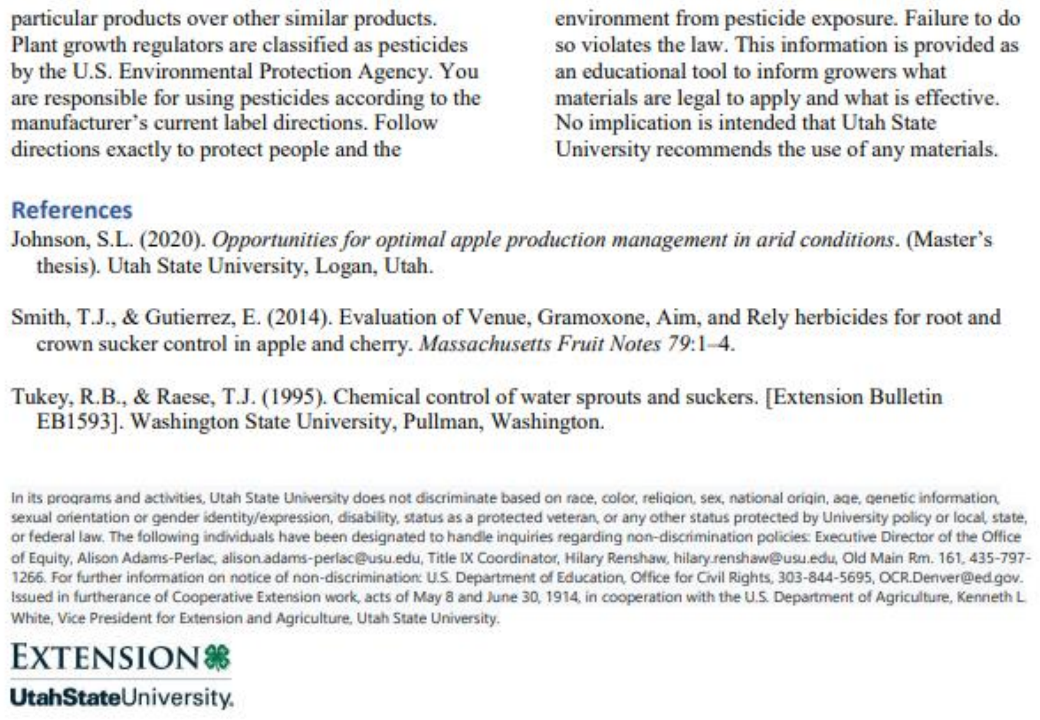

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