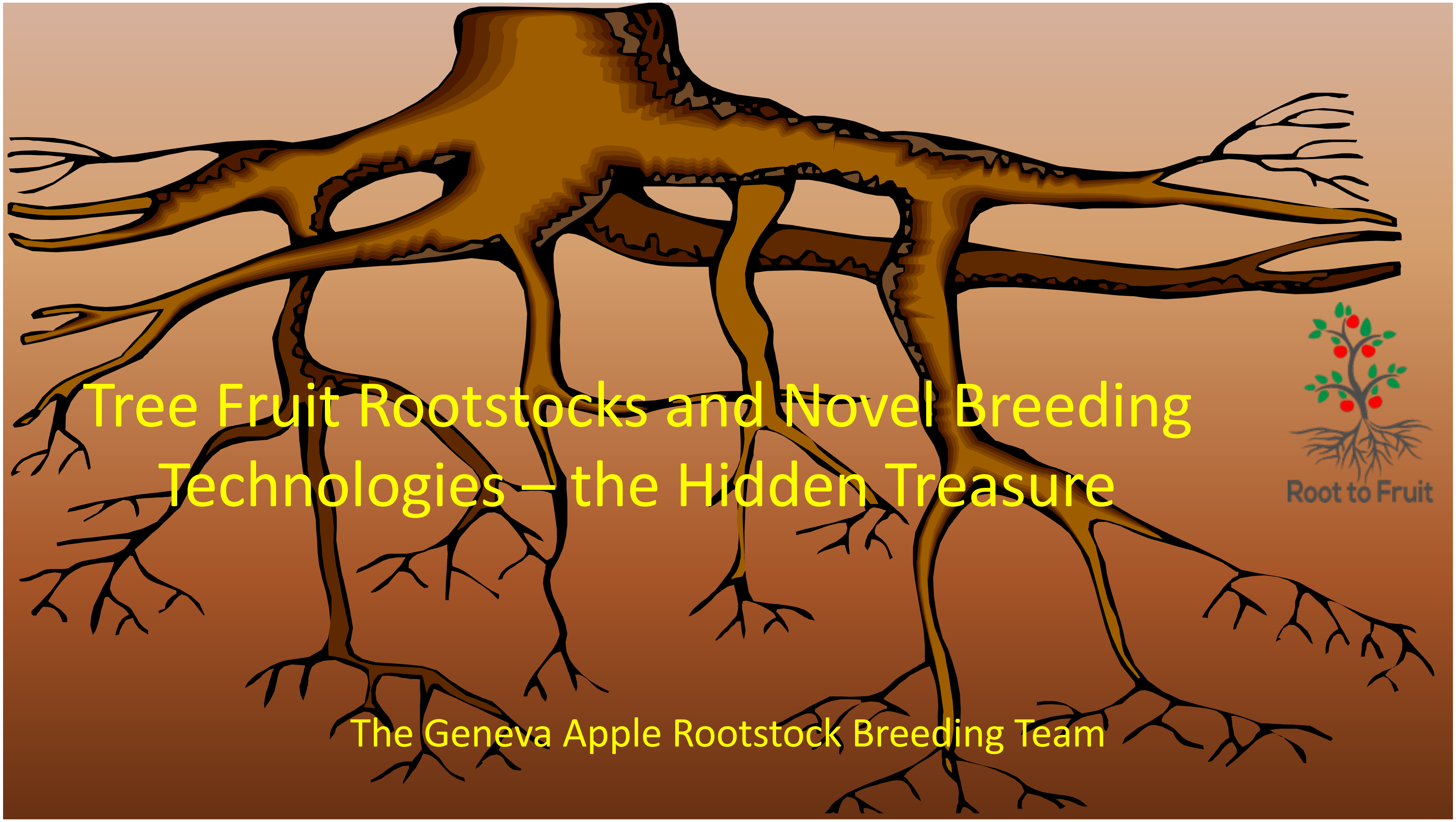
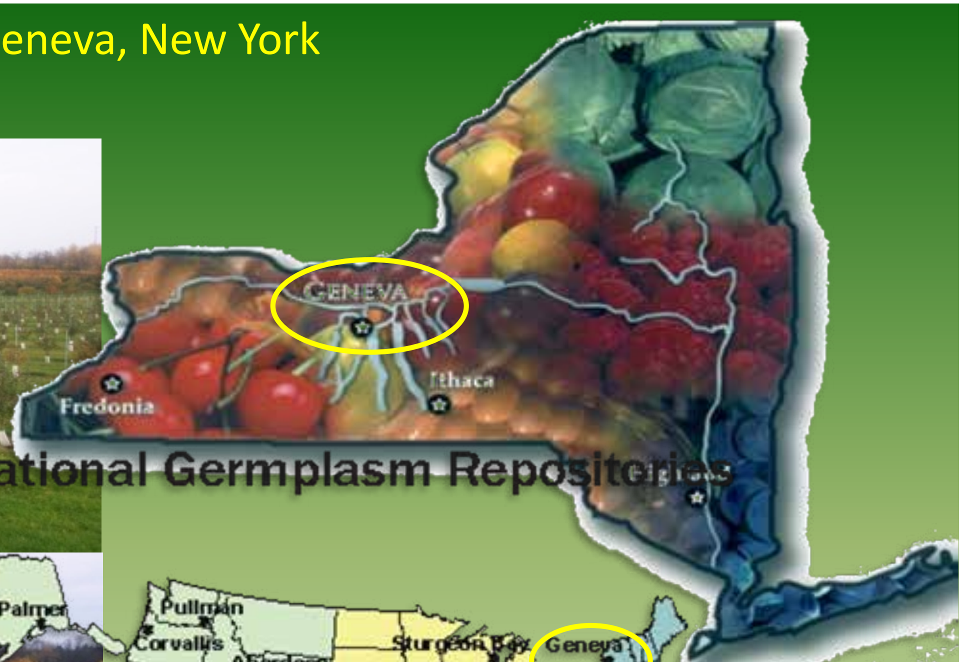

Tree Fruit Rootstocks and Novel Breeding Technologies – the Hidden Treasure
Root to Fruit
The Geneva Apple Rootstock Breeding Team

Plant Genetic Resources Unit (PGRU) Geneva, New York

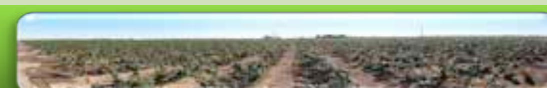
***Malus* - Apple - 3995 accessions 2430 clones (grafted) and 1565 seedlots from wild**

Wild *Malus* seedlings from 310 populations from Kazakhstan, Russia, China & Turkey



USDA United States Department of Agriculture
Agricultural Research Service

Apple Rootstock Breeding Program
Plant Genetic Resources Unit, Geneva, NY



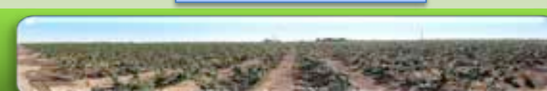
The Geneva® Apple Rootstock Breeding Program

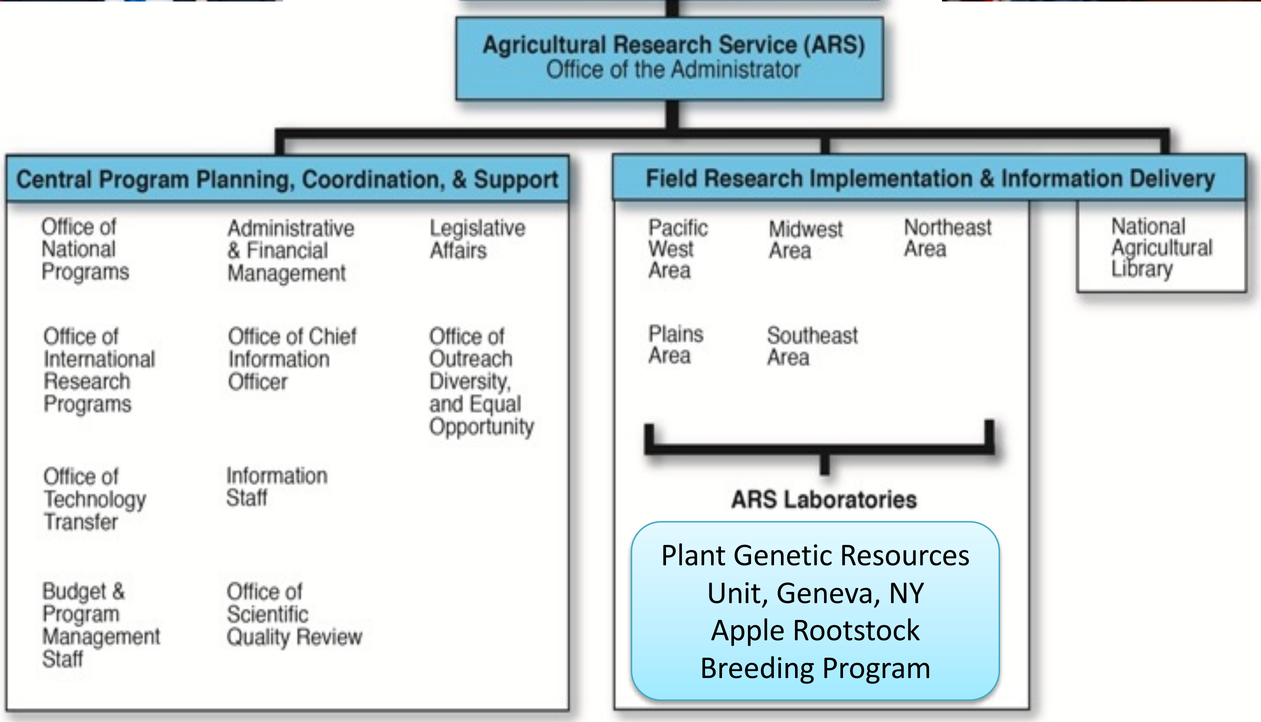
James Cummins Terence Robinson Herb Aldwinckle and Awais Khan

Charlie

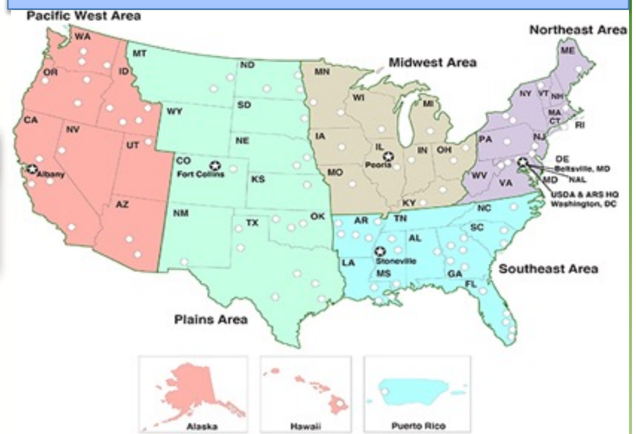
Sarah Bauer

Todd Holleran





ARS has about 2,000 scientists in 700 research projects working at 90+ locations, including overseas labs. The National Agricultural Library and the National Arboretum are also part of ARS.



USDA **United States Department of Agriculture**
Agricultural Research Service

Apple Rootstock Breeding Program
Plant Genetic Resources Unit, Geneva, NY

Courtesy of Dr. Tim Rinehart

ARS MISSION

ARS delivers scientific solutions to national and global agricultural challenges.

ARS will deliver cutting-edge, scientific tools and innovative solutions for American farmers, producers, industry, and communities to support the nourishment and well-being of all people; sustain our nation's agroecosystems and natural resources; and ensure the economic competitiveness and excellence of our agriculture.

ARS VISION

Global leadership in agricultural discoveries through scientific excellence.

ARS CORE VALUES

Scientific excellence, creativity, innovation, integrity, leadership, collaboration, accountability, transparency, diversity, respect, inclusiveness, and public service.

Courtesy of Dr. Tim Rinehart

complementary federal research

Agricultural Research Service

USDA's principal in-house research agency. In consultation with industry, ARS **National Program Leaders (NPLs) assign research objectives and funding** to 700 projects that are distributed at ARS labs across the U.S. ARS scientists at those locations perform the research to meet objectives and fulfil the mission. Base funding is perpetual and timelines are typically 10 years or more.

NIFA

National Institute of Food and Agriculture's (NIFA) advances agricultural research, education, and extension through extramural grant programs. **NIFA National Program Leaders distribute funding through competitive grant programs** to scientists, mostly university groups. Grant programs address specific agricultural problems or commodities authorized in the Farm Bill. Grant-based research funding typically lasts 3-5 years.

FFAR Foundation for Food and Agriculture Research

DEPARTMENT OF ENERGY UNITED STATES OF AMERICA

NSF

NIH National Institutes of Health

NASA

DARPA

Apple Rootstock Breeding Partnership between USDA-ARS and Cornell University

Leadership, Breeding and Genetics, human resources, funds

USDA ARS

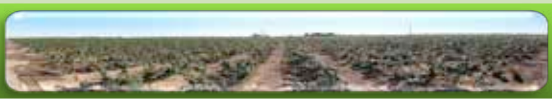
+

Cornell University

Horticulture, Plant Pathology, human resources, land

→

Apple Rootstock Breeding Program



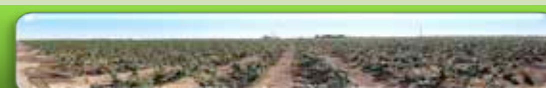
Commercial apple trees are a combination of two different genetic types: the ROOTSTOCK and the SCION (aerial system) which bears fruit.

1. The rootstock mother plants are layered with sawdust in a stoolbed to generate rooted rootstock shoots

2. Rooted rootstock shoots are harvested from the mother plant and planted in a nursery

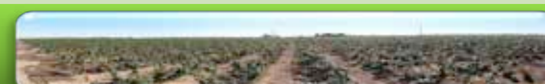
3. A bud from a scion variety like Gala or Granny Smith is grafted on the rootstock

4. The scion bud grows into a shoot and then into a mature apple tree. The rootstock will influence the productivity, size and precocity of the apple tree.



Courtesy of Richard Adams

Courtesy of Richard Adams



Budding/Grafting in Apples

Chip bud

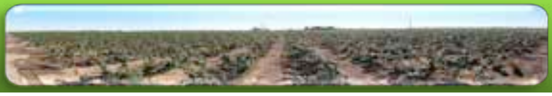
Source: Royal Horticultural Society

Whip/tongue

Source: Adelaide Kitchen Gardeners

Saddle

Source: Chris Vernon



Geneva Historical Perspective

Drs. Cummins and Aldwickle start selecting parents for apple rootstock breeding program

NOVOLE

G.65

G.30

G.11

G.16

G.202

G.41
G.935

G.214
G.969
G.890
G.210
G.222

G.814
G.213

G.484
G.66
G.257

1968 — 1978 — 1988 — 1998 — 2008

Robusta 5 identified as a good parent for fire blight resistance

Dr. Cummins retires

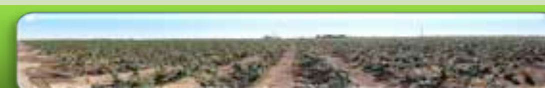
Production of Geneva rootstocks < 100 K Trees/Year

USDA ARS takes lead of the breeding program

Dr. Aldwinckle retires

Production of Geneva rootstocks > 15M Trees/Year

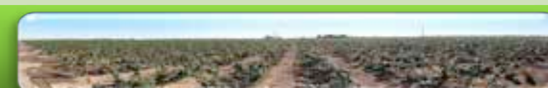
FOCUS: disease resistance (fire blight, phytophthora), productivity (dwarfing, precocity)



G.41

- M.9 vigor
- Very high yield efficient
- Highly productive
- Very precocious
- Resistant to replant disease
- Very cold hardy
- Does well in warmer climates (Mexico)
- Highly Resistant to Fire Blight and Crown Rot and Wooly Apple Aphid
- Requires tissue culture mother plants for stoolbed


G.41 Fuji CIV 2008



G.210

- Vigor similar to M.7
- Precocious, productive
- Yield efficiency similar or better than M.9
- Resistant to apple replant disease.
- Resistance to woolly apple aphid, fire blight, and crown rot.
- Good rooting in stoolbed few spines.
- Mostly for Organic Production

G.890

- Vigor between M.7 and MM.106
- Replacements for G.30
- Free standing
- Precocious, productive
- Yield efficiency similar or better than M.9
- Resistance to woolly apple aphid, fire blight, and crown rot.
- Tolerance to apple replant disease.
- Good rooting in stoolbed few spines.
- Mostly for processing industry

G.202

- Size similar to M.26
- Precocious, productive
- Resistant to woolly apple aphid, fire blight, and crown rot
- Tolerant to apple replant disease
- Good choice for weak growing cultivars like Honeycrisp
- Moderate rooting in stoolbed

G.214

- Vigor similar to M.9 Paj.2
- Highly yield efficient
- Highly productive (most U.S. trials yields 100-125% of M.9 check)
- Good precocity
- Resistant to Fire Blight, Crown Rot and Wooly Apple Aphid
- Replant tolerant
- Very good stool bed propagation
- Strong Graft Union

G.11

- Tree size similar to M.9 T337.
- Very high yield efficiency
- Large fruit size
- Partial tolerance to Replant Disease
- Resistant to Fire Blight but not immune.
- Resistant to Crown Rot
- Susceptible to Wooly Apple Aphid
- Good rooting in stoolbed
- Advances Maturation (France, Gala and Red Delicious)

G.969

- Vigor between M.26 and M.7
- Very efficient and productive
- Very cold tolerant
- Resistant to fire blight
- Resistant to Phytopthora
- Resistant to Wolly Apple Aphid
- Good Anchorage
- Excellent rootstock for weak scions like Honeycrisp

G.213

- Vigor similar to M.9 Paj.2
- Good yield efficiency
- High productivity 100-125% of M.9 check
- Very good precocity
- Resistant to Fire Blight, Crown Rot and Wooly Apple Aphid
- Replant tolerant
- Some spines in stool bed propagation
- Reduces chill requirement

G.213 VanAcker Williamson, NY

G.213 Vacaria, Brazil

G.814

- Size similar to Pajam 2
- Precocious, productive
- Promotes larger Fruit Size
- Upright branches
- Immune to fire blight, and resistant to crown rot
- Very tolerant to apple replant disease
- Susceptible to Wooly Apple Aphid
- Very susceptible to viruses (ASPV, ASGV, ACLV)
- Good rooting in stoolbed

G.202

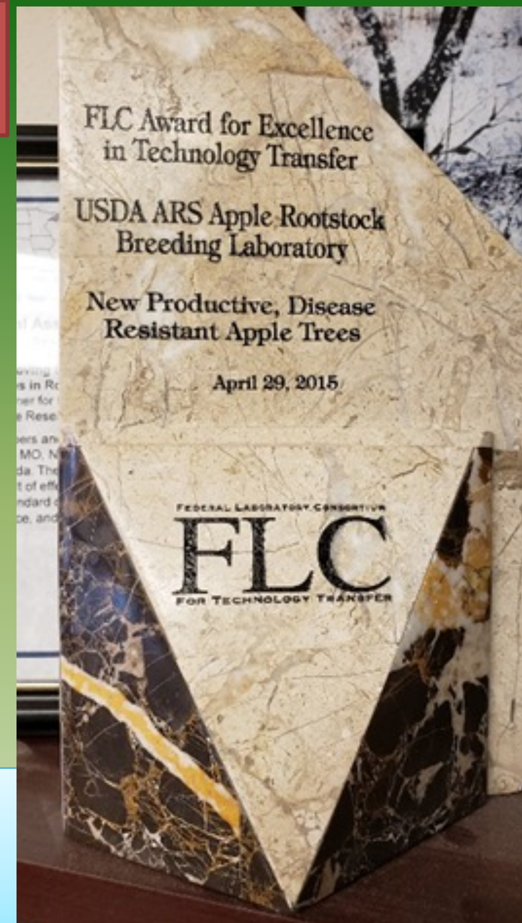
- Size similar to M.26
- Precocious, productive
- Resistant to woolly apple aphid, fire blight, and crown rot
- Tolerant to apple replant disease
- Good choice for weak growing cultivars like Honeycrisp
- Moderate rooting in stoolbed

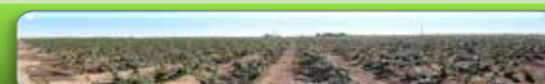
GOOD Tech Transfer is Essential for Success!!

Apple Rootstock Breeding Program (USDA ARS and Cornell Partnership) was Awardee of the Federal Labs Consortium 2015 Excellence in Technology Transfer – competing against other federal labs (NASA, U.S. Army, Naval Research Laboratory, etc.)

- Feedback on nursery performance.
- Support research.
- Word of mouth Extension
- May be able to do things that some other public institutions can't

Really?!?!? Apple Rootstocks?

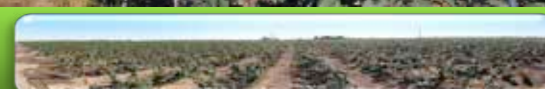





Left: Honeycrisp tree on G.969 rootstock grafted with clean, virus free wood growing well. Above and right: Rootstock field trial at a Stemilt Growers orchard in Quincy, WA featuring Geneva rootstocks. These growers' trials are essential for field performance evaluation.

United States Department of Agriculture
Agricultural Research Service

Apple Rootstock Breeding Program
Plant Genetic Resources Unit, Geneva, NY

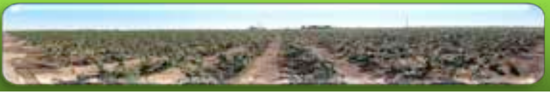


Apple trees on Geneva rootstocks at Willow Drive Nursery (family owned) in Ephrata, WA.

Geneva Rootstock Propagation Beds at Willow Drive Nursery in Ephrata, WA

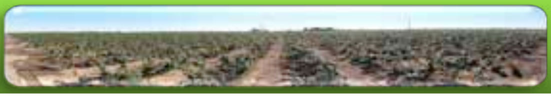
USDA United States Department of Agriculture
Agricultural Research Service

Apple Rootstock Breeding Program
Plant Genetic Resources Unit, Geneva, NY

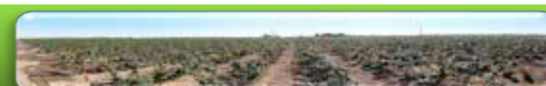


Geneva Apple Rootstock Propagation Beds in Full Production at Cameron Nursery in Eltopia, WA

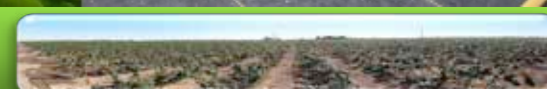
Experimental Apple Rootstocks being tested at Cameron Nursery after being planted in June of 2021. Before propagation beds look like the ones above, they need to be tested for several years to monitor rooting and architecture properties.



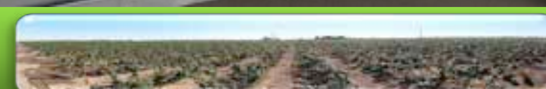
Apple trees raised in pots and apple rootstock propagation beds at Kit Johnston Nursery in Oregon



Tissue culture (micropropagation) derived Geneva rootstocks at different stages all the way to grafted finished potted trees ready for transplant into the orchard. (North American Plants, OR)

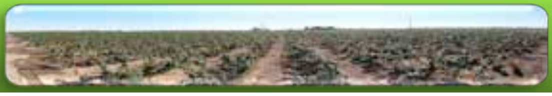


The next set of California and US (NC140) cider apple trials being propagated at Sierra Gold Nursery, Yuba City, CA. Dr. Micah Stevens showing off the experimental material.



In addition to growing experimental rootstocks and trees, Sierra Gold produces millions of cherry, peach, almond and apple trees

Organic Rootstock Field Trial at Lodi Fruit Farms (Replacement trees where trees on different rootstocks had died)

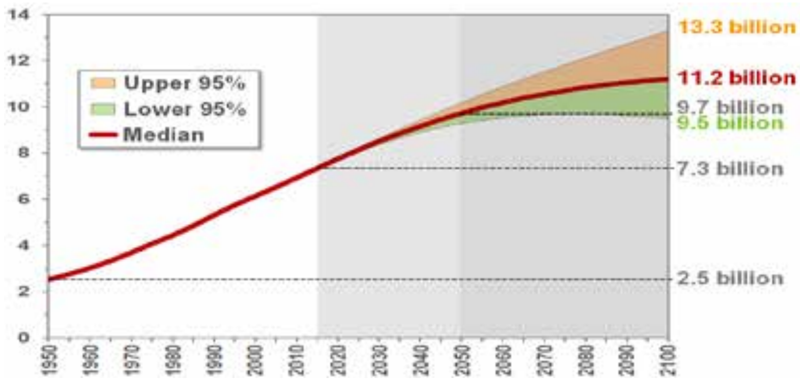


Geneva® rootstock field day in Brazil




Geneva® rootstock field day in Mexico

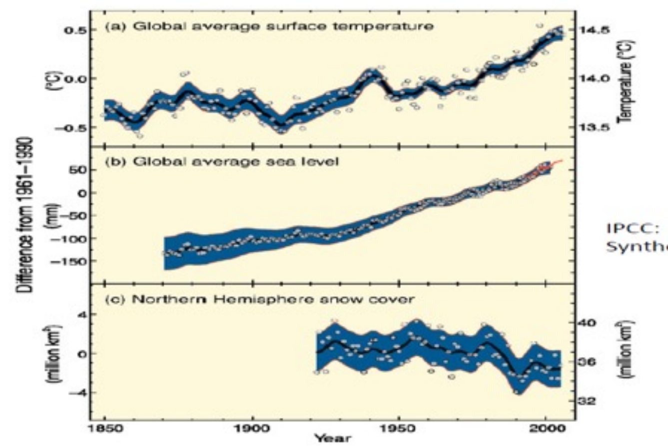
POBLACIÓN MUNDIAL-2050



PRODUCCIÓN ALIMENTOS

Dr. Ignasi Iglesias

CAMBIO CLIMÁTICO



USO EFICIENTE RECURSOS + INN. TEC.

SOSTENIBILIDAD AMBIENTAL

SOSTENIBILIDAD DE RENTAS

COSTES

COSTE MANO DE OBRA-2019

Dr. Ignasi Iglesias

País	Coste horario (€/h)	Coste diario (€/dia) 8h
Francia	12,2	97,6
Italia (Emilia Romagna)	10,7	85,6
Israel (Rosh Pina)*	10,2	81,6
España	8,6	68,8
Portugal	5,7	45,6
Grècia	3,7	29,6
Sèrbia	2,6	20,8
Polònia	2,5	20,0
Brasil	4,3	34,4
Chile	2,7 6,5	21,6 (fijo) 52,0 (temporal+cereza)
USA (Califor.-Washing.)	15,0-24,0	120-192
Argentina	5,6	44,8 (temporal) / (30 al 2008)
Armènia	2,6	20,8
Georgia	2,4	19,2
Rússia meridional	2,6	20,8
Bulgària	1,6	12,8
Rumania	1,5	12,0
Ucraïna	1,3	10,4
Turquia	1,6-2,2	12,8-17,6
Marruecos	0,9-1,5	7,2-12,0
Tunez	0,8	6,4

(*): 8.000 m^3/ha water = 3.500 €/ha

Iglesias, 2019

Dr. Ignasi Iglesias

Two key factors for sustainability: environmental and grower's income

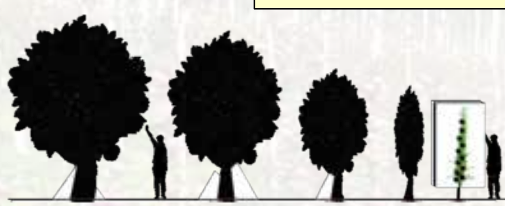
Dr. Ignasi Iglesias

- The variety:

Price consumer-grower
SUSTAINABILITY INCOME

- The rootstock/training system:

Cost of production
ENVIRONMENTAL SUSTAINABILITY



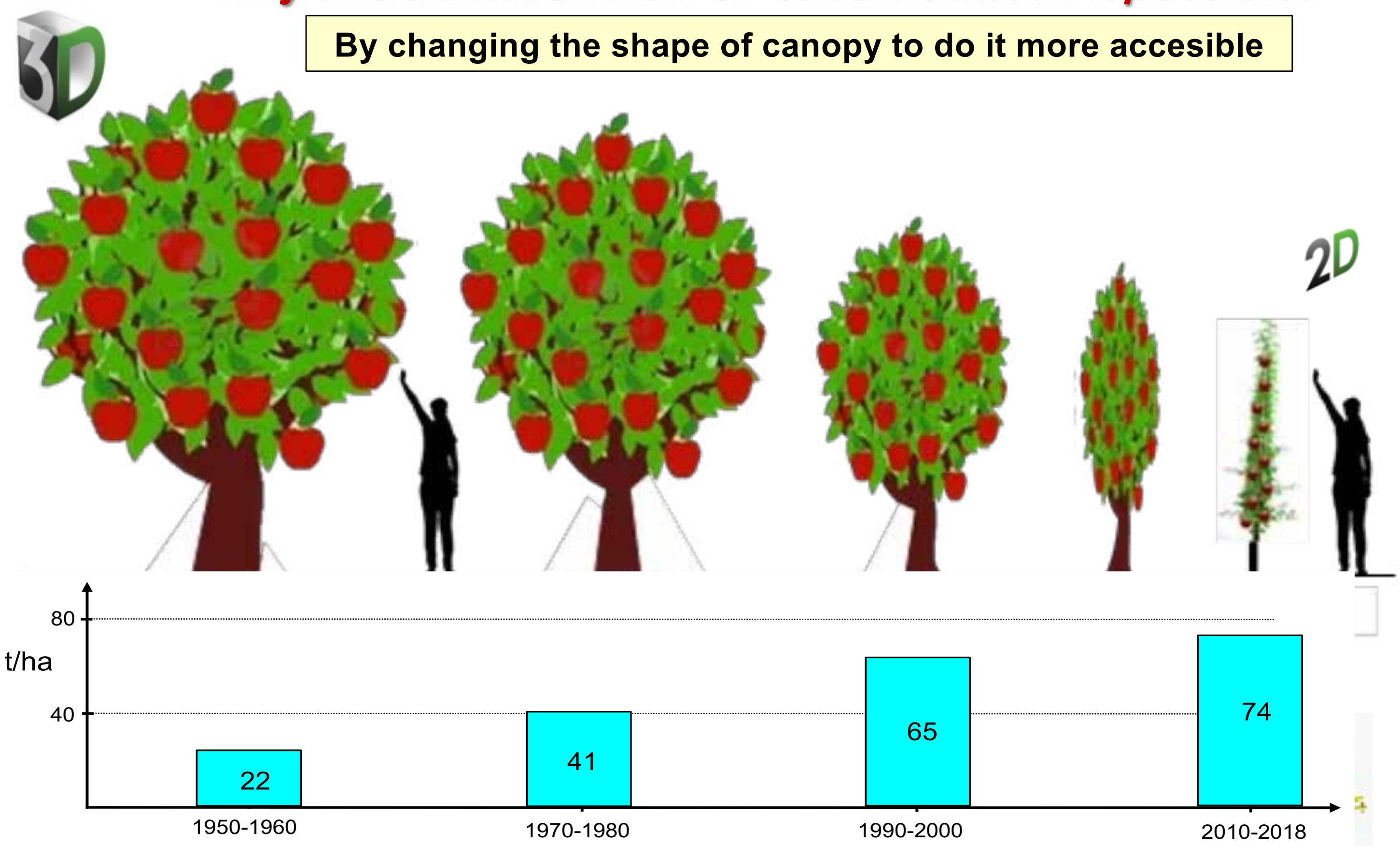
What is more productive?

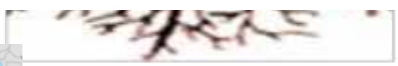
Same Fuji apple scion.

Different rootstocks!

Why this transition from 3D to 2D has been it possible?

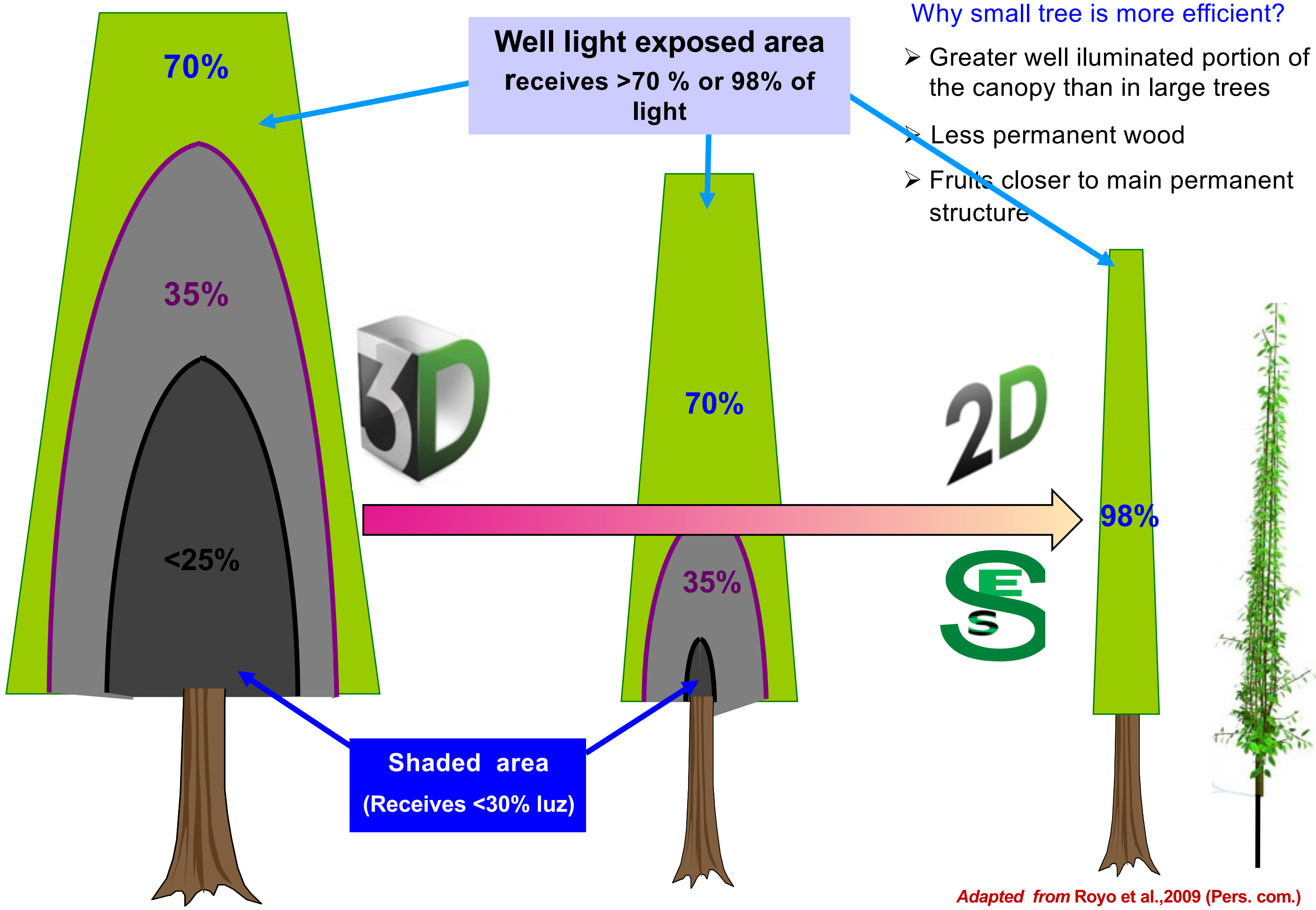
By changing the shape of canopy to do it more accesible





By genetics: breeding for new rootstocks

The effect of volume canopy on yield & light exposition



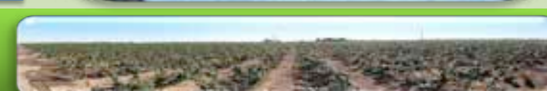
Adapted from Royo et al.,2009 (Pers. com.)

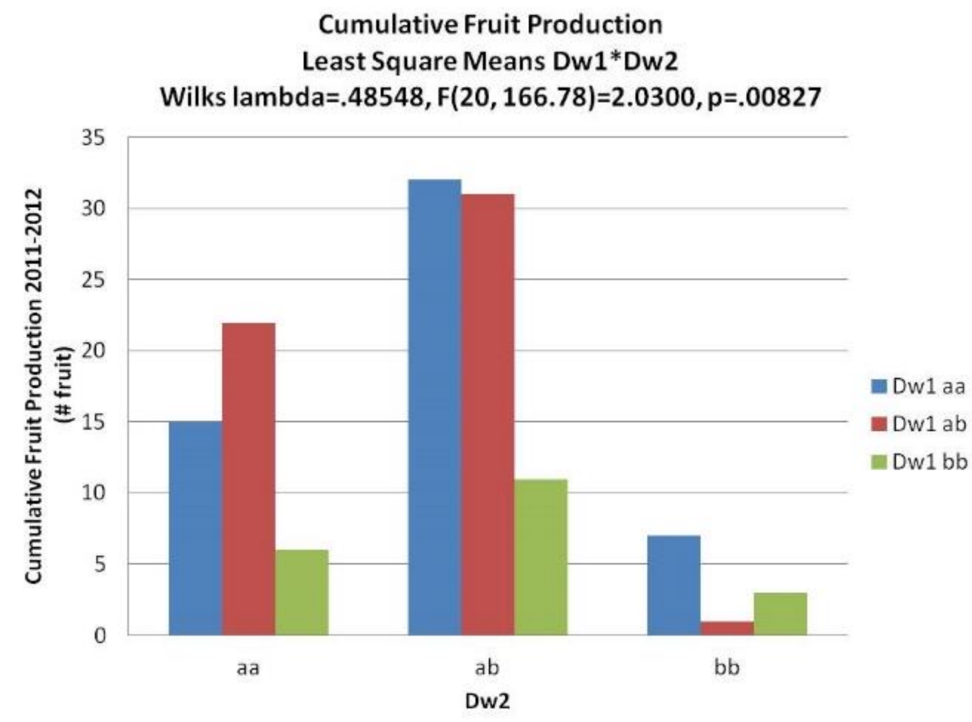
Benefits from the implementation of dwarfing rootstocks

Less sprays, easier mechanization

Less ladder accidents, improved ergonomics for picking

Increased productivity and efficiency





Possible to predict
Tree Size
on the basis of allelic combinations
Dw1 aa ab bb with DW2 aa ab bb

J. Amer. Soc. Hort. Sci. 139(2):1–12. 2014.

Dw2, a New Dwarfing Locus in Apple Rootstocks and Its Relationship to Induction of Early Bearing in Apple Scions

Gennaro Fazio[1]
Plant Genetics Resources Unit, USDA-ARS, 630 W. North Street, Geneva, NY 14456

Yizhen Wan
Apple Research Center, College of Horticulture, Northwest A&F University, Yangling, Shaanxi 712100, China

Dariusz Kviklys
Lithuanian Institute of Horticulture, Babtai, Lithuania

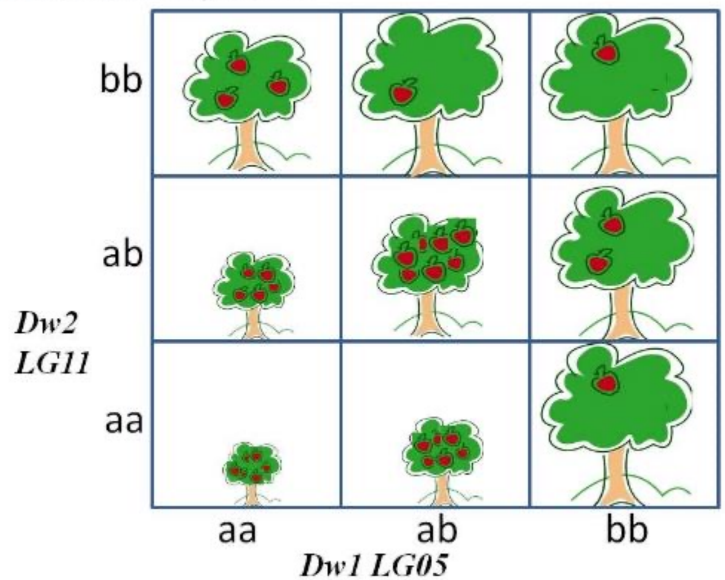
Letitia Romero
Facultad de Ciencias Agrotecnológicas, Ciudad Universitaria s/n Campus 1 C.P. 31310 A.P. 24 Chihuahua, Mexico

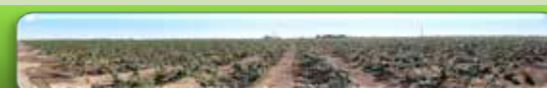
Richard Adams
Willow Drive Nursery, 3539 RD 5 NW, Ephrata, WA 98823

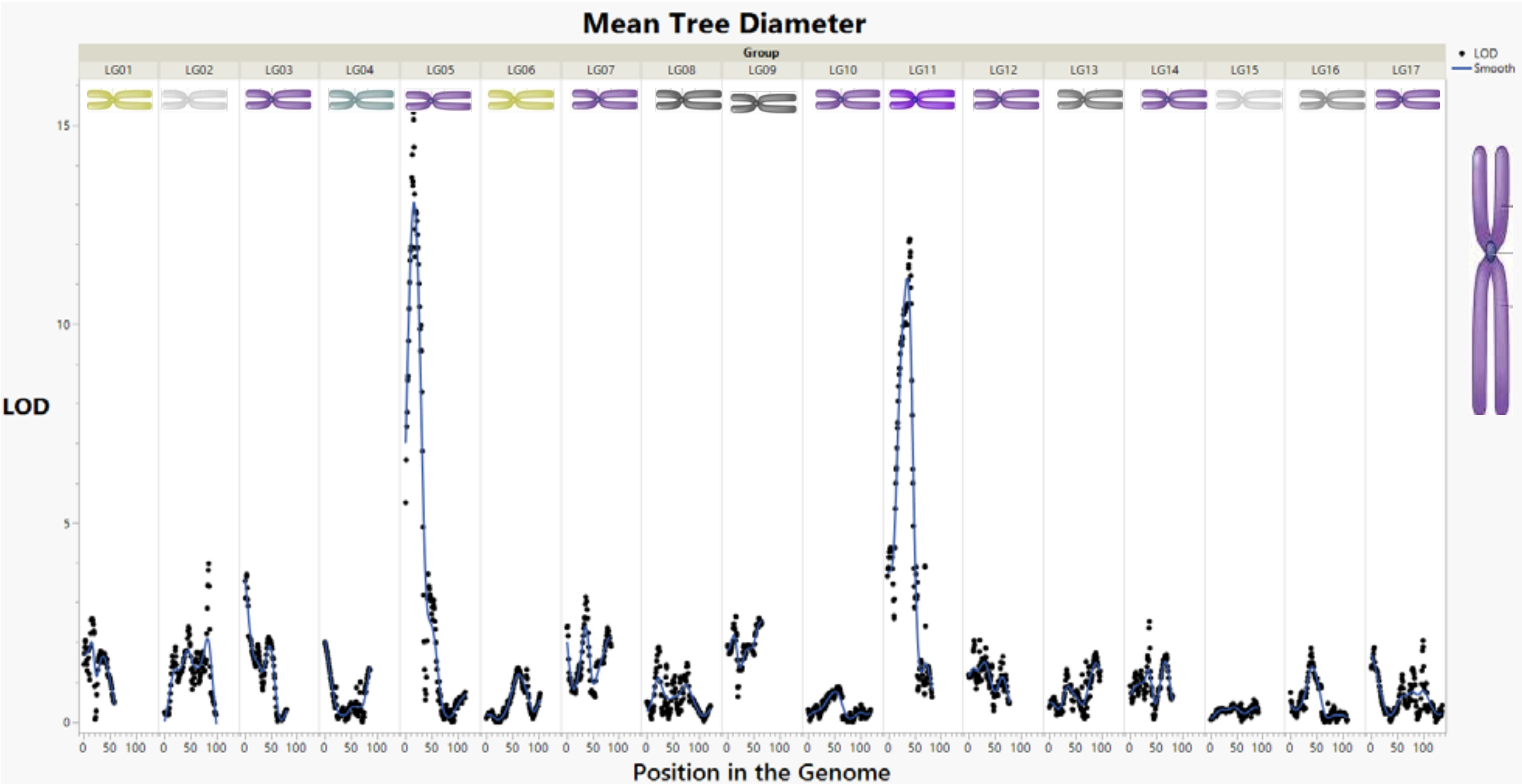
David Strickland
Department of Molecular & Cellular Biology, Dartmouth University, Hanover, NH 03755

Terence Robinson
Department of Horticulture, NYSAES, Cornell University, Geneva, NY 14456

Highest fruit production in heterozygous plants



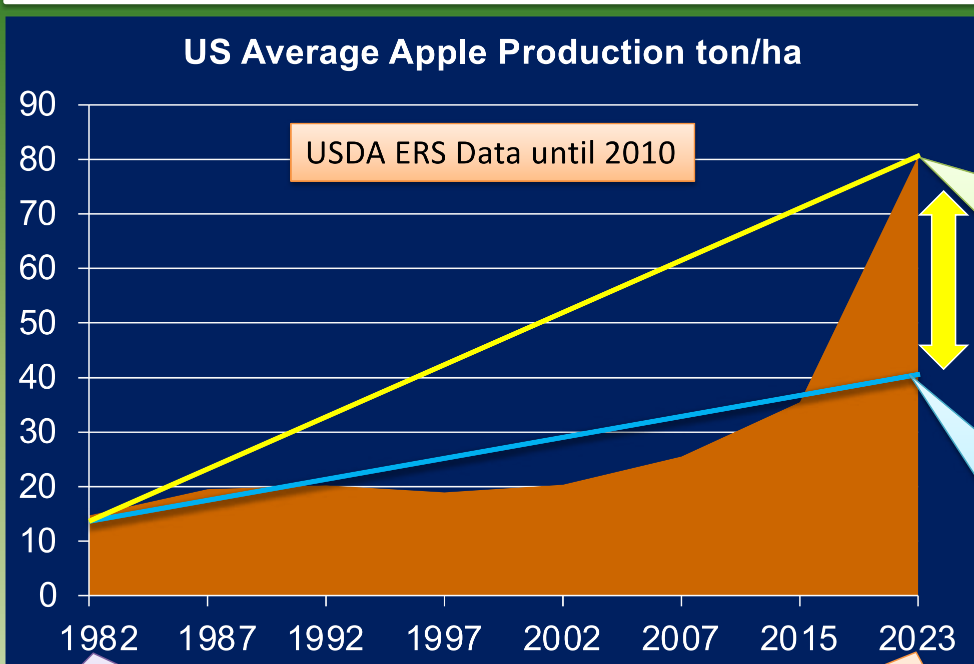




USDA United States Department of Agriculture
Agricultural Research Service

Apple Rootstock Breeding Program
Plant Genetic Resources Unit, Geneva, NY

Economic Impact of Dwarfing Precocious Apple Rootstocks on U.S. Apple Production



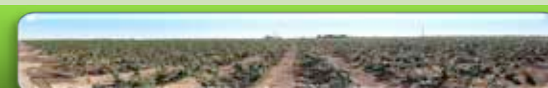
61% Increase due to the application of **dwarfing** and **early bearing** rootstocks

38% Increase due to better management practices and inputs (fertilizers, sprays, etc.)

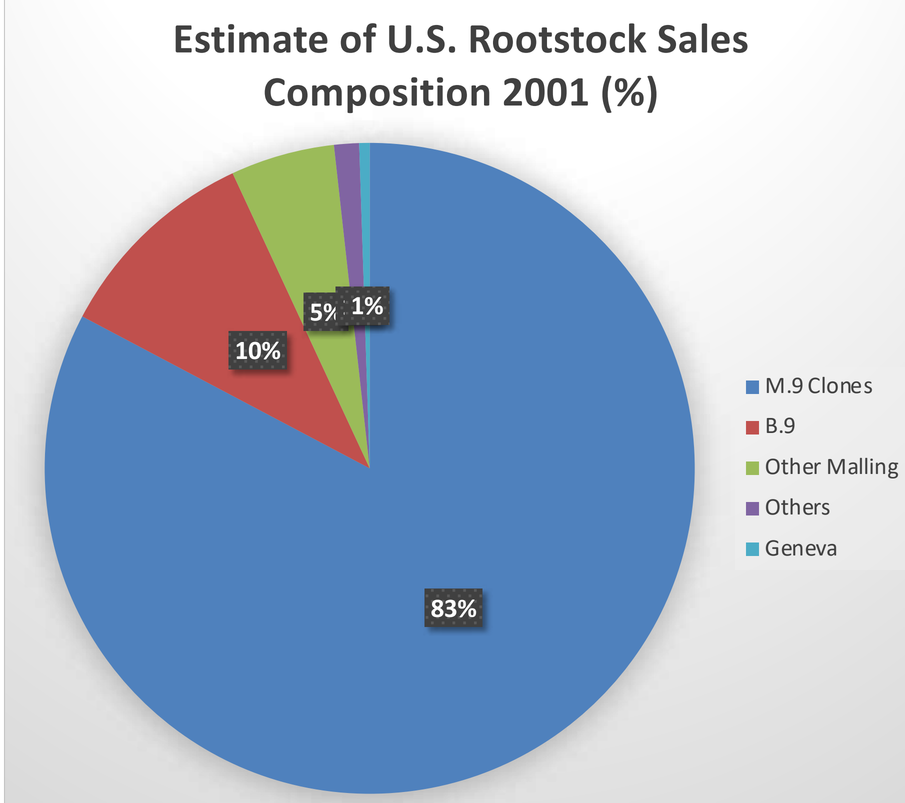
40% of rootstocks sold were dwarfing and early bearing

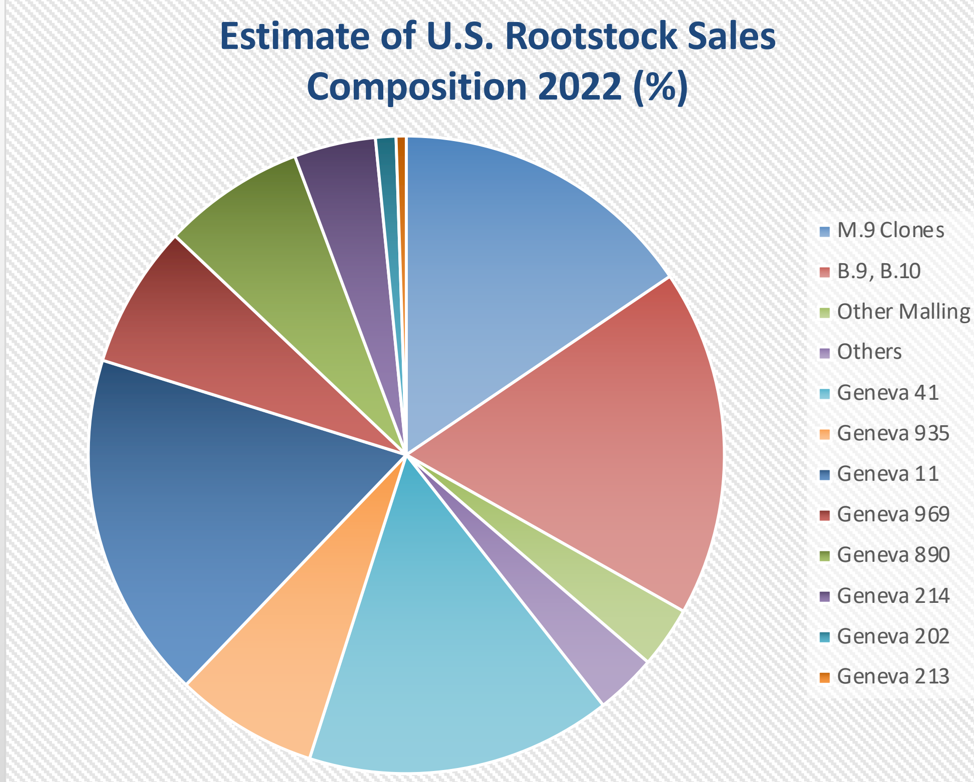
93% of rootstocks sold were dwarfing and early bearing

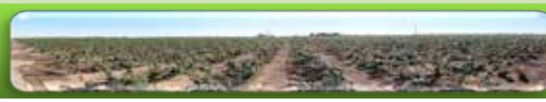
Farmgate value of U.S Apples is $ 3.6 Billion.
There are 2-3 major genes involved in **dwarfing and early bearing** in apple rootstocks.
One can extrapolate that at least 50% ($1.8B) of that farmgate value can be attributed to the application of genes involved in the implementation of dwarfing and early bearing



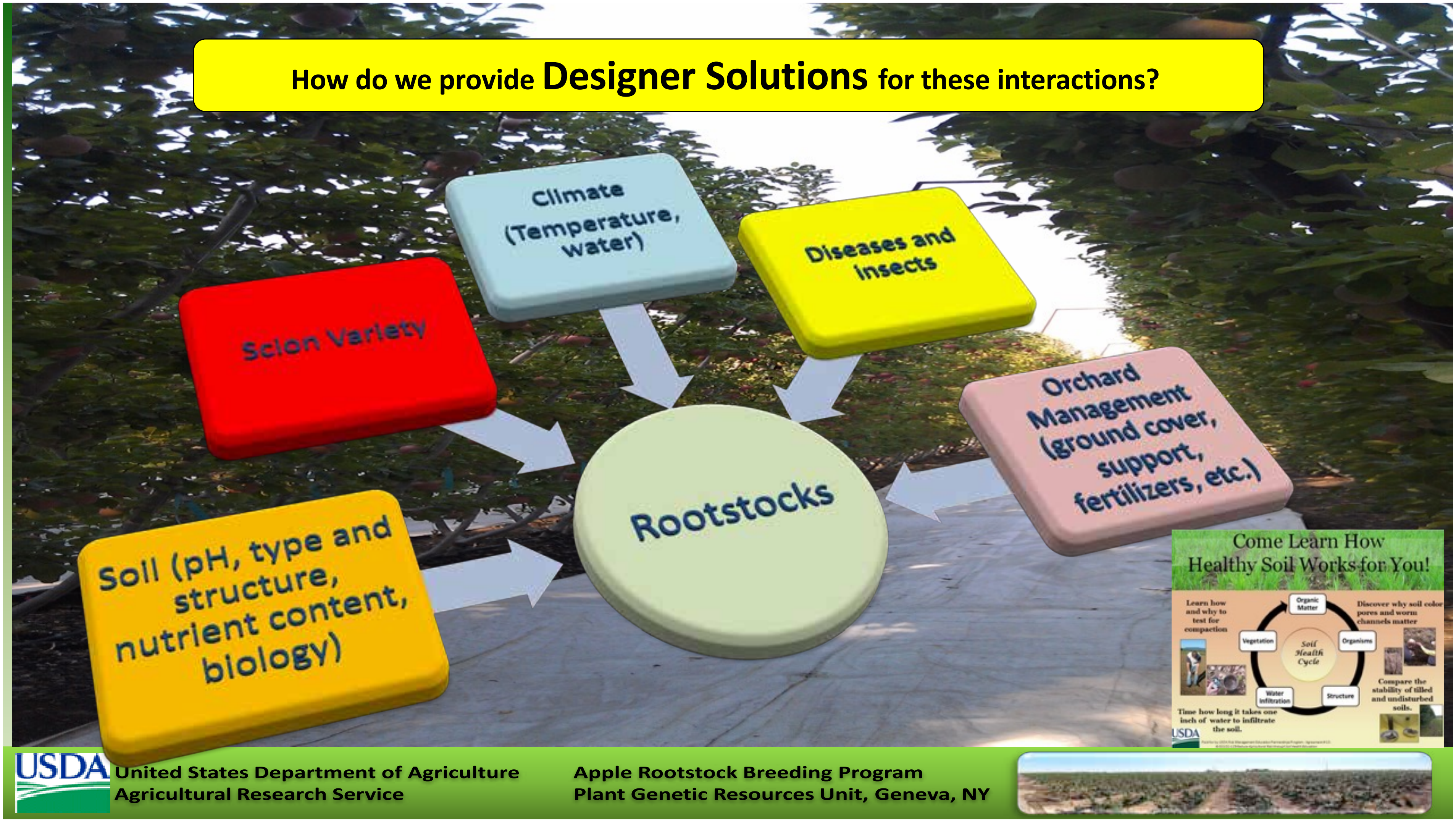
Genetic (Phenotypic) Diversity is the Key!







Diverse rootstocks can support different training system dynamics: fruiting wall vs V trellis, single vs multi axes.


How do we provide Designer Solutions for these interactions?
Climate (Temperature, water)
Diseases and insects
Scion Variety
Orchard Management (ground cover, support, fertilizers, etc.)
Rootstocks
Soil (pH, type and structure, nutrient content, biology)
Come Learn How Healthy Soil Works for You!
Soil Health Cycle
Organic Matter
Organisms
Structure
Water Infiltration
Vegetation
USDA
United States Department of Agriculture
Agricultural Research Service
Apple Rootstock Breeding Program
Plant Genetic Resources Unit, Geneva, NY

Decade Level Research needed for rootstocks!

ELSEVIER
Scientia Horticulturae
Volume 246, 27 February 2019, Pages 506-517

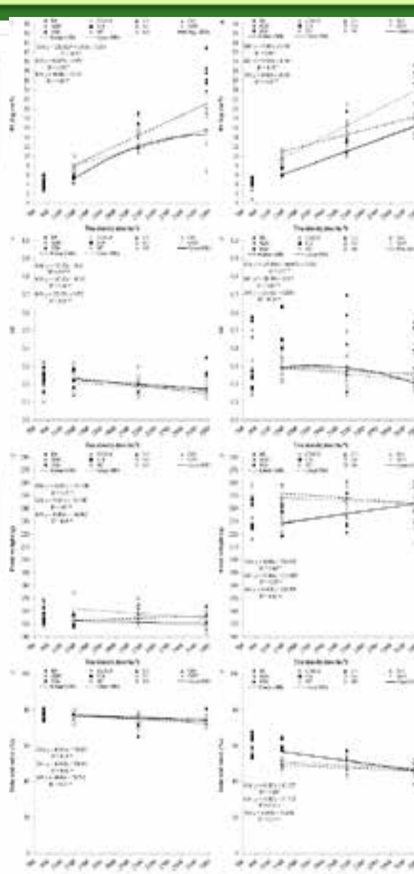
Effect of tree type and rootstock on the long-term performance of 'Gala', 'Fuji' and 'Honeycrisp' apple trees trained to Tall Spindle under New York State climatic conditions

Gemma Reig[a,b], Jaume Lordan[b], Mario Miranda Sazo[c], Stephen Anthony Hoying[a], Michael J. Fargione[d], Gabino Hernan Reginato[e], Daniel J. Donahue[f], Poliana Francescatto[b], Gennaro Fazio[b], Terence Lee Robinson[b]

ELSEVIER
Scientia Horticulturae
Volume 244, 26 January 2019, Pages 277-293

Long-term performance of 'Gala', Fuji' and 'Honeycrisp' apple trees grafted on Geneva® rootstocks and trained to four production systems under New York State climatic conditions

Gemma Reig[a], Jaume Lordan[b], Mario Miranda Sazo[c], Stephen Hoying[a], Michael Fargione[d], Gabino Reginato[e], Daniel J. Donahue[d], Poliana Francescatto[b], Gennaro Fazio[b,f], Terence Robinson[b]



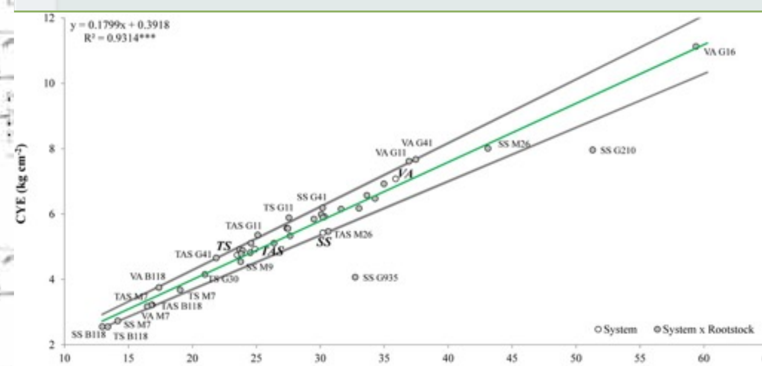
American Society for Horticultural Science

Long-term Performance of 'Delicious' Apple Trees Grafted on Geneva® Rootstocks and Trained to Four High-density Systems under New York State Climatic Conditions

in HortScience

Authors: Gemma Reig[1], Jaume Lordan[2], Stephen Hoying[3], Michael Fargione[4], Da... View More +

DOI: https://doi.org/10.21273/HORTSCI14904-20
Page Count: 1538–1550
Volume/Issue: Volume 55: Issue 10
Article Category: Research Article
Online Publication Date: 21 Aug 2020



Regression relationship of cumulative crop load (CCL) with cumulative yield efficiency (CYE) for four orchard systems and 40 treatments. The linear regression is represented by the green line, whereas the 95% confidence interval is represented by the gray lines. Regressions were analyzed by a Student t-test (*P < 0.05; **P < 0.01; ***P < 0.001; ns, not significant). SS = Super Spindle; TAS = Triple Axis Spindle; TS = Tall Spindle; VA = Vertical Axis.

LONG TERM PERFORMANCE

Average life of an apple orchard is 15 years; therefore, decade long research is needed to properly evaluate rootstock performance "Long Term" is key for Tech Transfer

HortScience 55(10):1538–1550. 2020. https://doi.org/10.21273/HORTSCI14904-20

Long-term Performance of 'Delicious' Apple Trees Grafted on Geneva® Rootstocks and Trained to Four High-density Systems under New York State Climatic Conditions

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Long-term performance of 'Gala', Fuji' and 'Honeycrisp' apple trees grafted on Geneva® rootstocks and trained to four production systems under New York State climatic conditions

I. Mineral nutrient profiles and relationships of 'Honeycrisp' grown on a genetically diverse set of rootstocks under Western New York climatic conditions

II. Horticultural performance of 'Honeycrisp' grown on a genetically diverse set of rootstocks under Western New York climatic conditions

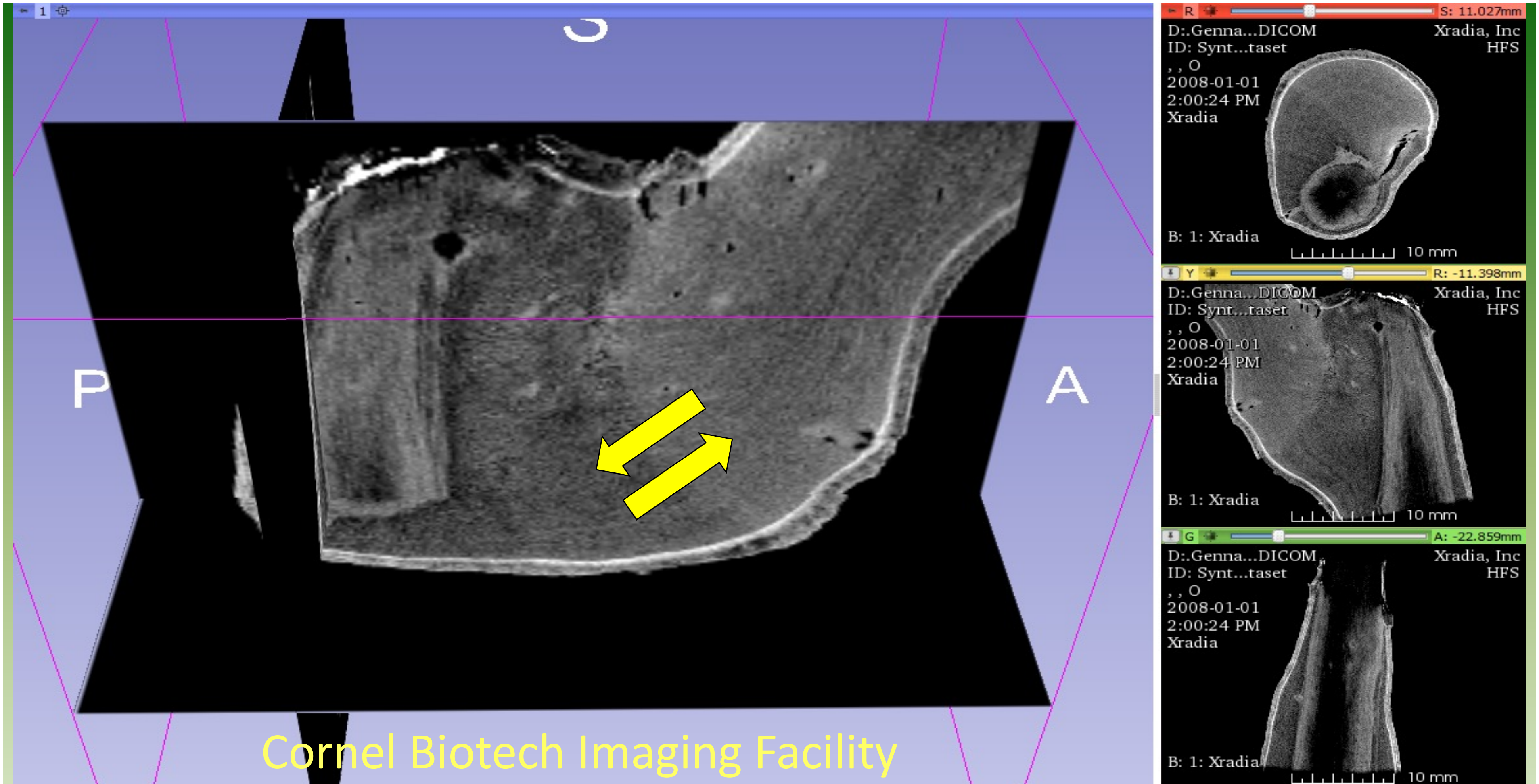
HortScience · https://doi.org/10.21273/HORTSCI15492-20

Performance of Semi-dwarf Apple Rootstocks in Two-dimensional Training Systems

Nicola Dallabetta, Andrea Guerra, and Jonathan Pasqualini
FEM-IASMA, Technology Transfer Center, San Michele a/A, TN, Italy

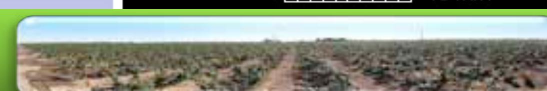
Gennaro Fazio
U.S. Department of Agriculture Agricultural Research Service, Plant Genetics Resources Unit, Cornell AgriTech, Geneva, NY 14456; and Horticulture Section, School of Integrative Plant Sciences, Cornell AgriTech, Cornell University, Geneva, NY 14456

Additional index words. fruit size, fruit quality, yield efficiency, planar training system, mechanical pruning, crop value



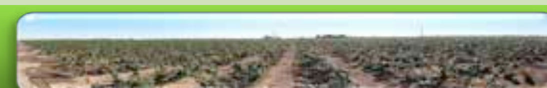
United States Department of Agriculture
Agricultural Research Service

Apple Rootstock Breeding Program
Plant Genetic Resources Unit, Geneva, NY



Examples of root(stock) induced traits on the scion

- Dwarfing and Early Bearing of Scion
- Branch angle modification and increased branching
- Increased flowering and bud break in low chill environments
- Hormone balances through the graft union
- Mineral nutrient concentration in the scion
- Increased whole tree tolerance to fire blight

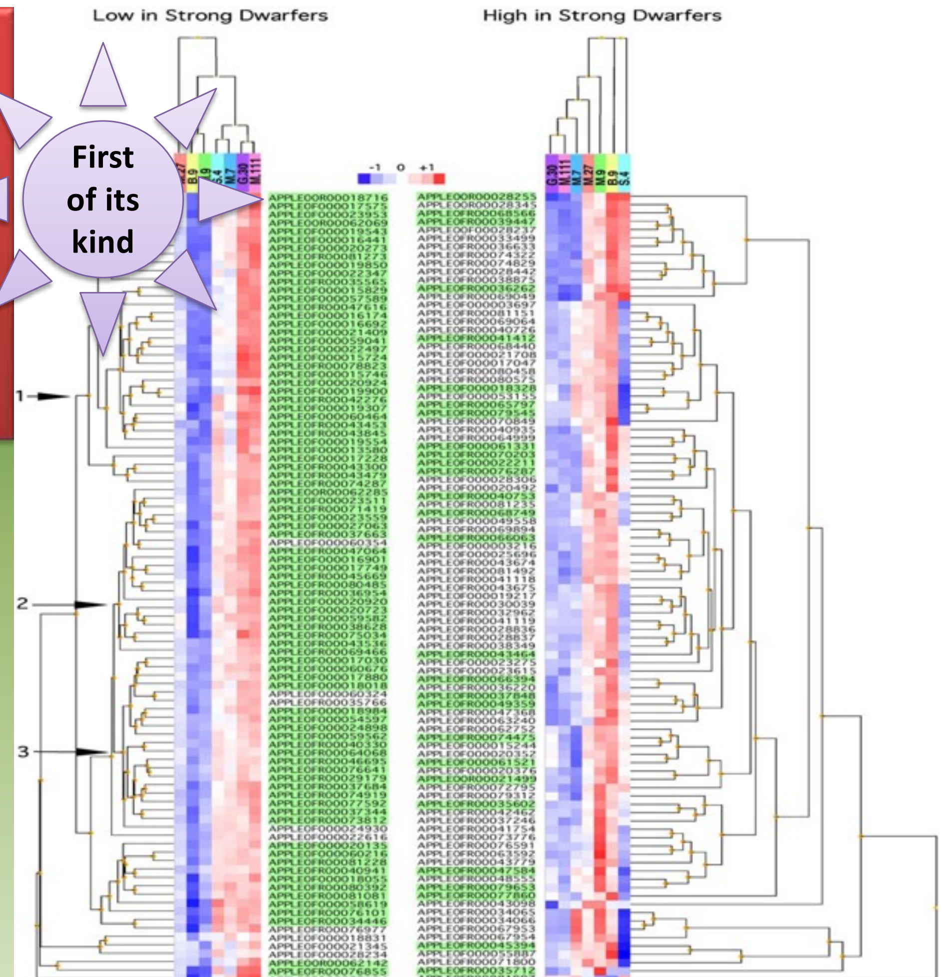


Rootstock-regulated gene expression patterns in apple tree scions

Philip J. Jensen, Izabela Makalowska , Naomi Altman, Gennaro Fazio, Craig Praul, Siela N. Maximova, Robert M. Crassweller, James W. Travis, Timothy W. McNellis

Tree Genetics & Genomes (2010) 6:57–72

First of its kind

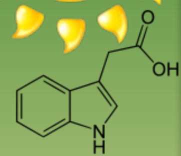


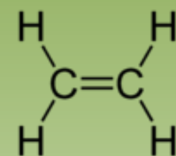
- How do different root(stock) genotypes communicate with scion tissues such that they modify global and specific gene expression of the same scion in a unique way?

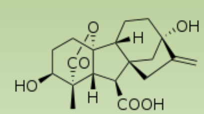
- Same Gala Scion
- Based on Nimblegen Apple EST Chip
- 26,020 unigene contigs
- 60 mer oligonucleotides
- 3-6x internal replication

How Do Rootstocks Affect Fruit Quality?

- **Changes in tree architecture cause different exposure to the sun.**
- **Changes in water availability**
- **Changes in nutrient availability**
- **Changes in phytohormone status**
- **And more….**






Ca

Zn

Na

Mo

Mn

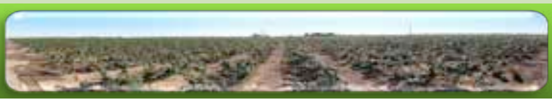
Mg

Cu

K

P

Fe



CRISIS CLIMÁTICA · Informe de la Organización Meteorológica Mundial

La concentración de gases de efecto invernadero alcanza un nuevo récord

Los niveles de CO2 llegaron a las 407,8 partes por millón en 2018, una cifra nunca antes vista. Los expertos advierten de que seguirá aumentando "con efectos cada vez más graves"

El secretario general de la OMM, Petteri Taalas, presenta el informe sobre el calentamiento global. FABRICE COFFRINI AFP

La concentración de gases de efecto invernadero en la atmósfera ha alcanzado un nuevo récord histórico. Los científicos, además, advierten de que el incremento está

25. nov. 2019

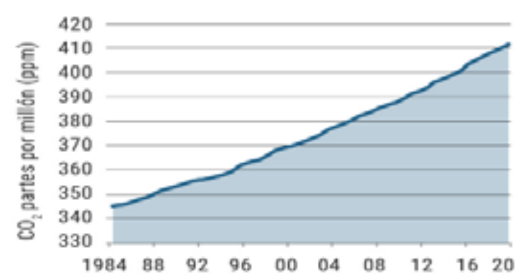
La cifra es la más elevada desde que existen mediciones y, según estiman los expertos, equivale a la concentración de CO2 que se dio en la Tierra **hace entre tres y cinco millones de años,** un dato que se obtiene al analizar las burbujas de aire que quedan atrapadas en el hielo.

"En ese entonces, la temperatura era de 2 a 3 grados centígrados más cálida y el nivel del mar, entre 10 y 20 metros superior al actual", indica el secretario general de la OMM, Petteri Taalas.

Además, "hay una diferencia fundamental", advierte Emilio Cuevas, director del Observatorio Atmosférico de Izaña (AEMET), uno de los puntos desde los que se miden las concentraciones de gases. "Esas variaciones que había antes se producían de forma natural a lo largo de miles de millones de años, pero los cambios que estamos viendo ahora mismo **se están produciendo en décadas**".

AUMENTO DE DIÓXIDO DE CARBONO

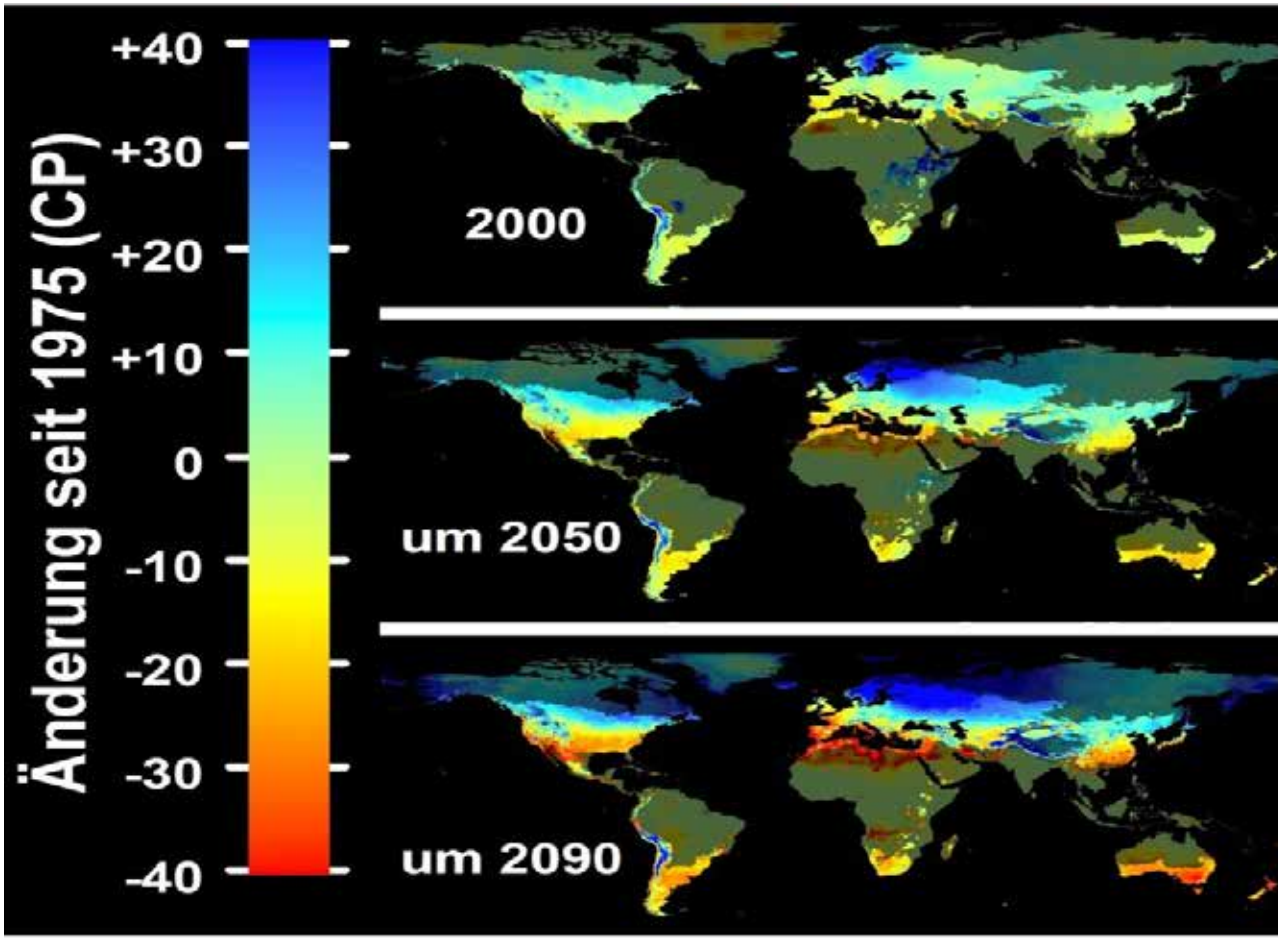
Tendencia interanual (+1,9 ppm/año)



FUENTE: Aemet.

Dr. Ignasi Iglesias

Prediction of lack of winter chill worlwide



Dr. Ignasi Iglesias

Luedeling, Blanke et al. 2013: Int J Biometerology 57, 679f

universitätbonn

Impact on chilling hours

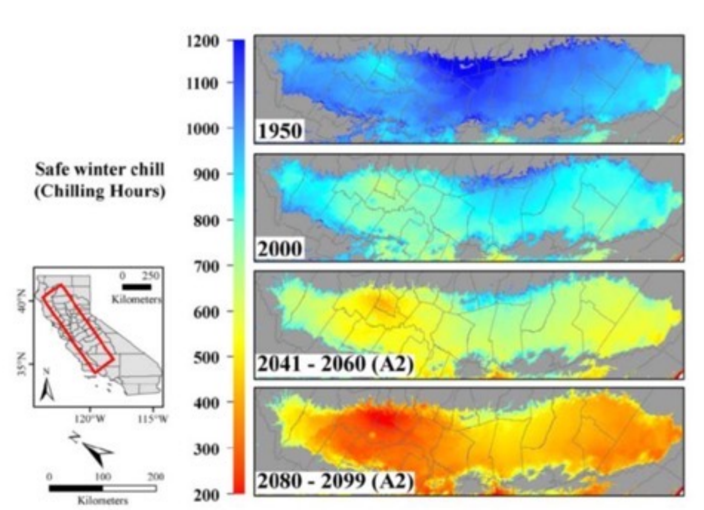
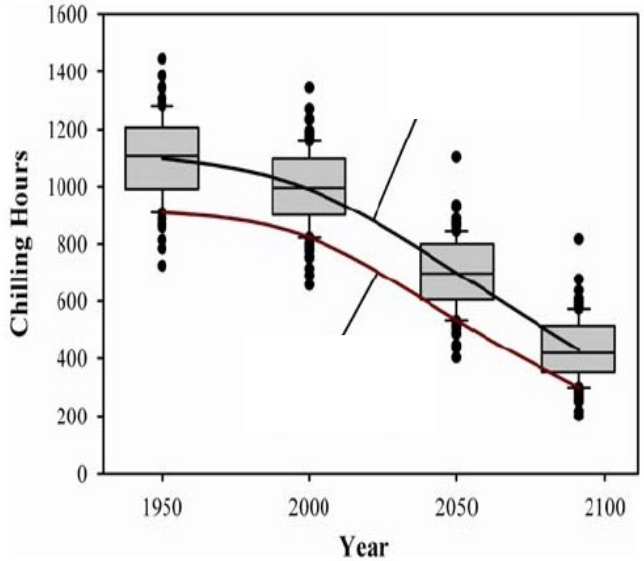


Figure 3. Safe winter chill in California's Central Valley in 1950, 2000, 2041–2060 and 2080–2099, calculated with the Chilling Hours Model. Future winter chill was quantified using the A2 IPCC greenhouse gas emissions scenario.
doi:10.1371/journal.pone.0006166.g003



Dr. Ignasi Iglesias

OPEN ACCESS Freely available online — PLoS one

Climatic Changes Lead to Declining Winter Chill for Fruit and Nut Trees in California during 1950–2099

Eike Luedeling[1,2*], Minghua Zhang[1*], Evan H. Girvetz[3]

Some Geneva® apple rootstocks show increased productivity in low chill environments by causing more floral and vegetative buds to break. What is the signal that lowers the endodormancy requirement of high chill scion varieties?


ISHS Acta Horticulturae 1228: XI International Symposium on Integrating Canopy, Rootstock and Environmental Physiology in Orchard Systems

Chilling requirement and budburst uniformity of cultivar 'Maxi Gala' grafted on different rootstocks

Authors: T.A. Macedo, G.F. Sander, M.F. Michelon, J.F. Carminatti, A.R. Rufato, L. Rufato, T.L. Robinson

Keywords: *Malus domestica* B., chill hours, CG series, Marubakaido, interstem

DOI: 10.17660/ActaHortic.2018.1228.36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Scientia Horticulturae

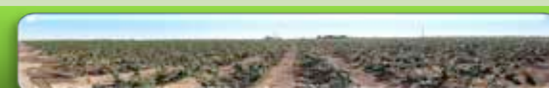
Volume 256, 15 October 2019, 108651

Productivity and quality of 'Fuji Suprema' apple fruit in different rootstocks and growing conditions

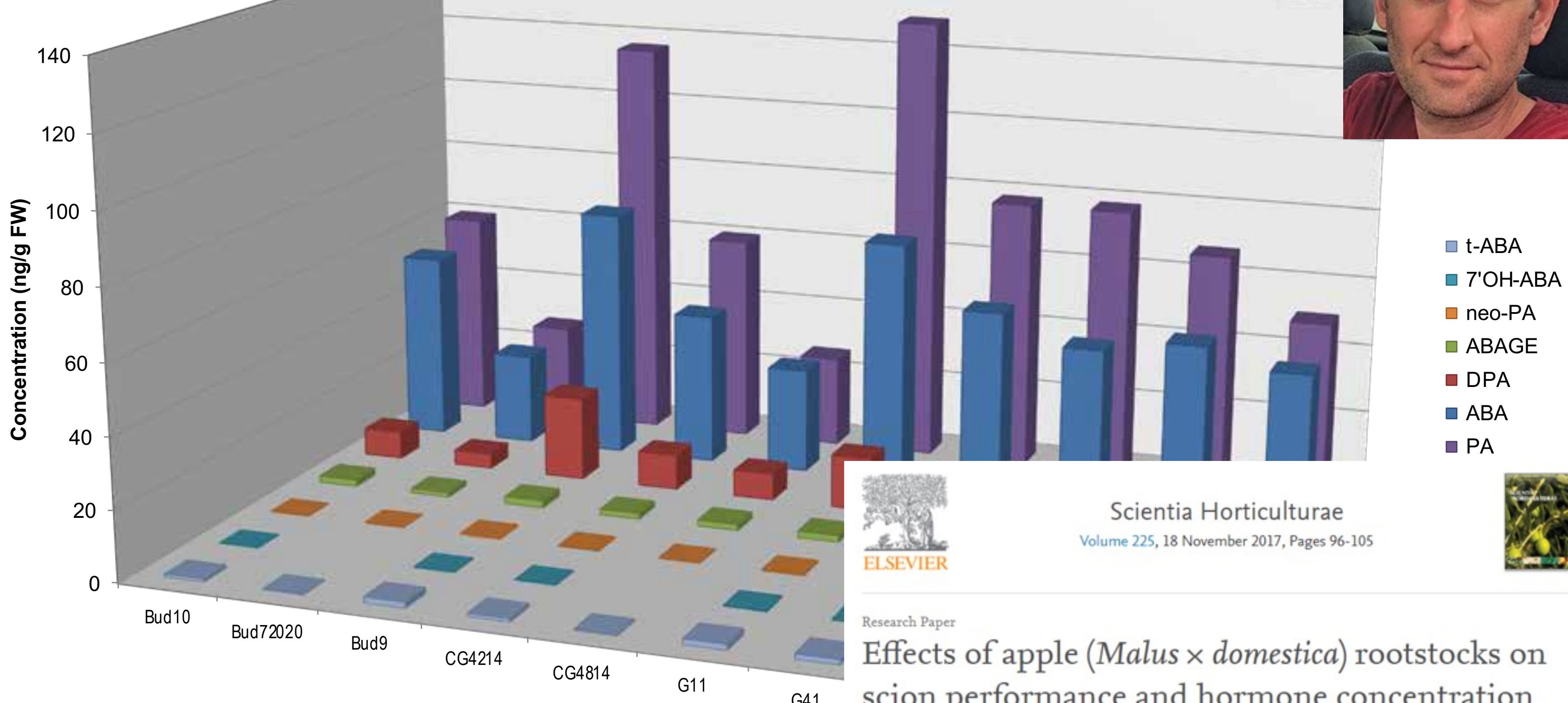
Tiago Afonso de Macedo [a], Pricila Santos da Silva [b], Guilherme Fontanella Sander [b], Juliana Fátima Welter [b], Leo Rufato [c], Andrea de Rossi [d]

USDA **United States Department of Agriculture**
Agricultural Research Service

Apple Rootstock Breeding Program
Plant Genetic Resources Unit, Geneva, NY



ABA and ABA catabolites content in apple tree xylem tissue under different rootstocks



$P < 0.0213^*$

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Scientia Horticulturae

Volume 225, 18 November 2017, Pages 96-105

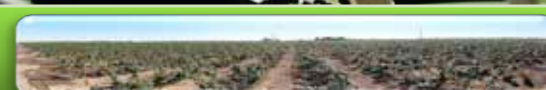
Research Paper

Effects of apple (*Malus* × *domestica*) rootstocks on scion performance and hormone concentration

J. Lordan [a], G. Fazio [a, b], P. Francescatto [a], T. Robinson [a]

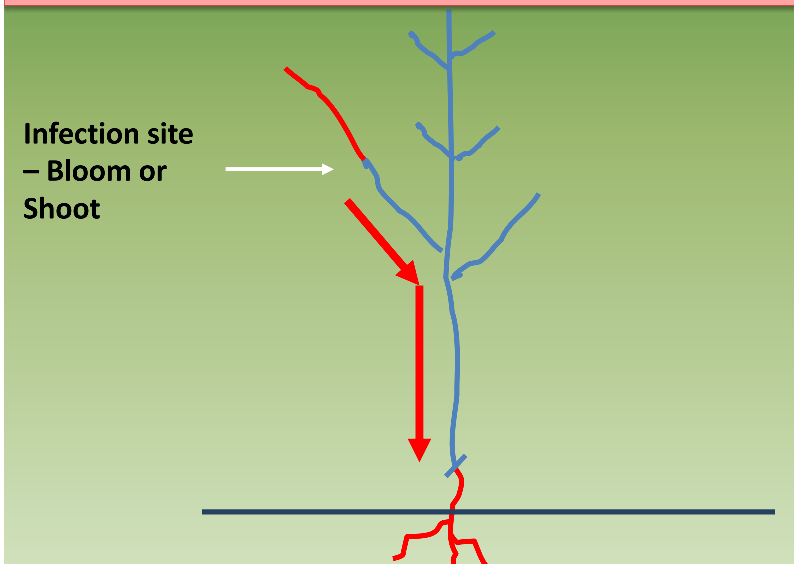

G. 41
Courtesy Betsy Beers
WSU Wenatchee

M.9

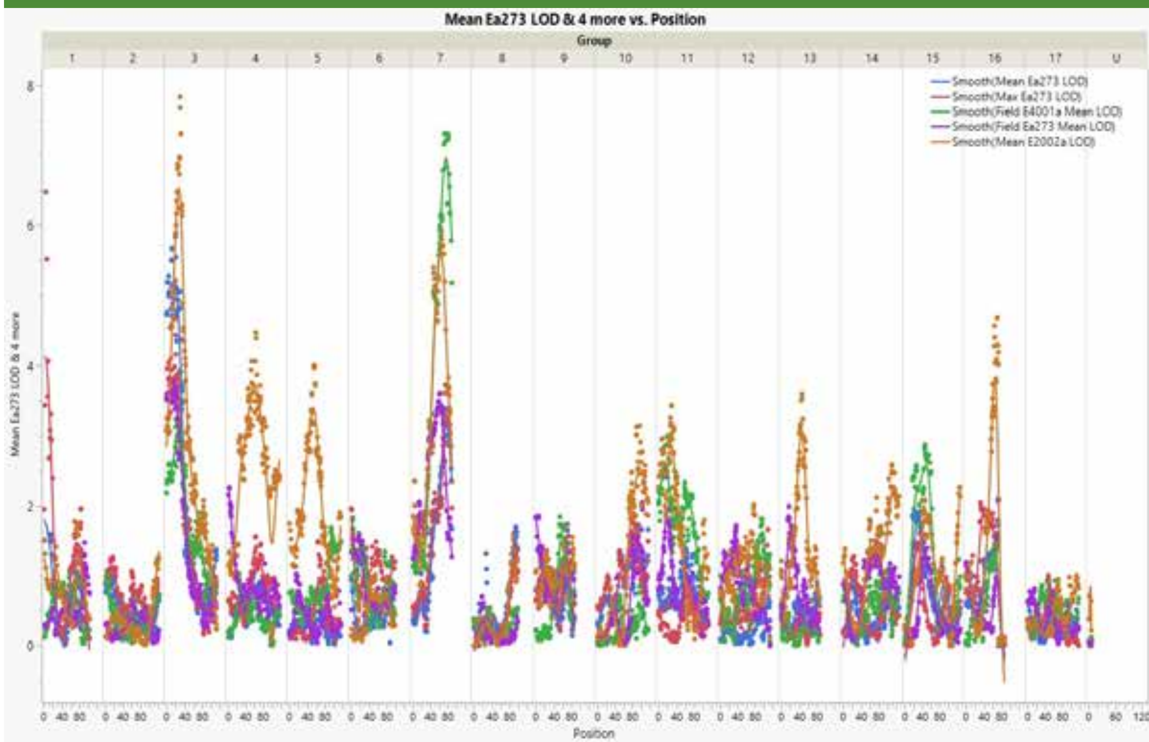


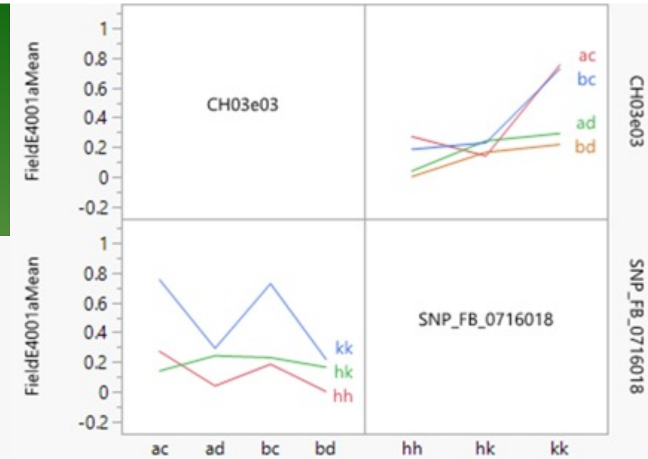
The Rootstock Phase of Fire Blight is a Major Problem:

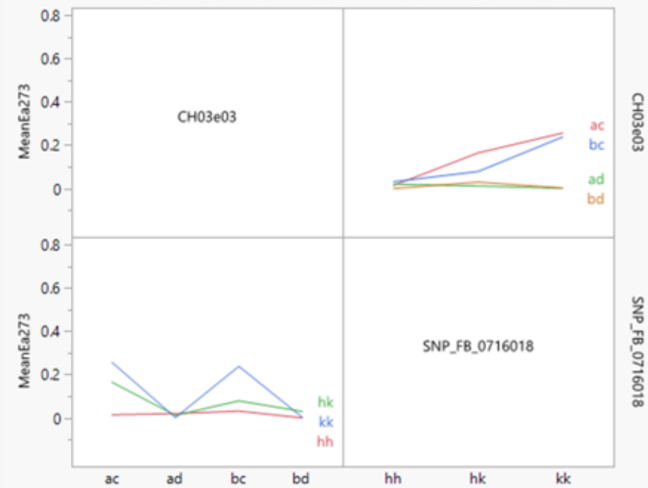
- Infection of susceptible rootstocks results in the death of the tree.
- Blight can enter the tree through blooms, mechanical wounds and insect wounds (burr knots, suckers)
- Fire Blight bacteria can travel from the top of the tree to the rootstock in less than 2 weeks.



QTLs for fire blight resistance on same population – different strains and years







frontiers in Plant Science

ORIGINAL RESEARCH
published: 21 September 2018
doi: 10.3389/fpls.2018.01336

Targeted Metabolic Profiling Indicates Apple Rootstock Genotype-Specific Differences in Primary and Secondary Metabolite Production and Validate Quantitative Contribution From Vegetative Growth

Rachel Leisso[1*], Dave Rudell[2] and Mark Mazzola[2]

[1] Montana State University Western Agriculture Research Center, Corvallis, MT, United States, [2] Physiology and Pathology of Tree Fruits Research, Agricultural Research Service (ARS), United States Department of Agriculture (USDA), Wenatchee, WA, United States

OPEN ACCESS

Edited by:
Philipp Zerbe,

Previous reports regarding rhizodeposits from apple roots are limited, and complicated by microbes, which readily colonize root systems and contribute to modify rhizodeposit metabolite composition. This study delineates methods for collection of apple rhizodeposits under axenic conditions, indicates rootstock genotype-specific differences

Zhu et al. Horticulture Research (2019)6:10
DOI 10.1038/s41438-018-0087-1

Horticulture Research
www.nature.com/hortres

ARTICLE | Open Access

Genotype-specific suppression of multiple defense pathways in apple root during infection by *Pythium ultimum*

Yanmin Zhu[1], Jonathan Shao[2], Zhe Zhou[3] and Robert E. Davis[2]

Abstract

The genotype-specific defense activation in the roots of perennial tree crops to soilborne necrotrophic pathogens remains largely unknown. A recent phenotyping study indicated that the apple rootstock genotypes B.9 and G.935 have contrasting resistance responses to infection by *Pythium ultimum*. In the current study, a comparative transcriptome analysis by Illumina Solexa HiSeq 3000 platform was carried out to identify the global transcriptional regulation networks between the susceptible B.9 and the resistant G.935 to *P. ultimum* infection. Thirty-six libraries were sequenced to cover three timepoints after pathogen inoculation, with three biological replicates for each sample. The transcriptomes in the roots of the susceptible genotype B.9 were reflected by overrepresented differentially expressed genes (DEGs) with downregulated patterns and systematic suppression of cellular processes at 48 h post inoculation (hpi). In contrast, DEGs with annotated functions, such as kinase receptors, MAPK signaling, JA biosynthesis enzymes, transcription factors, and transporters, were readily induced at 24 hpi and continued up-regulation at 48 hpi in G.935 roots. The earlier and stronger defense activation is likely associated with an effective inhibition of necrosis progression in G.935 roots. Lack of effector-triggered immunity or existence of a susceptibility gene could contribute to the severely disturbed transcriptome and susceptibility in B.9 roots. The identified DEGs constitute a valuable resource for hypothesis-driven studies to elucidate the resistance/tolerance mechanisms in apple roots and validating their potential association with resistance traits.

Soil Biology & Biochemistry 113 (2017) 201–214

Contents lists available at ScienceDirect

Soil Biology & Biochemistry

ELSEVIER

journal homepage: www.elsevier.com/locate/soilbio

Metabolic composition of apple rootstock rhizodeposits differs in a genotype-specific manner and affects growth of subsequent plantings

CrossMark

Rachel Leisso*, David Rudell, Mark Mazzola

USDA-ARS Tree Fruit Research Laboratory, 1104 N. Western Avenue, Wenatchee, WA 98801, United States

ARTICLE INFO

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ABSTRACT

Apple replant disease (ARD) negatively impacts apple tree health and reduces crop yield in new orchards established on sites previously grown to the same or related species. Use of tolerant rootstock genotypes can diminish the growth limiting effects of ARD, and while current research characterizes differential root gene expression by ARD tolerance among genotypes, the potential role of genotype-specific rhizodeposits contributing to ARD tolerance has not been intensively examined. A Q-TOF LC/MS metabolic profiling approach targeting phenolic compounds was used to characterize water-soluble phenolic rhizodeposit metabolites collected from water percolated through the rhizosphere of apple rootstocks planted in pasteurized quartz sand. Four rootstock genotypes (two with ARD field tolerance, G935 and

Transcriptomic analysis of molecular responses in *Malus domestica* 'M26' roots affected by apple replant disease

Stefan Weiß[1] · Melanie Bartsch[1] · Traud Winkelmann[1]

Received: 15 August 2016 / Accepted: 23 March 2017 / Published online: 19 April 2017
© Springer Science+Business Media Dordrecht 2017

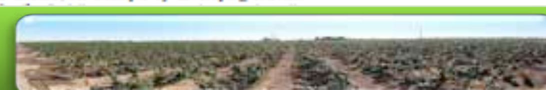
Abstract

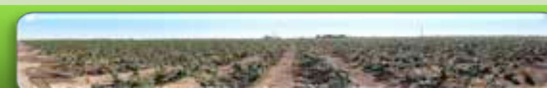
Key message **Gene expression studies in roots of apple replant disease affected plants suggested defense reactions towards biotic stress to occur which did not lead to adequate responses to the biotic stressors.**

Abstract Apple replant disease (ARD) leads to growth inhibition and fruit yield reduction in replanted populations and results in economic losses for tree nurseries and fruit producers. The etiology is not well understood on a molecular level and causal agents show a great diversity indicating that no definitive cause, which applies to the majority of cases, has been found out yet. Hence, it is pivotal to gain a better understanding of the molecular and physiological reactions of the plant when affected by ARD and later to overcome the disease, for example by developing tolerant

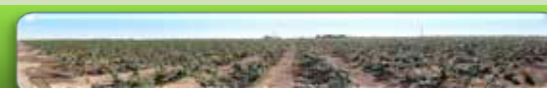
upregulated whereas for several genes
metabolism lower expression was de
verification of MACE data, candidate
via RT-qPCR and a strong positive
both datasets was observed. Compari
roots cultivated in ARD soil or γ-irrad
gests that typical defense reactions t
take place in ARD affected plants bu
responding to the biotic stressors attac
to the observed growth depressions in

Keywords Biotic stress response · Ge
Growth depression · MACE · Phytoale
Quantitative real-time PCR



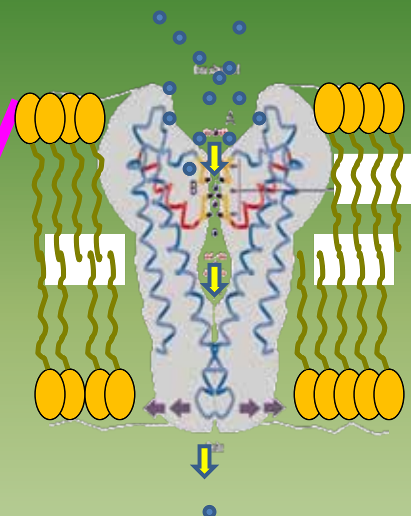


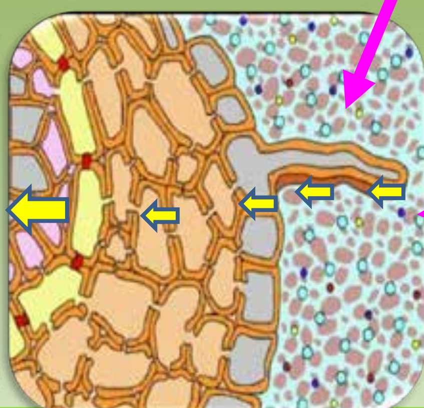
Color, Firmness, Maturity, Sugar, Size are affected by Apple Rootstocks



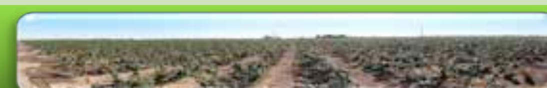
Journey of nutrients from soil to scion

Different sinks competing for same resources



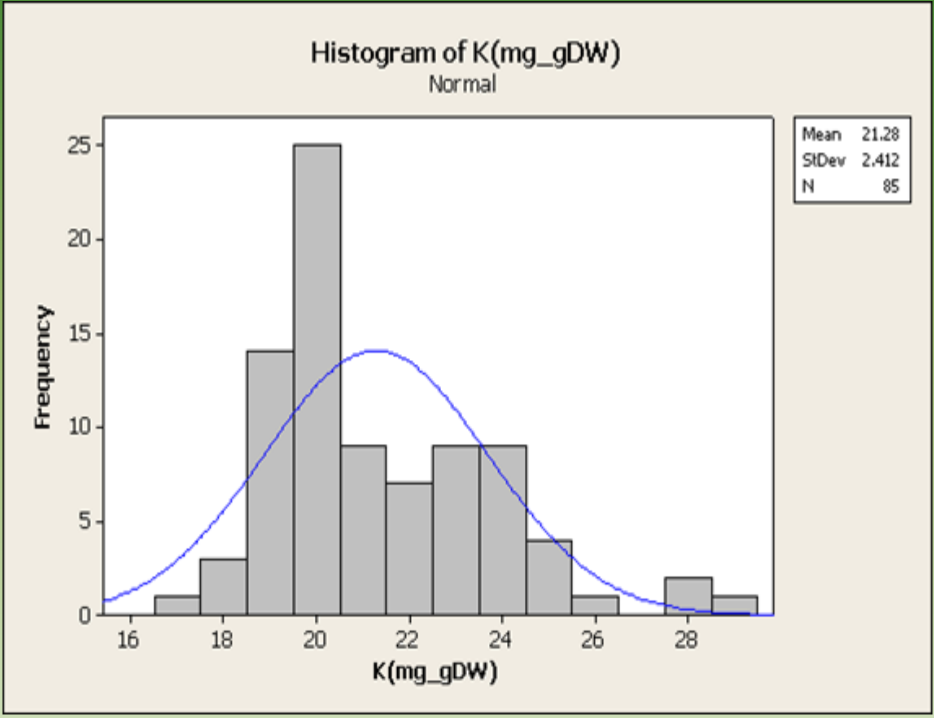


Different apple rootstocks genotypes may possess different absorbance and/or transport efficiencies.



What sparked our interest in root mediated ionomics (nutrient uptake)?

- Apple rootstocks response/interaction to a range of soil conditions (pH, water, soil borne diseases, soil type)
- Possibility to mitigate fruit disorders associated with nutrient deficiencies (calcium-bitterpit)
- Possibility to improve efficiency of fertilizer applications



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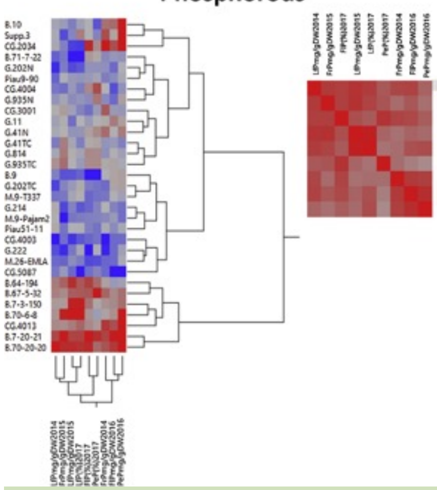
Scientia Horticulturae
Volume 266, 10 May 2020, 108477

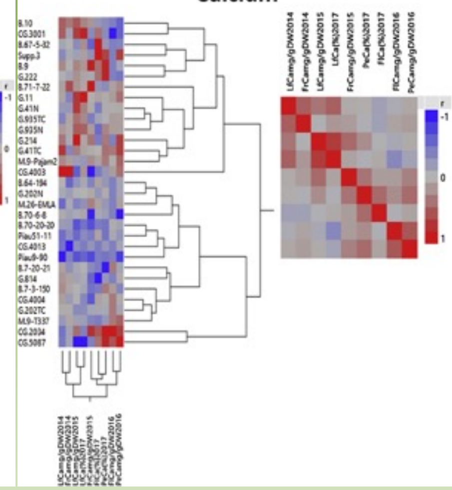
I. Mineral nutrient profiles and relationships of 'Honeycrisp' grown on a genetically diverse set of rootstocks under Western New York climatic conditions

Gennaro Fazio [a, b], Jaume Lordan [b, c], Michael A. Grusak [d], Poliana Francescatto [b], Terence L. Robinson [b]

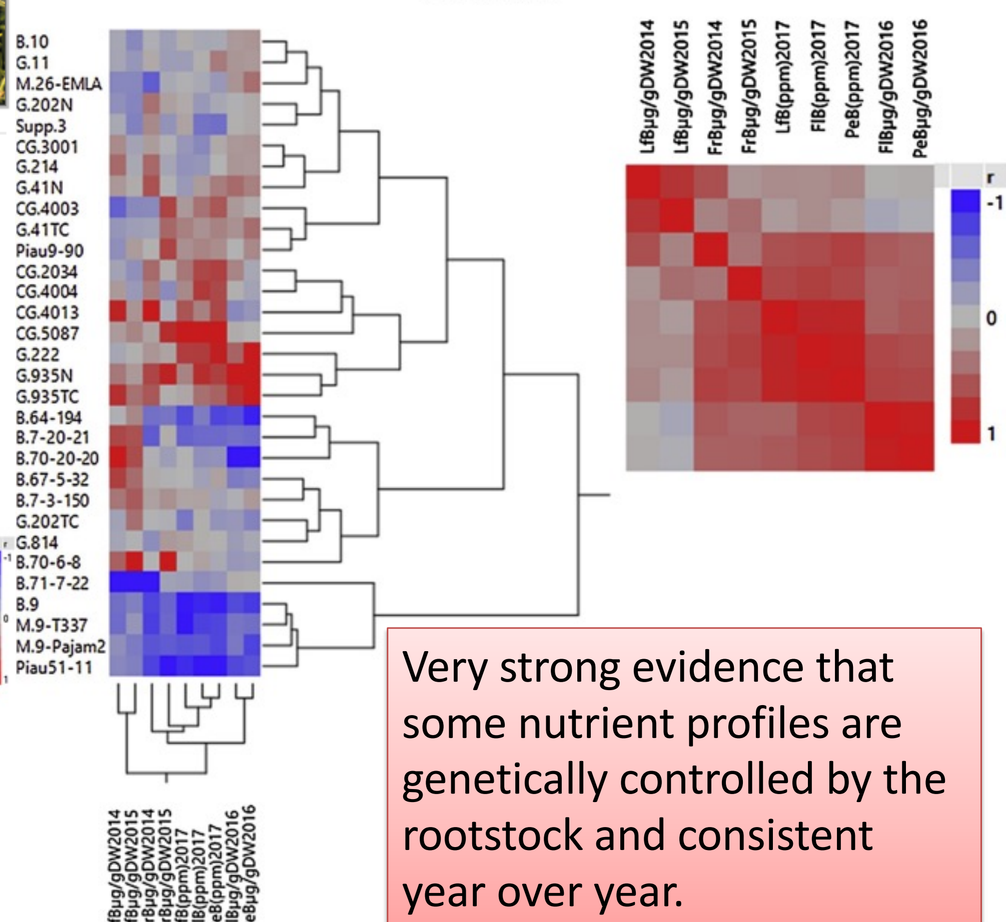
Phosphorous



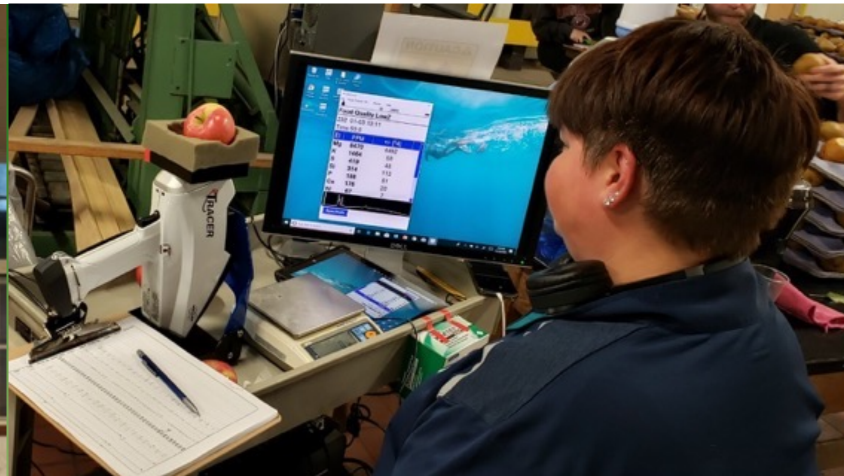
Calcium

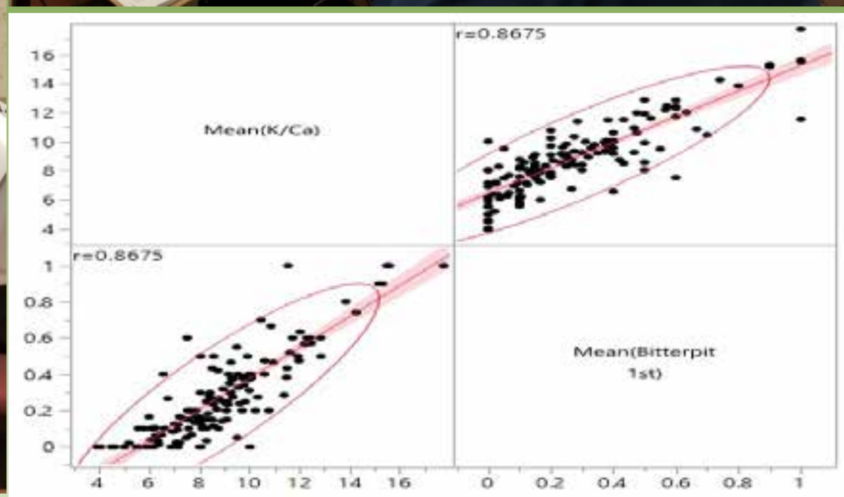


Boron

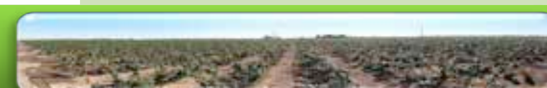


Very strong evidence that some nutrient profiles are genetically controlled by the rootstock and consistent year over year.



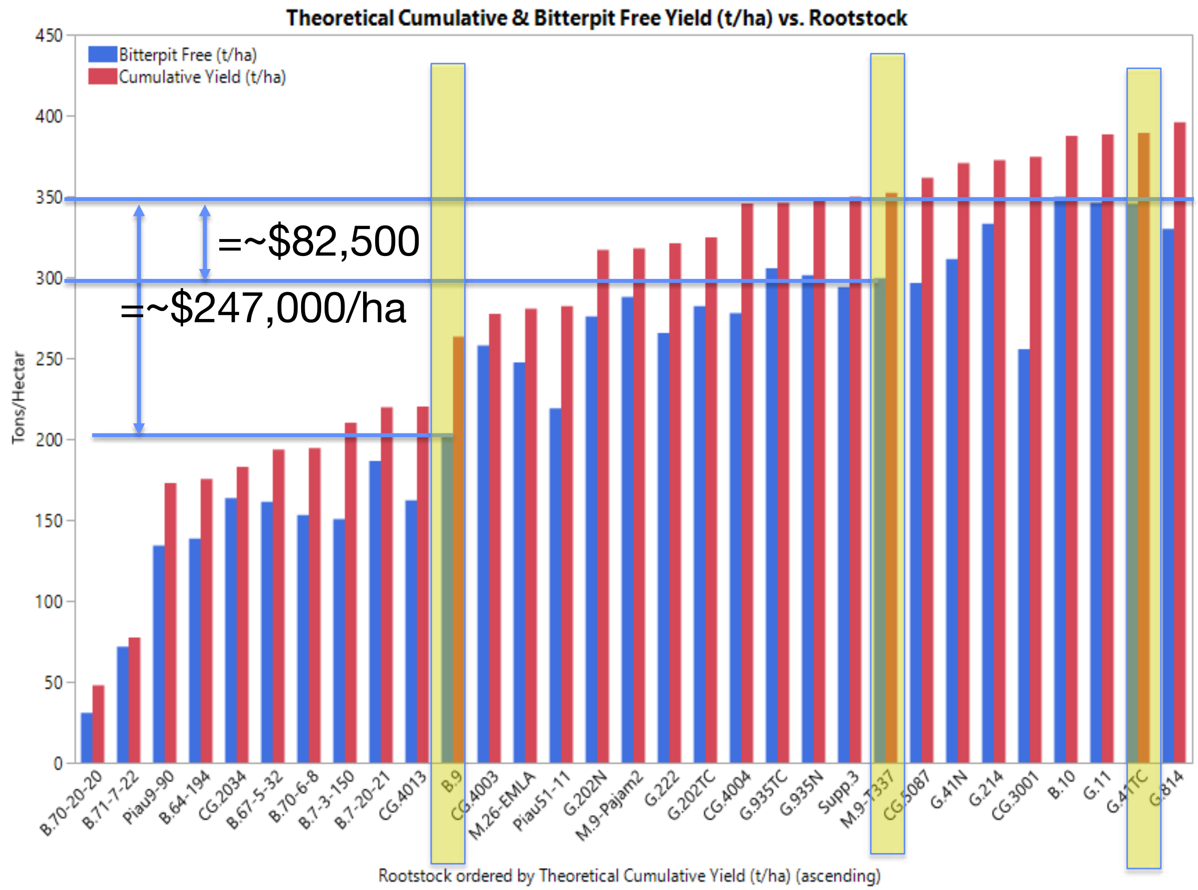


Bitter Pit of Honeycrisp apples is affected by many variables including some that are modulated by rootstocks: Nutrient Balance (IONOMICS) involving **K, N, Mg, and Ca**. Crop load, and some responses to climate.



Economic effects of rootstock influenced bitter pit and yield potential

- **Rootstocks affect cumulative yield of the orchard**
- **Rootstocks affect the K/Ca ratio which in turn affects the percentage of bitter pit free apple yield**
- **The combination of the two can result in significant money $$$ gained or lost.**



Aspects of Applied Biology ***119****, 2013*
Fruits and Roots: A Celebration and Forward Look

Phenotypic Diversity and QTL Mapping of Absorption and Translocation of Nutrients by Apple Rootstocks

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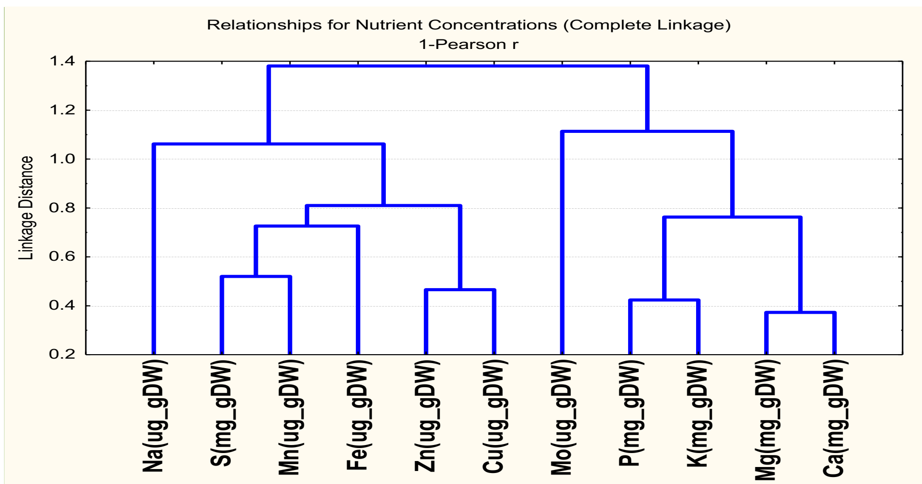
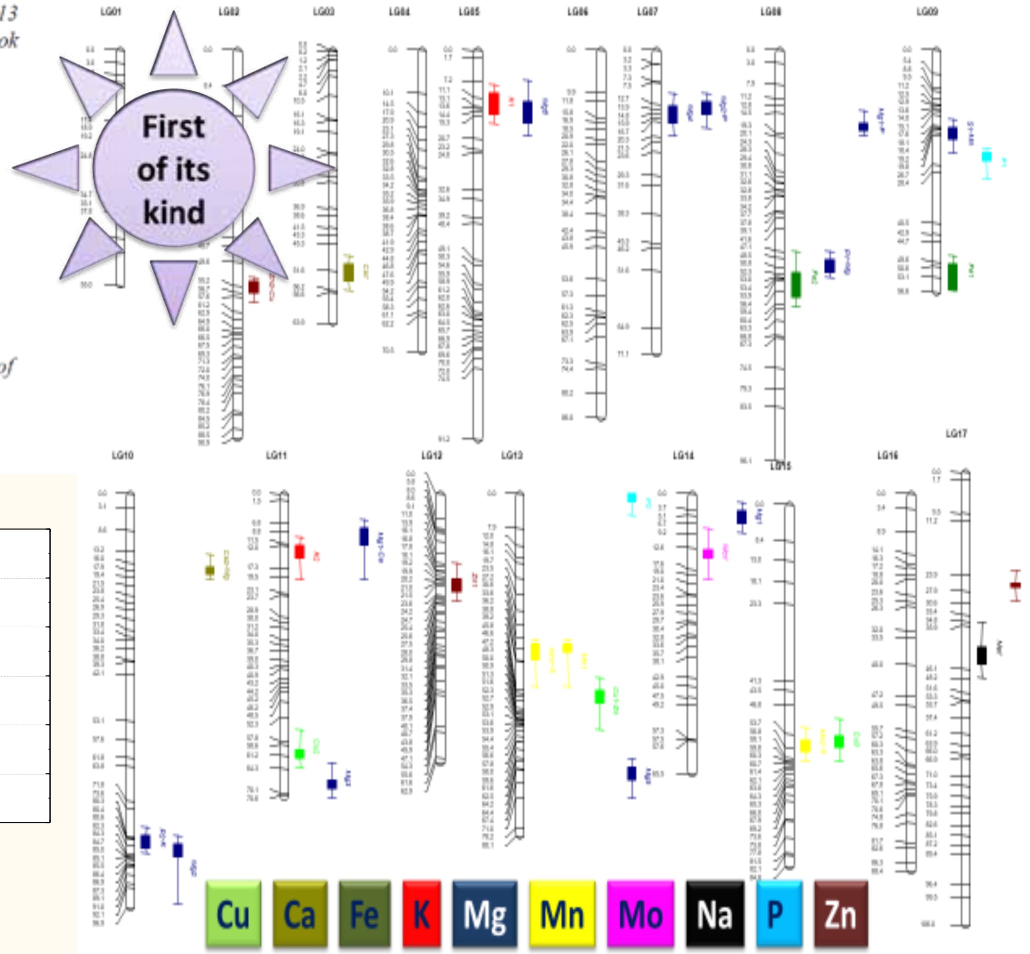
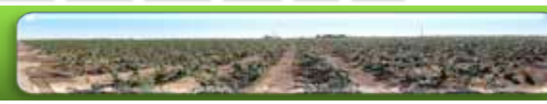


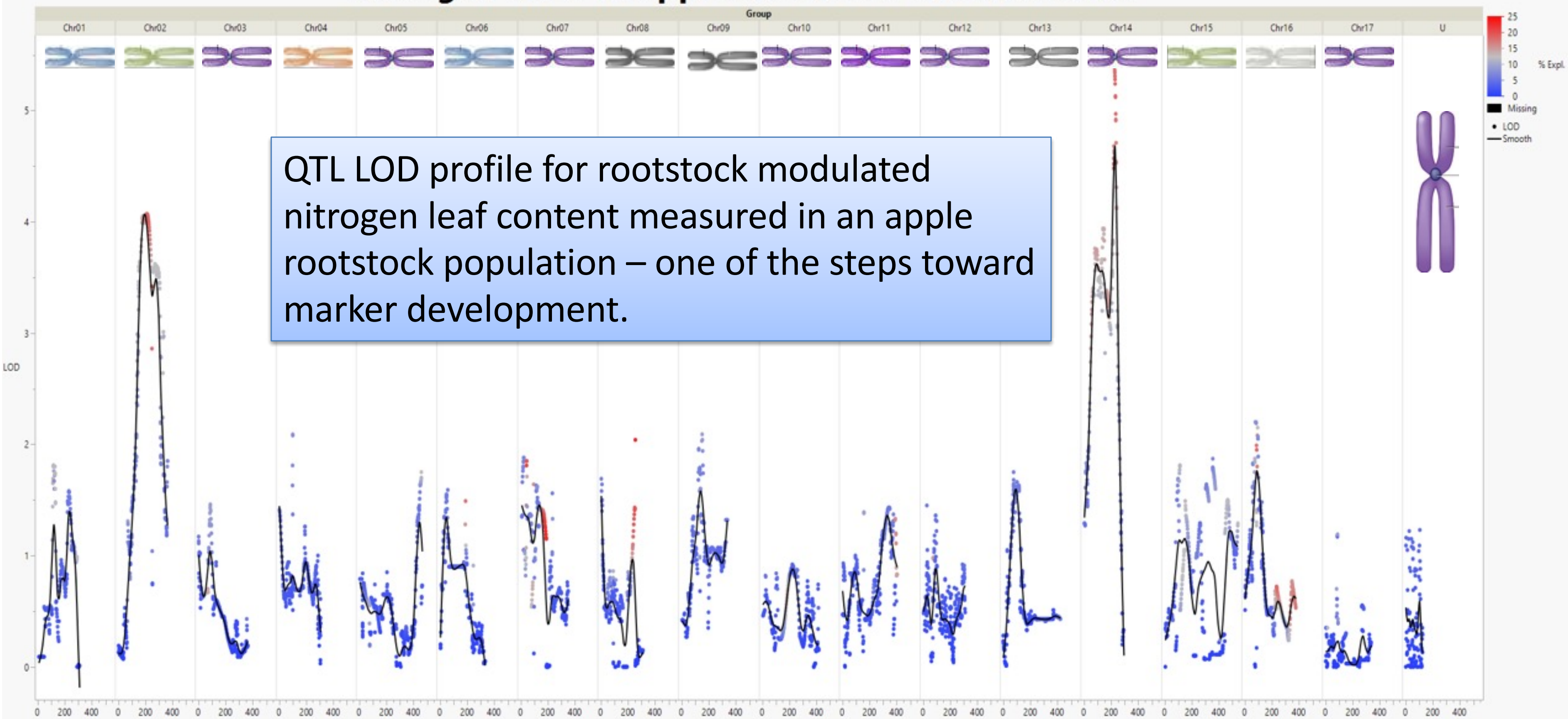


United States Department of Agriculture
Agricultural Research Service

Apple Rootstock Breeding Program
Plant Genetic Resources Unit, Geneva, NY

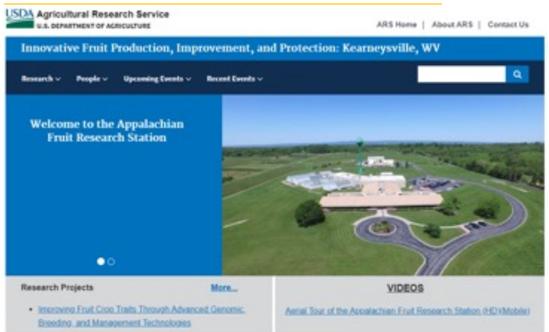


Nitrogen QTLs in Apple Rootstock Chromosomes

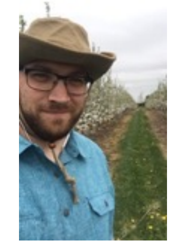


QTL LOD profile for rootstock modulated nitrogen leaf content measured in an apple rootstock population – one of the steps toward marker development.

Geneva 213 and Geneva 214 at Cameron Nursery in Eltopia, WA



AFRS Rapid cycle breeding system timeline



Dr. Chris Gottschalk

Spring Year 1: Make cross with early flowering line

Fall Year 1: Harvest seed

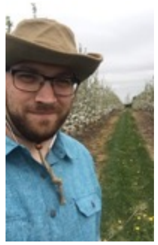
Transgene segregates in 1:1

Winter Year 1 - Spring Year 2: Stratify and Germinate seedlings

Summer Year 2: Marker-assisted selection

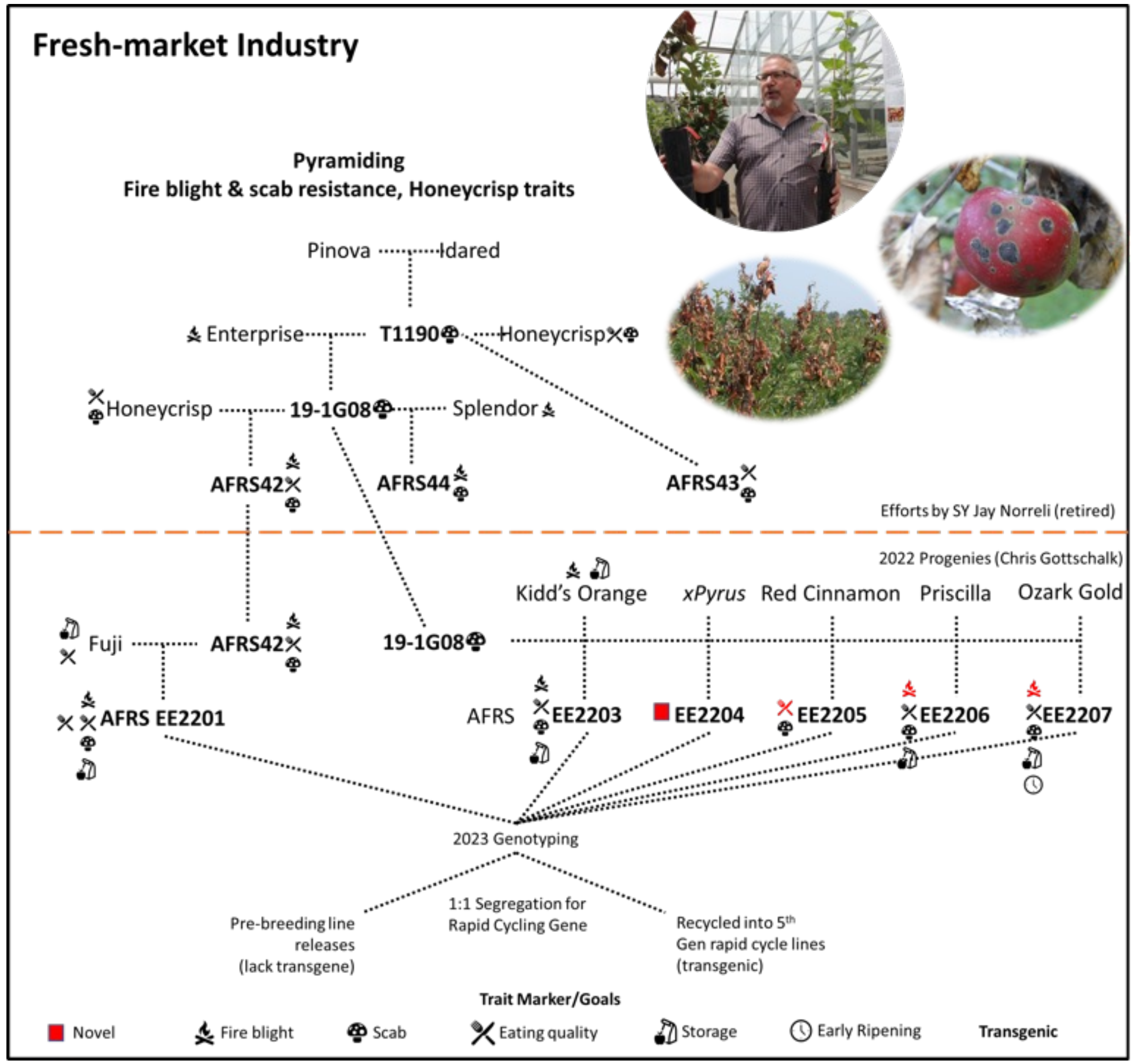
Fall/Winter Year 2: Phenotypic selection for simple fruit traits

Utilizes Novel Breeding Technologies (NBC)

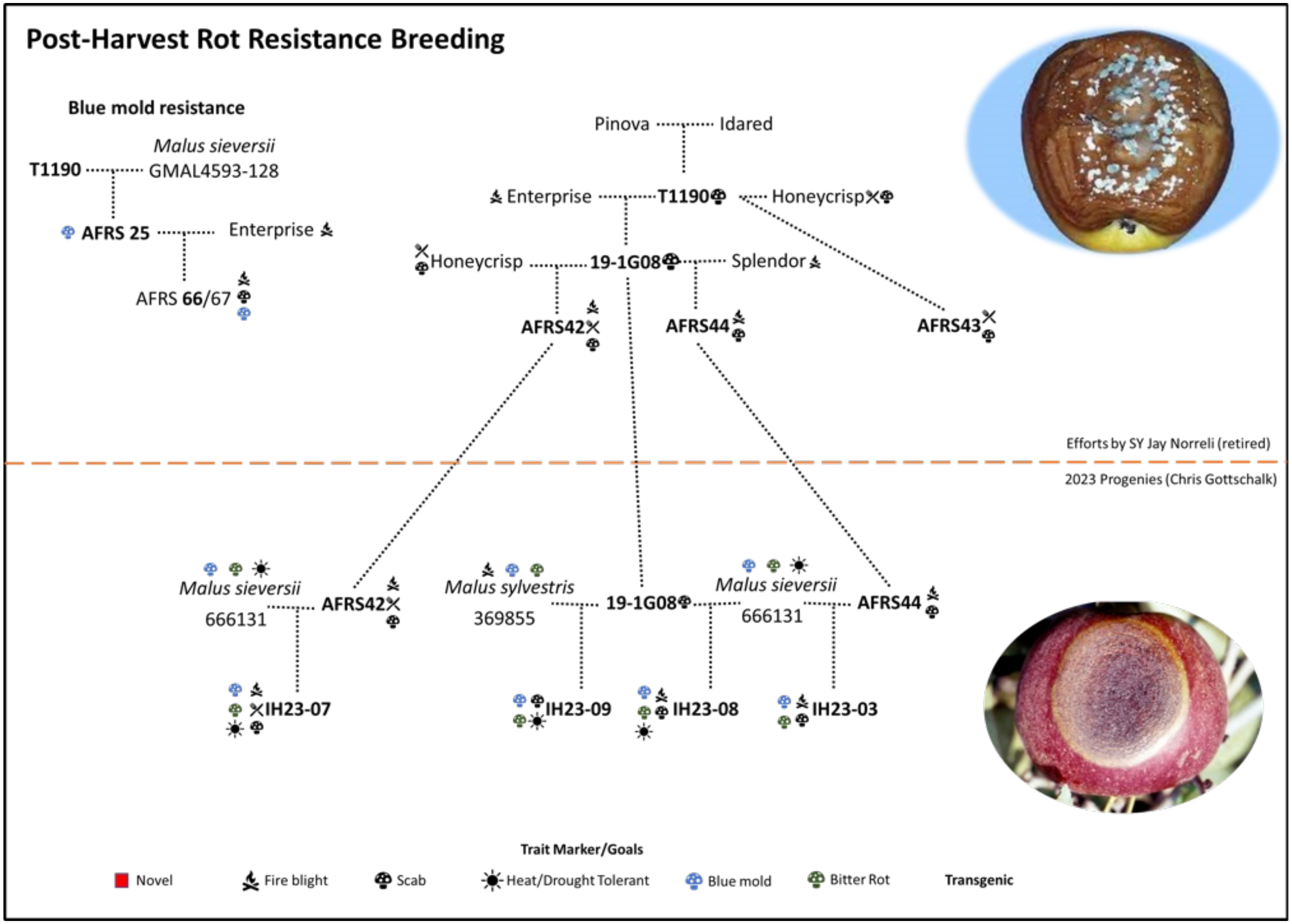


Dr. Chris Gottschalk

Current progress



New directions for post-harvest rot resistance



Introgression Breeding Using Rapid Cycle

Dr. Chris Gottschalk

Idared — Pinova

Seedling

T1190

Carries *BpMADS4* Transgene on Chr. 4

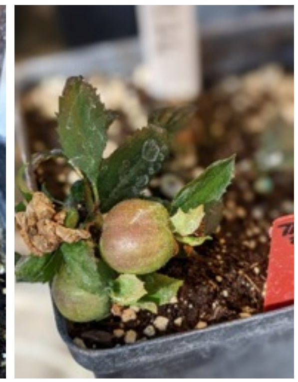
M. Fusca (M)

AFRS *Mf21* Lines

Allows us to target novel genetics such as *Mfu10* loci for fire blight resistance.

Use of a TFL RNAi Cassette Screen for Seedless Traits

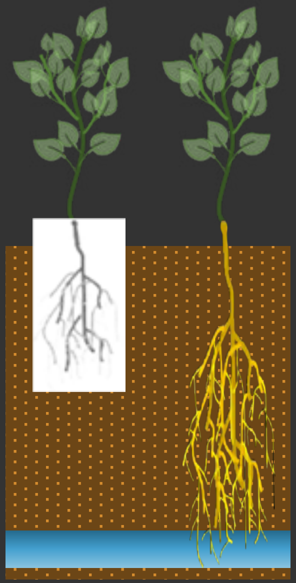
Dr. Chris Dardick



Construct	# of Lines/Plants	Flowering	Non-flowering	Seeds
Seedless1	5/26	0%	100%	?
Seedless2	4/19	0%	100%	?
Seedless3	9/45	0%	100%	?
TFL RNAi	9/43	35%	65%	No
Seedless1 + TFL RNAi	6/34	76%	24%	No
Seedless2 + TFL RNAi	7/30	53%	47%	No
Seedless3 + TFL RNAi	7/62	50%	50%	No

*Charrier, A., Vergne, E., Dousset, N., Richer, A., Petiteau, A., & Chevreau, E. (2019). Efficient Targeted Mutagenesis in Apple and First Time Edition of Pear Using the CRISPR-Cas9 System. Frontiers in plant science, 10, 40.

Enhancing drought resilience in apple through *DRO1*?

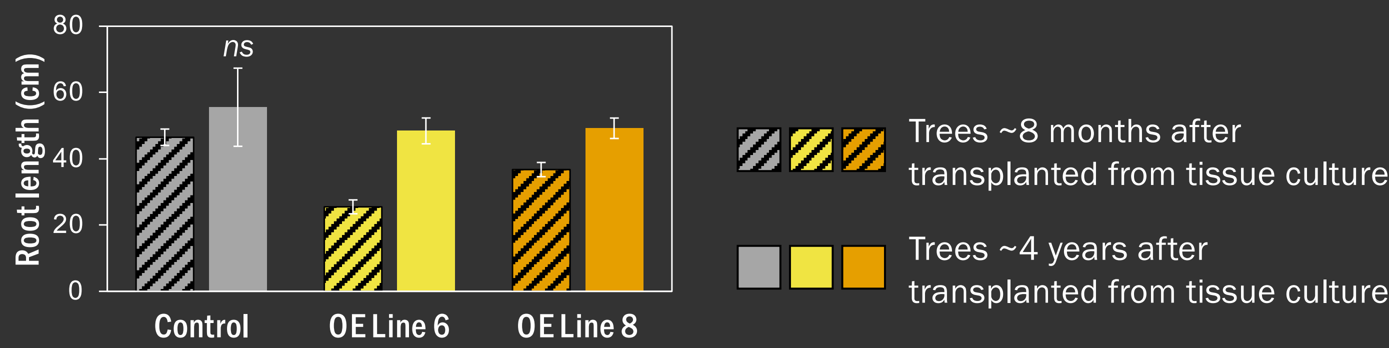


- Hypothesis:
  Deeper rooting of ‘M.26’ apple due to *DEEPER ROOTING 1 (DRO1)* overexpression allows water access in deeper soil domains and hence better drought tolerance (avoidance)

Dr. Lisa Tang

Root morphology of apple overexpressing *PpeDRO1*

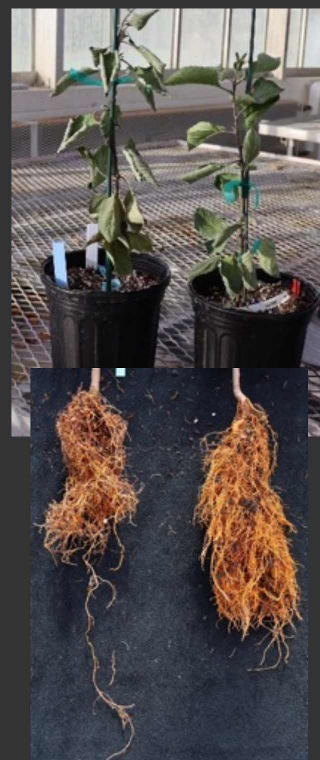
- At 8 months after transplanted, roots of both *DRO1* OE lines were shorter than non-transgenic control
- For 4-yr-old trees, *no* significance difference in root length or root biomass between transgenic OE lines and control

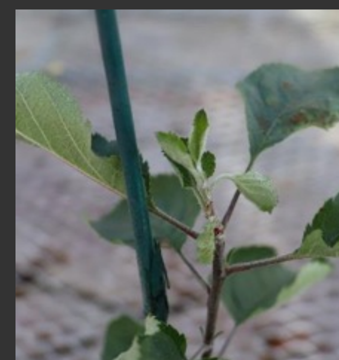


- But drought tolerance in apple was altered by *DRO1* overexpression

Apple saplings overexpressing *PpeDRO1* under drought

- 3-month saplings after no water for 4 weeks:

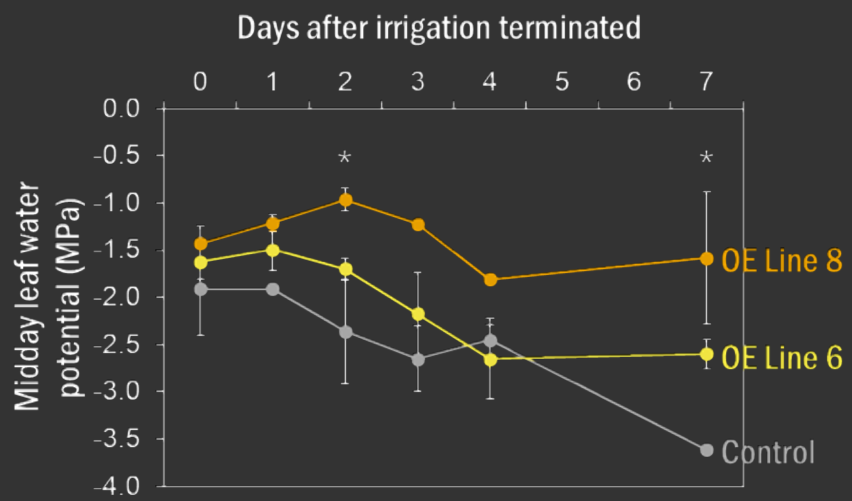




▲ Non-transgenic control ▶ ◀ *PpeDRO1* OE line ▲

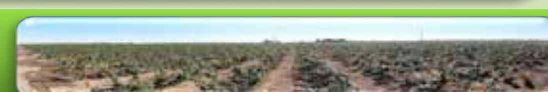
Young apple trees overexpressing *PpeDRO1* under drought

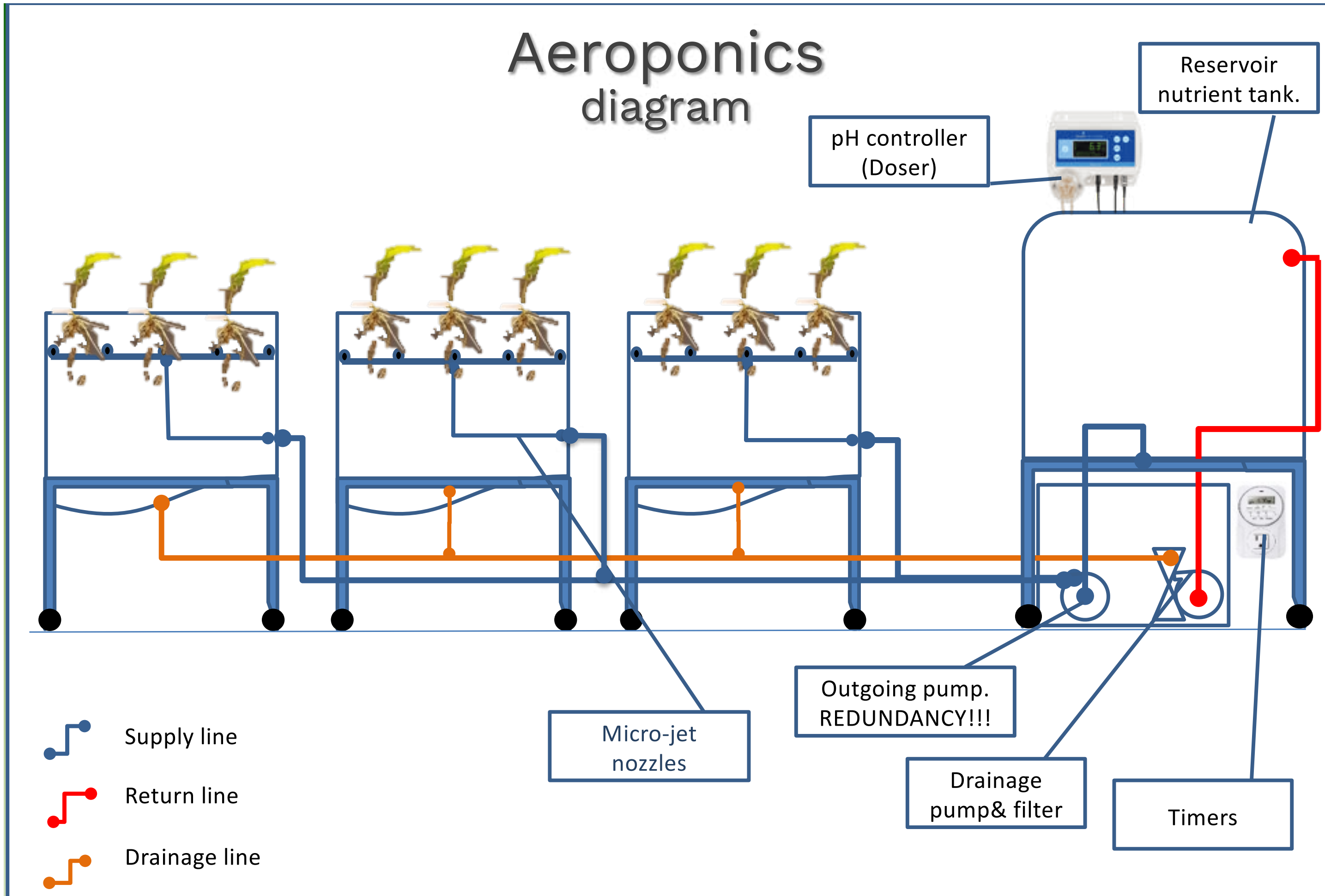
- 4-year-old non-nearing trees, after no water for 7 days:
  Both *DRO1* OE Lines were less stressed than non-transgenic control

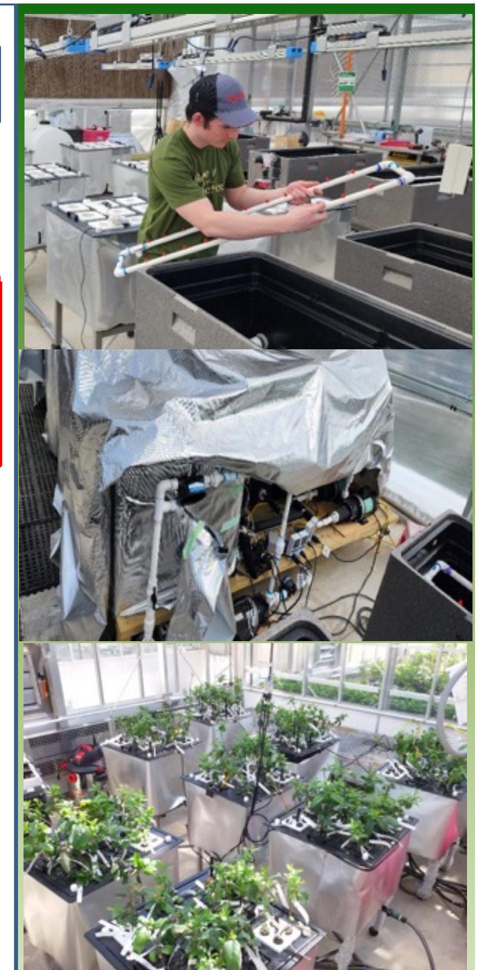


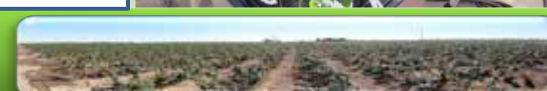
➔ Investigation of the mechanism underlying increased drought tolerance by *DRO1* OE is underway

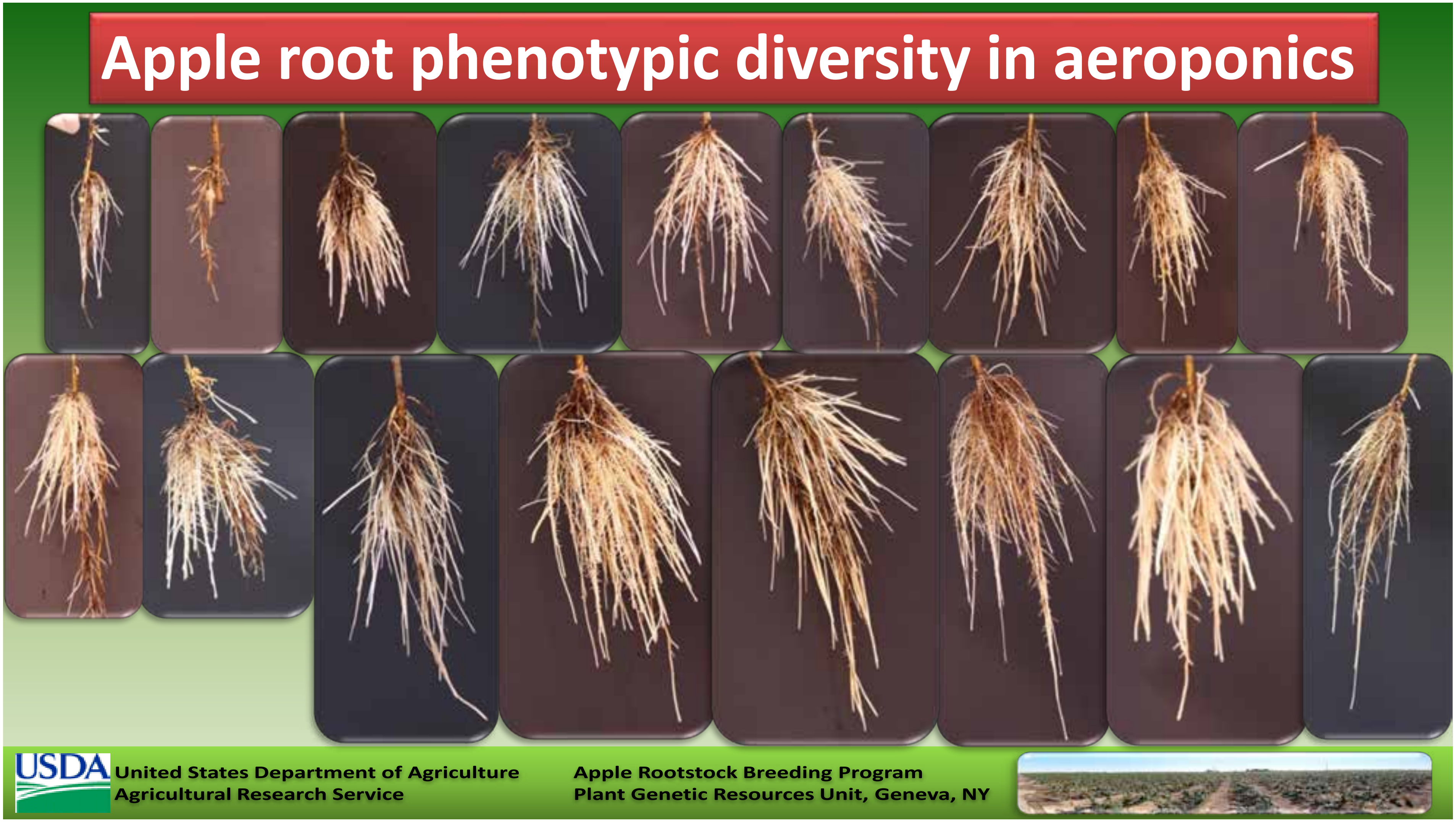
Aeroponics Systems to study apple roots




Aeroponics
diagram
pH controller
(Doser)
Reservoir
nutrient tank.
Micro-jet
nozzles
Outgoing pump.
REDUNDANCY!!!
Drainage
pump& filter
Timers
Supply line
Return line
Drainage line






Apple root phenotypic diversity in aeroponics
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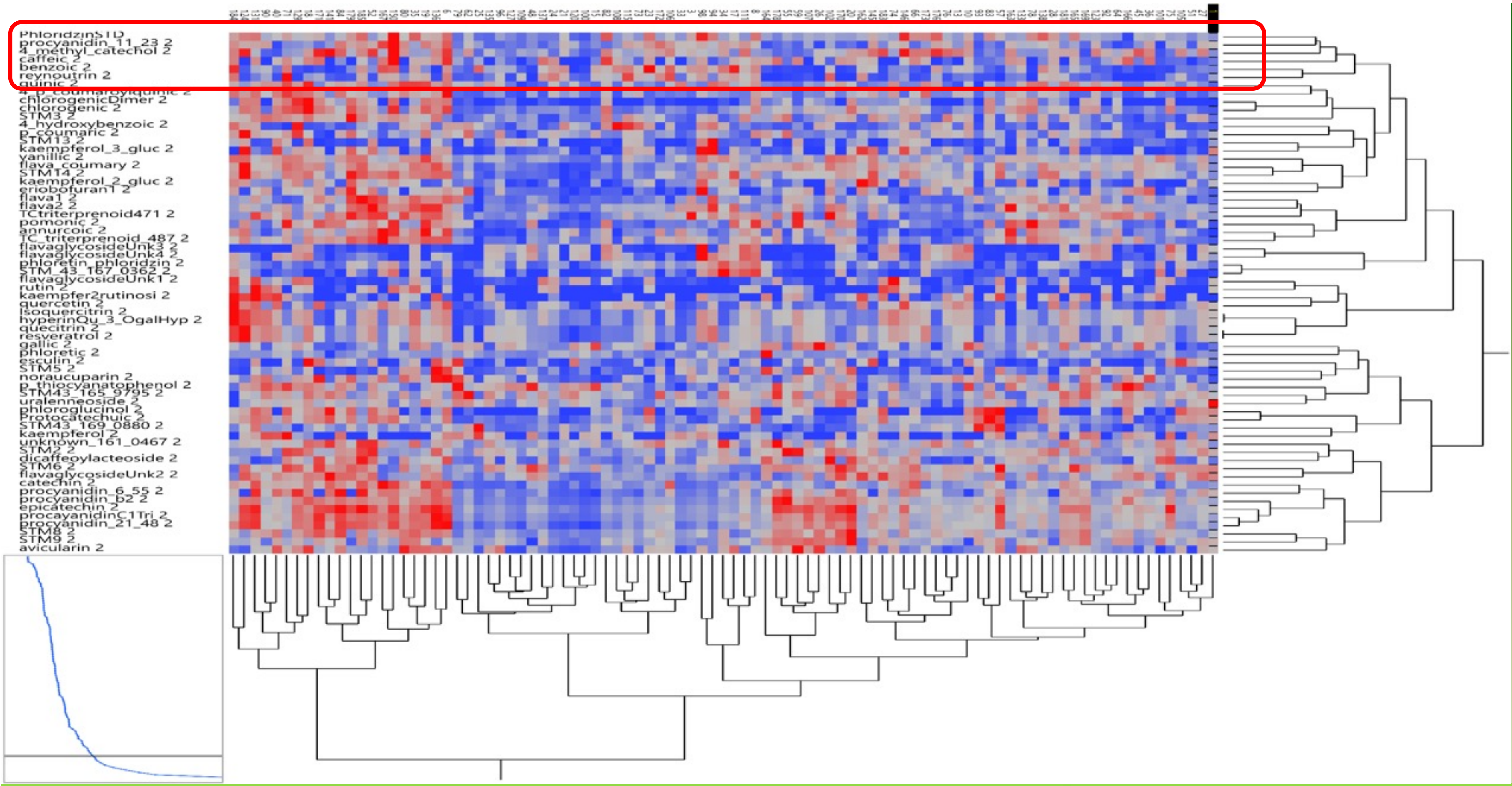
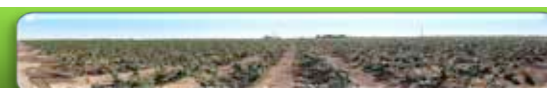
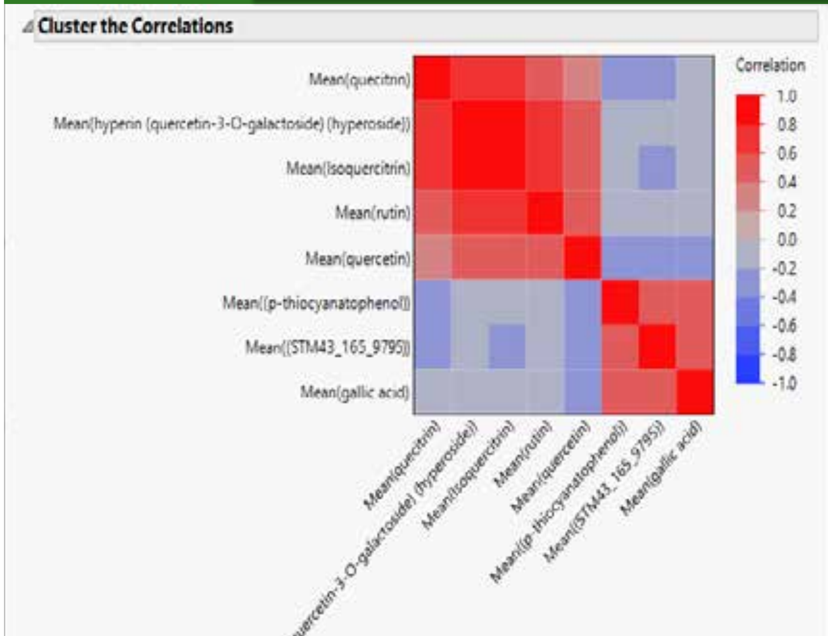


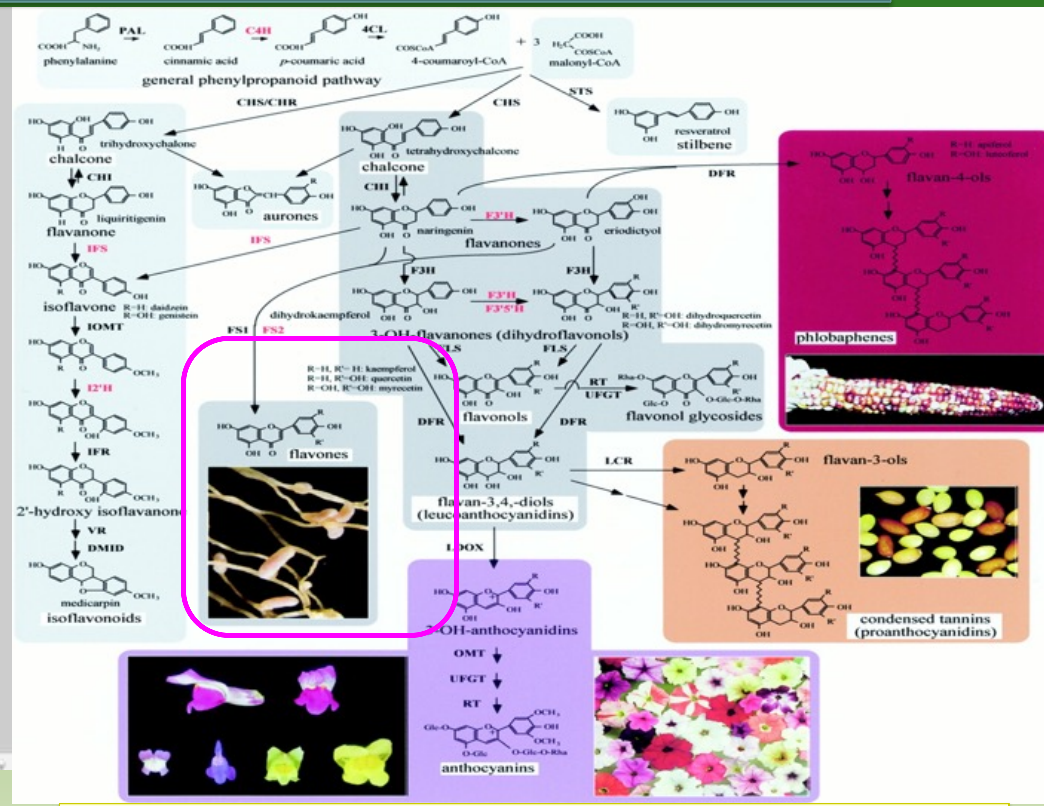
PhloridzinSTD
procyanidin_11_23 2
4_methyl_catechol 2
caffeic 2
benzoic 2
reynoutrin 2
quinic 2
4_p_coumaroylquinic 2
chlorogenicDimer 2
chlorogenic 2
STM3 2
4_hydroxybenzoic 2
p_coumaric 2
STM13 2
kaempferol_3_gluc 2
vanillic 2
flava_coumary 2
STM14 2
kaempferol_2_gluc 2
eriobofuran1 2
flava1 2
flava2 2
TCtriterprenoid471 2
pomonic 2
annurcoic 2
TC_triterprenoid_487 2
flavaglycosideUnk3 2
flavaglycosideUnk4 2
phloretin_phloridzin 2
STM_43_167_0362 2
flavaglycosideUnk1 2
rutin 2
kaempfer2rutinosi 2
quercetin 2
isoquercitrin 2
hyperinQu_3_OgalHyp 2
quecitrin 2
resveratrol 2
gallic 2
phloretic 2
esculin 2
STM5 2
noraucuparin 2
p_thiocyanatophenol 2
STM43_165_9795 2
uralenneoside 2
phloroglucinol 2
Protocatechuic 2
STM43_169_0880 2
kaempferol 2
unknown_161_0467 2
dicaffeoylacteoside 2
STM6 2
flavaglycosideUnk2 2
catechin 2
procyanidin_6_55 2
procyanidin_b2 2
epicatechin 2
procyanidinC1Tri 2
procyanidin_21_48 2
STM8 2
STM9 2
avicularin 2



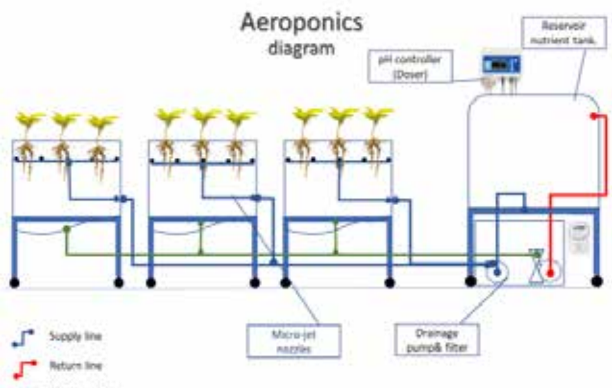
Root Isoquercitrin relationships and pathways



Quercetin 3-O-beta-D-glucofuranoside is a quercetin O-glucoside in which a glucofuranosyl residue is attached at position 3 of quercetin via a beta-glycosidic linkage. It has a role as a metabolite. It is a beta-D-glucoside, a quercetin O-glucoside, a monosaccharide derivative and a tetrahydroxyflavone.
Reaction: UDP-α-D-glucose + quercetin ⟶ H^+ + UDP + quercetin-3-glucoside
Source: https://pubchem.ncbi.nlm.nih.gov/compound/5484006

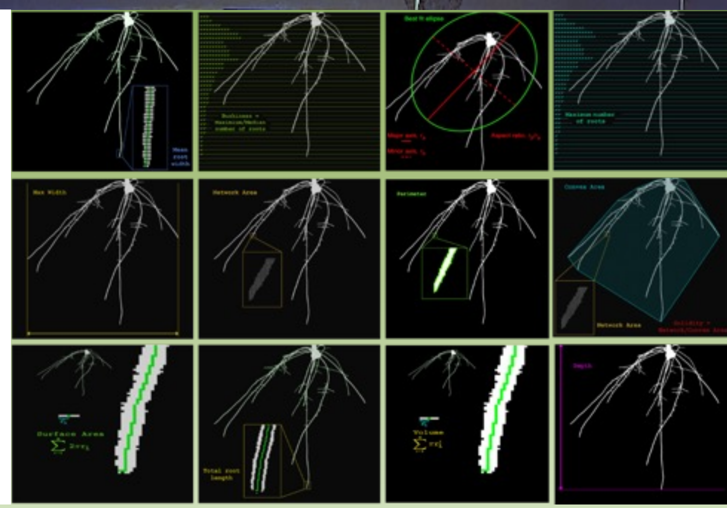


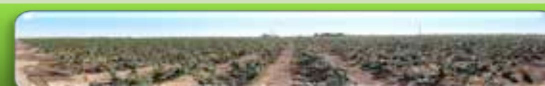
Plant Physiology June 2001 vol. 126 no. 2 485-493

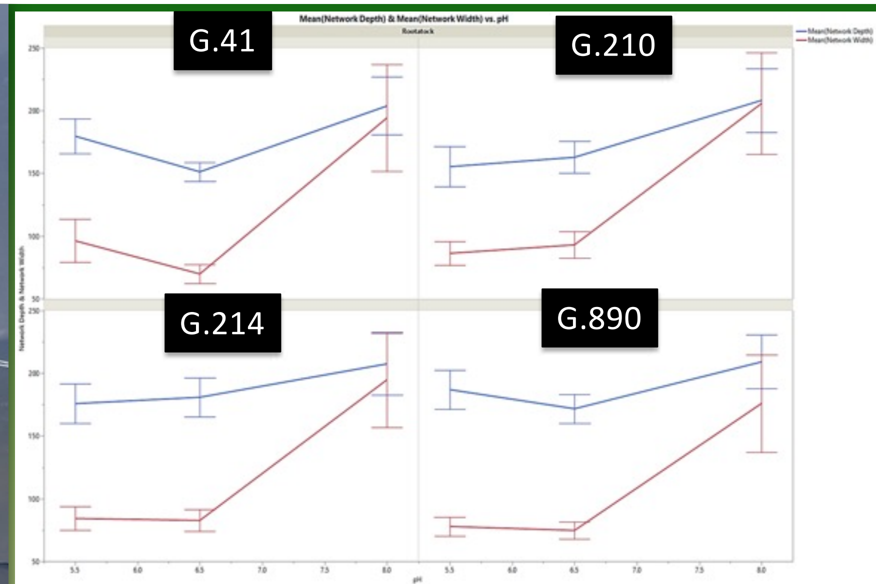


Dr. Ali Farqani PhD work

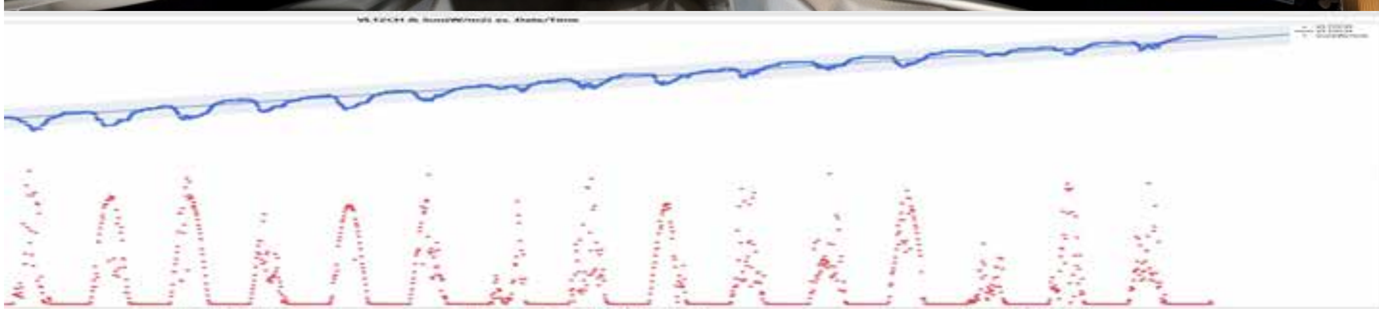
Images processing steps by GiaRoot software from rootstocks (M9, G41, G214, G890, G210) grown in aeroponics with adjusted solution's pH.

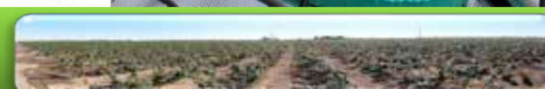






Effect of solution pH on **network depth and width in** (mm) on four Geneva rootstocks grown in aeroponics system in 2018.





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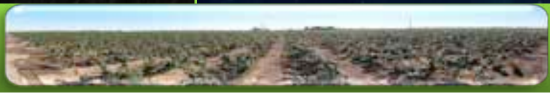
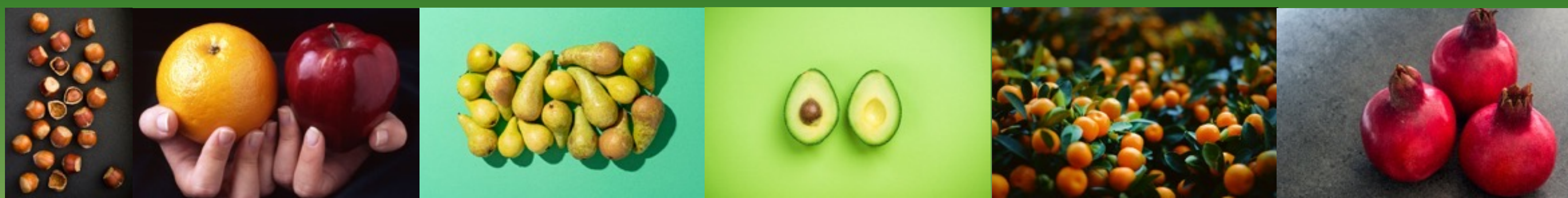
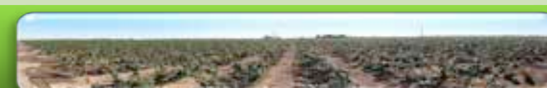


Is the rootstock revolution limited to Apples?





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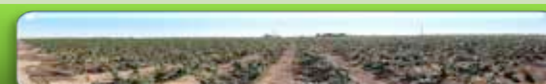

Thank You!

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