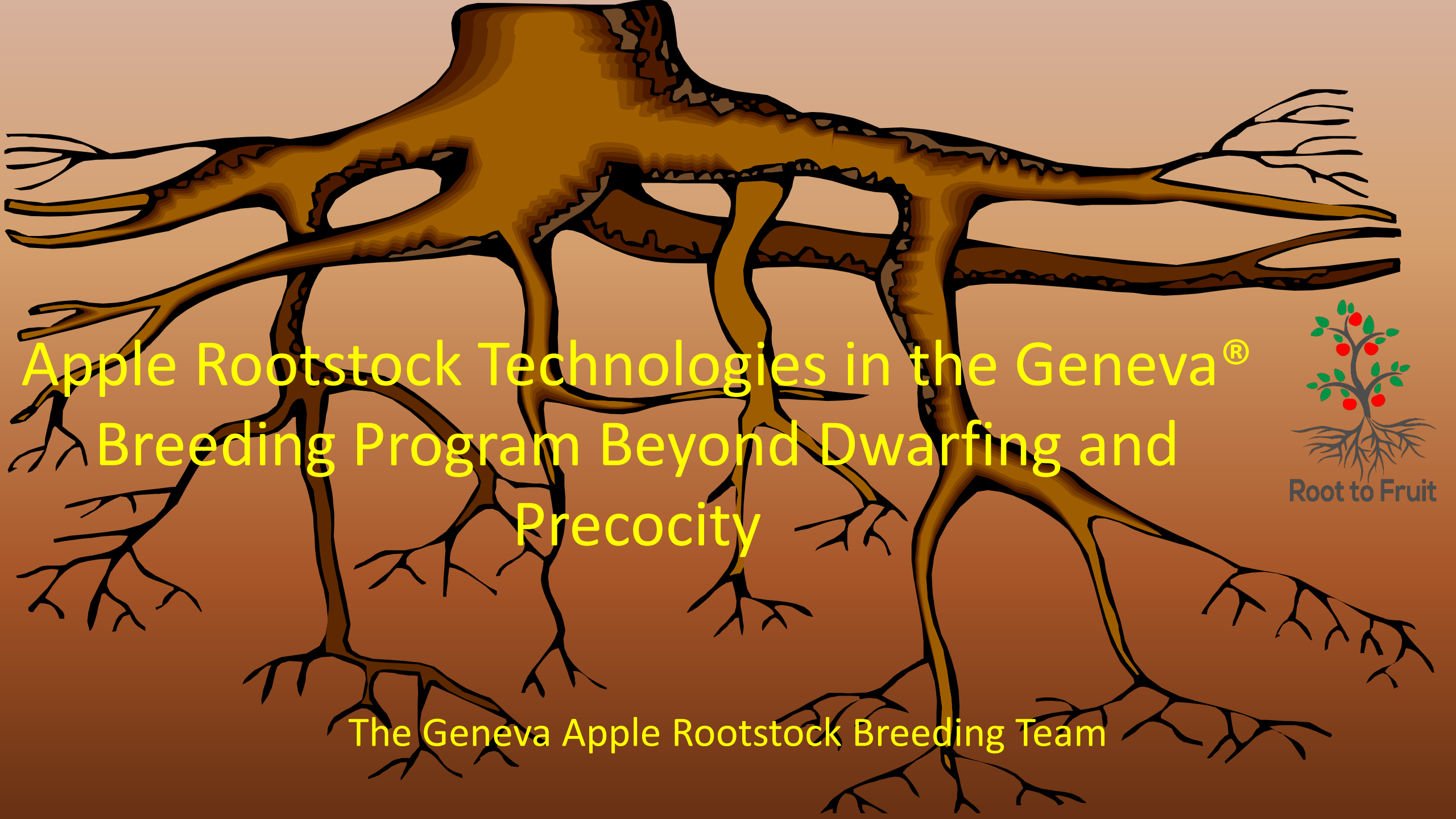
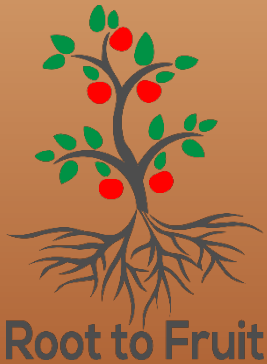




Apple Rootstock Technologies in the Geneva® Breeding Program Beyond Dwarfing and Precocity



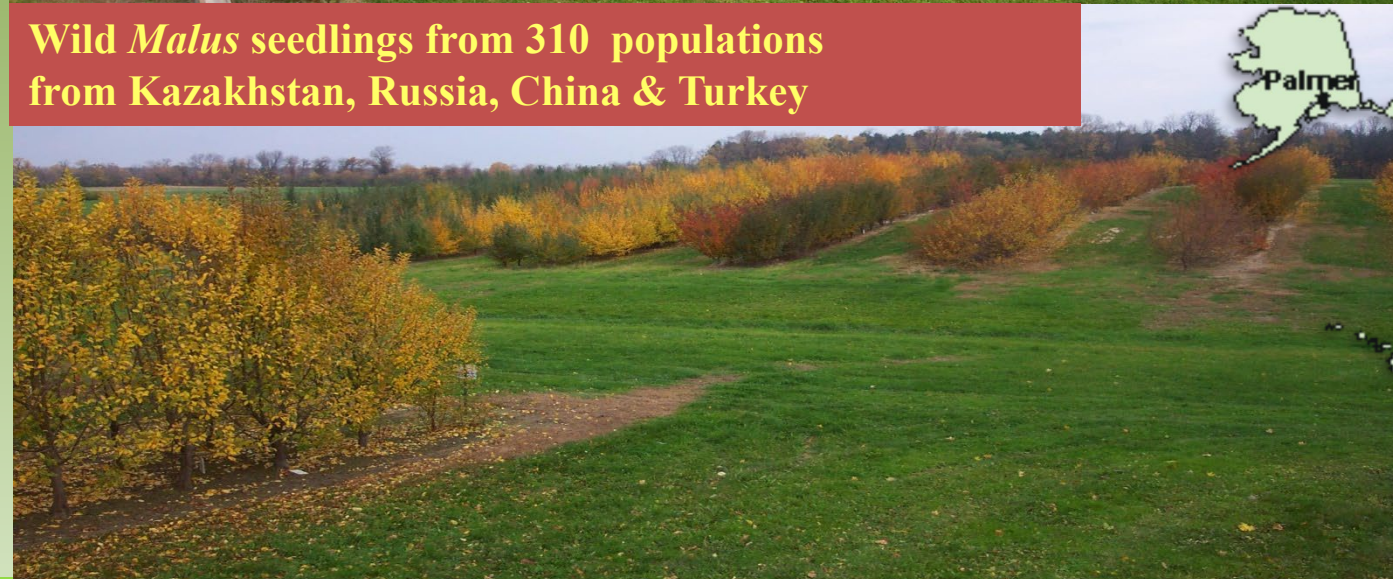
The Geneva Apple Rootstock Breeding Team

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

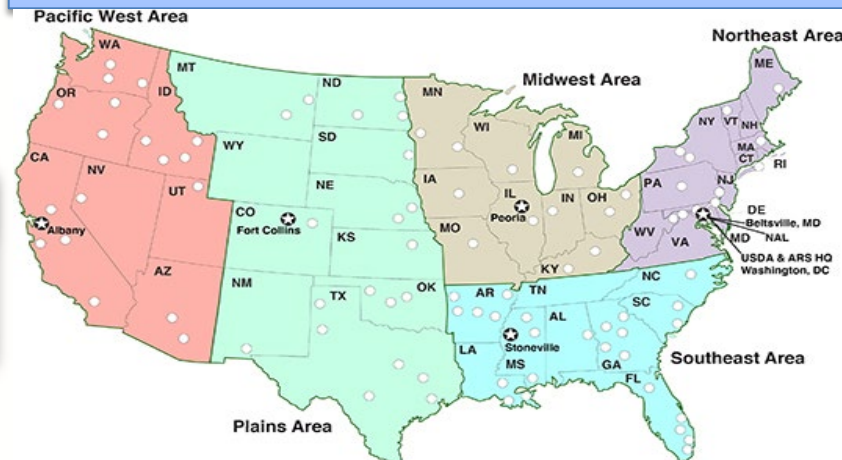




ARS Organization



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.



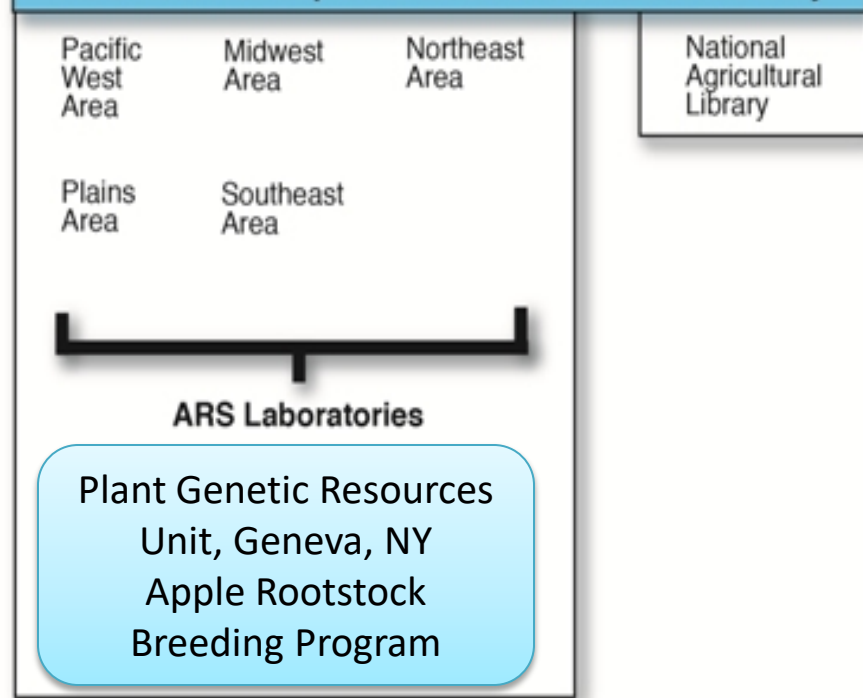
ARS scientists

Are federal employees, working directly under the Department of Agriculture (USDA) on U.S. agricultural problems.

Central Program Planning, Coordination, & Support

Office of National Programs	Administrative & Financial Management	Legislative Affairs
Office of International Research Programs	Office of Chief Information Officer	Office of Outreach Diversity, and Equal Opportunity
Office of Technology Transfer	Information Staff	
Budget & Program Management Staff	Office of Scientific Quality Review	

Field Research Implementation & Information Delivery



ARS Laboratories

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



United States Department of Agriculture
Agricultural Research Service

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



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.

complementary federal research



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.



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.



Relationship between ARS and Cornell

Leadership,
Breeding and
Genetics, human
resources, funds

USDA ARS



Horticulture,
Plant Pathology,
human resources,
land

Cornell
University

Apple
Rootstock
Breeding
Program



United States Department of Agriculture
Agricultural Research Service

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

The Geneva® Apple Rootstock Breeding Program



Sarah Bauer



James Cummins Terence Robinson Herb
Aldwinckle and Awais Khan

Charlie



Todd Holleran



United States Department of Agriculture
Agricultural Research Service

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



Abby, Amanda, Haleena, Jess, Jake, Jerlin, Josh, Cooper, Laura....



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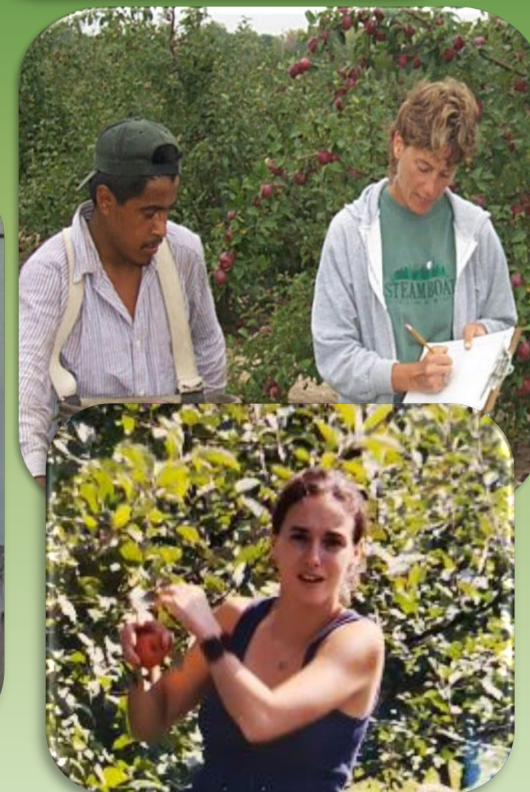
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Plant Genetic Resources Unit, Geneva, NY



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

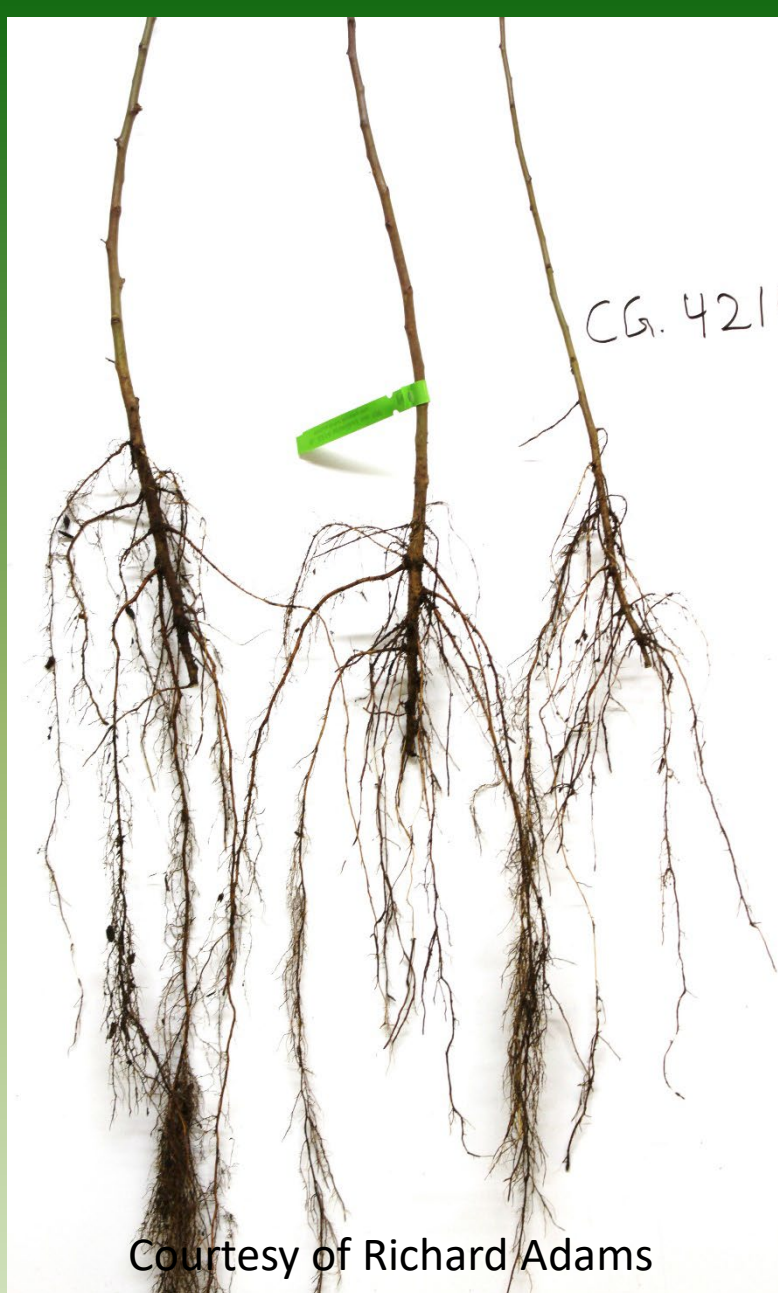


3. A bud from a **scion** variety like Gala or Granny Smith is grafted on the **rootstock**



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

Whip/tongue

Saddle



Source: Royal Horticultural Society



Source: Adelaide Kitchen Gardeners

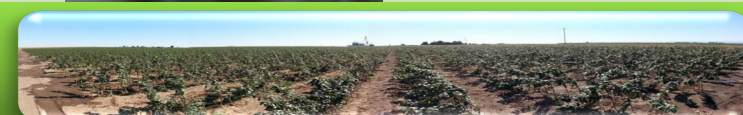


Source: Chris Vernon



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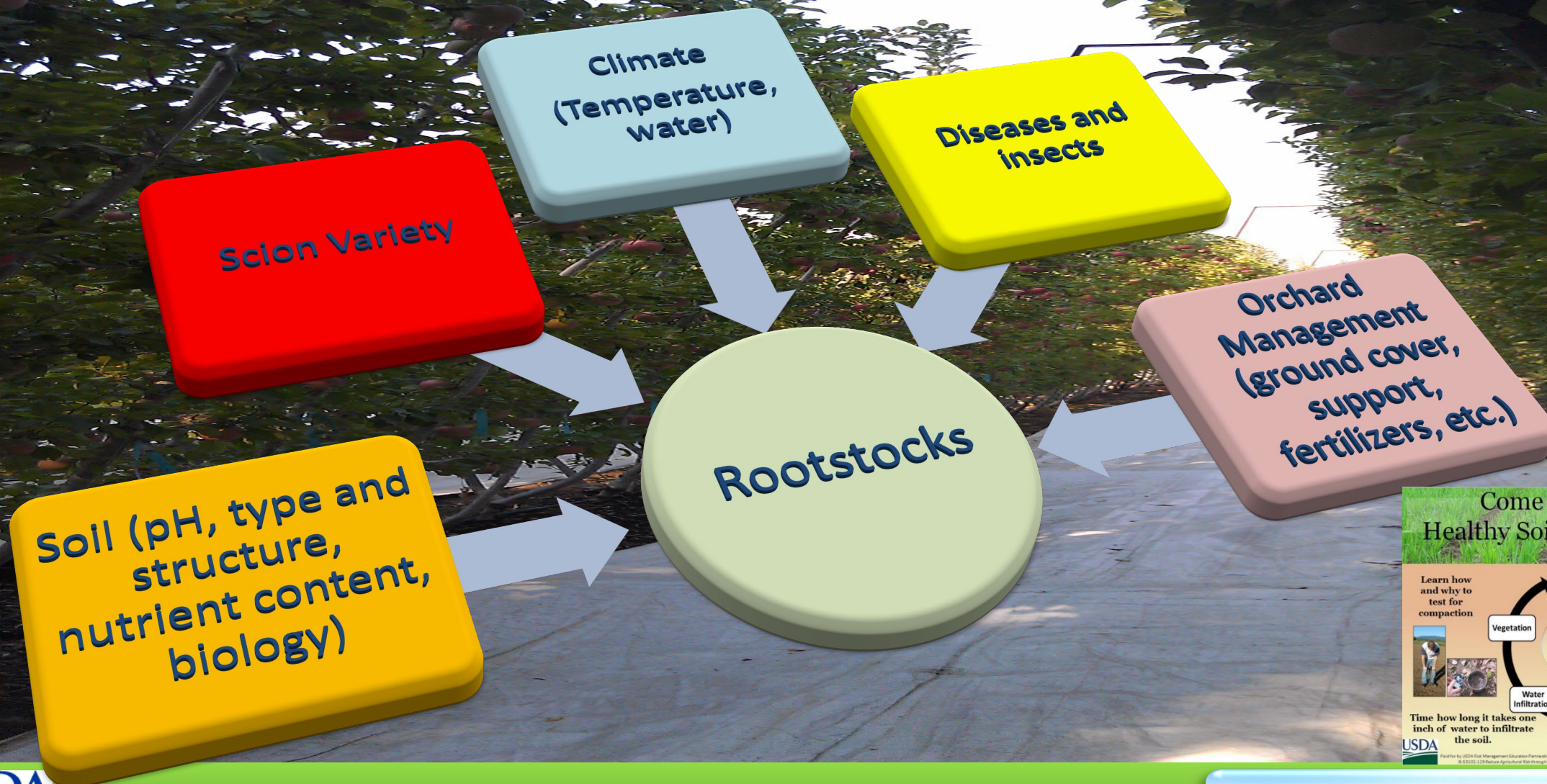


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How do we provide **Designer Solutions** for these interactions?



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Plant Genetic Resources Unit, Geneva, NY



Benefits from the implementation of dwarfing rootstocks



Less ladder accidents, improved ergonomics for picking



Increased productivity and efficiency

Less sprays, easier mechanization



MINIATURE FRUIT GARDEN;

OR, THE CULTURE OF

PYRAMIDAL AND BUSH FRUIT TREES.

"There is no kind of fruit, however delicious, that may not be deteriorated, or however worthless, that may not be ameliorated, by particular modes of management."—DR. LINDLEY. C

BY THOMAS RIVERS.

FROM THE THIRTEENTH ENGLISH EDITION.

36 113

NEW-YORK:
ORANGE JUDD & COMPANY,
245 BROADWAY.

[1866]

1866

camellias watered just as if the pears were not there. In severe frosts, the temperature was kept just above freezing. The autumn pears under this treatment ripened slowly, and were of excellent flavor. The late pears kept till April; but then, owing to the power of the sun, the air of the house became too warm and dry, and they shrivelled. I should therefore recommend winter pears to be kept in the greenhouse in covered pots or jars (I now use large clean flower-pots with wooden covers), placing them in early in December.

Mr. Tillery, of the Wellbeck Gardens, keeps his choice pears and apples in boxes of bran with great success. The bran, before it is used, should be thoroughly dried and sifted, so as to take from it all the small particles of meal. With this treatment pears and apples may be placed in it as soon as they are gathered. The boxes should be quite shallow, so as to admit of only one layer of fruit, which should be covered with the bran, and no lids placed on the boxes. The bran is apt to become musty.

PYRAMIDAL APPLE TREES ON THE PARADISE APPLE STOCK.

Apples as pyramids on the Paradise stock are objects of great beauty and utility. This stock, like the quince, is remarkable for its tendency to emit numerous fibrous roots near the surface, and for contracting the growth of the graft, causing it to become fruitful at a very early stage. On the Continent there are two varieties of the apple under this denomination—viz., the Doucin and the Pomme de Paradis; these are

called Paradise stocks in England, but on the Continent the first and last are used for distinct purposes—the first for pyramids, the latter for dwarf bushes.

The Doucin stock is, I am inclined to think, the same as that called "Dutch Creeper," or "Dutch Paradise," by Miller, in his Dictionary, folio edition of 1759. It puts forth abundance of fibrous roots near the surface of the soil, and is not inclined to root deeply into it like the crab. Apples grafted on this stock are more vigorous than when grafted on the true Paradise stock, and less so than those on the crab; it is, therefore, well adapted for garden trees, for they are easily lifted, their roots thus kept to the surface, and the tree consequently kept free from canker. There is another surface-rooting apple, also well adapted for stocks—the Burr Knot. This, like the Doucin, will strike root, if stout cuttings, two or three years old, are planted two-thirds of their length in a moist soil: it is a large, handsome, and very good culinary apple. At Ware Park, in Hertfordshire, this is called Byde's Walking-stick Apple, owing to Mr. Byde, the former proprietor of the place, often planting branches with his own hand, which soon formed nice bearing trees.

Among apples raised from seed, some will occasionally be found with this surface-rooting nature; and this is, I suspect, the reason why the Doucin stock, under the name of the Paradise, common in the English nurseries, differs from the sorts used as Doucins in France: there are also two or three varieties cultivated there.

About forty years since, I raised a large number of



TRAITÉ DES ARBRES FRUITIERS;

CONTENANT

LEUR FIGURE, LEUR DESCRIPTION,
LEUR CULTURE, &c.

Par M. DUHAMEL DU MONCEAU, de l'Académie Royale des
Sciences ; de la Société Royale de Londres ; des Académies de Petersbourg,
de Palerme, & de l'Institut de Bologne ; Honoraire de la Société d'Edim-
bourg, & de l'Académie de Marine ; Associé à plusieurs Sociétés d'Agricul-
ture ; Inspecteur Général de la Marine.

TOME PREMIER.



A PARIS,

Chez { SAILLANT, Libraire, rue Saint Jean de Beauvais.
DESAIN, Libraire, rue du Foin.

M. DCC. LXVIII.

Avec Approbation et Privilège du Roi.

1767

MALUS, POMMIER. 319

Le fruit est petit, alongé, de forme irrégulière, souvent applati sur son diamètre, ou relevé de côtes, plus gros vers la queue qu'à l'autre extrémité ; communément plus renflé par les bouts que par le milieu ; sa queue est très-peu enfoncée, quelquefois recouverte à sa naissance par une ou deux bosses très-saillantes ; son oeil est petit, & placé presque à fleur. La hauteur est d'environ deux pouces, & le diamètre de dix-huit ou vingt lignes.

La peau est d'un vert-jaunâtre, légèrement lavée de rouge-brun du côté du soleil.

L'ombilic, recouvert par les échancrures desséchées du calyce, est creux jusqu'au quart de la longueur du fruit ; dans le fond, on retrouve les pétales desséchés, & les styles du pistil. Six petites loges triangulaires sont disposées autour du tube ou canal de l'ombilic, & contiennent les étamines desséchées, avec leurs sommets. Vers la moitié de la longueur du fruit, il y a cinq autres petites loges sans pepins.

CULTURE.

LES SEMENCES sont un moyen très-incertain de multiplier les bonnes espèces de Pommiers. Elles se conservent & se perpétuent par la greffe en fente, en écusson, en couronne.

Le Pommier se greffe 1°. sur franc, c'est-à-dire, sur des sujets élevés de semences dans les pépinières, ou de drageons du pied des vieux Pommiers des vergers & des forêts. Ces sujets produisent des Arbres propres pour les vergers & les grands plein-vent : 2°. sur le Pommier de Doucin, qui forme des Arbres de moyenne grandeur, propres pour le buisson, l'espalier & le demi-plein vent ; lorsque le terrain plat

320 TRAITÉ DES ARBRES FRUITIERS.

au Doucin, ils deviennent presque aussi forts que sur le franc. Il se multiplie par les marcottes & les drageons. 3°. Les Pommiers greffés sur le Pommier nain de Paradis, forment des palissades basses, ou de très-petits buissons qui s'élèvent à peine à trois pieds. Ils donnent du fruit plus promptement, plus abondant à proportion, & beaucoup plus gros, que sur franc ou sur Doucin. Cet Arbrisseau se propage par les marcottes, les drageons enracinés & les boutures. Pendant les premières années après la plantation des Pommiers greffés sur Doucin, & sur Paradis, il sort du pied des sujets beaucoup de rejets qui peuvent servir à les multiplier, mais qui fatiguent l'Arbre, si l'on n'a soin de les éclater.

Un terrain gras, profond, un peu humide, est celui qui convient le mieux au Pommier. Il s'accommode de tout autre, même d'un terrain glaiseux. Mais il réussit médiocrement dans les terres sèches ; & ne vit pas long-temps dans celles qui ont peu de profondeur. Le Paradis veut une terre meuble & douce ; ses faibles racines ne pouvant s'étendre dans une terre compacte, il y périt en peu de temps, ou ne fait qu'y languir.

On plante peu de Pommiers en espalier, à moins qu'on ne veuille couvrir des murs à l'exposition du nord. On les élève dans les potagers, en buisson, en éventail, en contre-espalier ; & ils se taillent suivant les règles générales, mais un peu plus long que la plupart des autres Arbres fruitiers. Quant à ceux qui sont en plein-vent, donner quelques labours au pied ; détruire les parasites, le gui & la mousse, qui les fatiguent ; retrancher le bois mort ; les décharger des brindilles & des branches languissantes, qui les rendent trop confus, étioient les bonnes branches, & nuisent à leur fécondité ; soutenir leurs branches lorsqu'elles courent risque de rompre

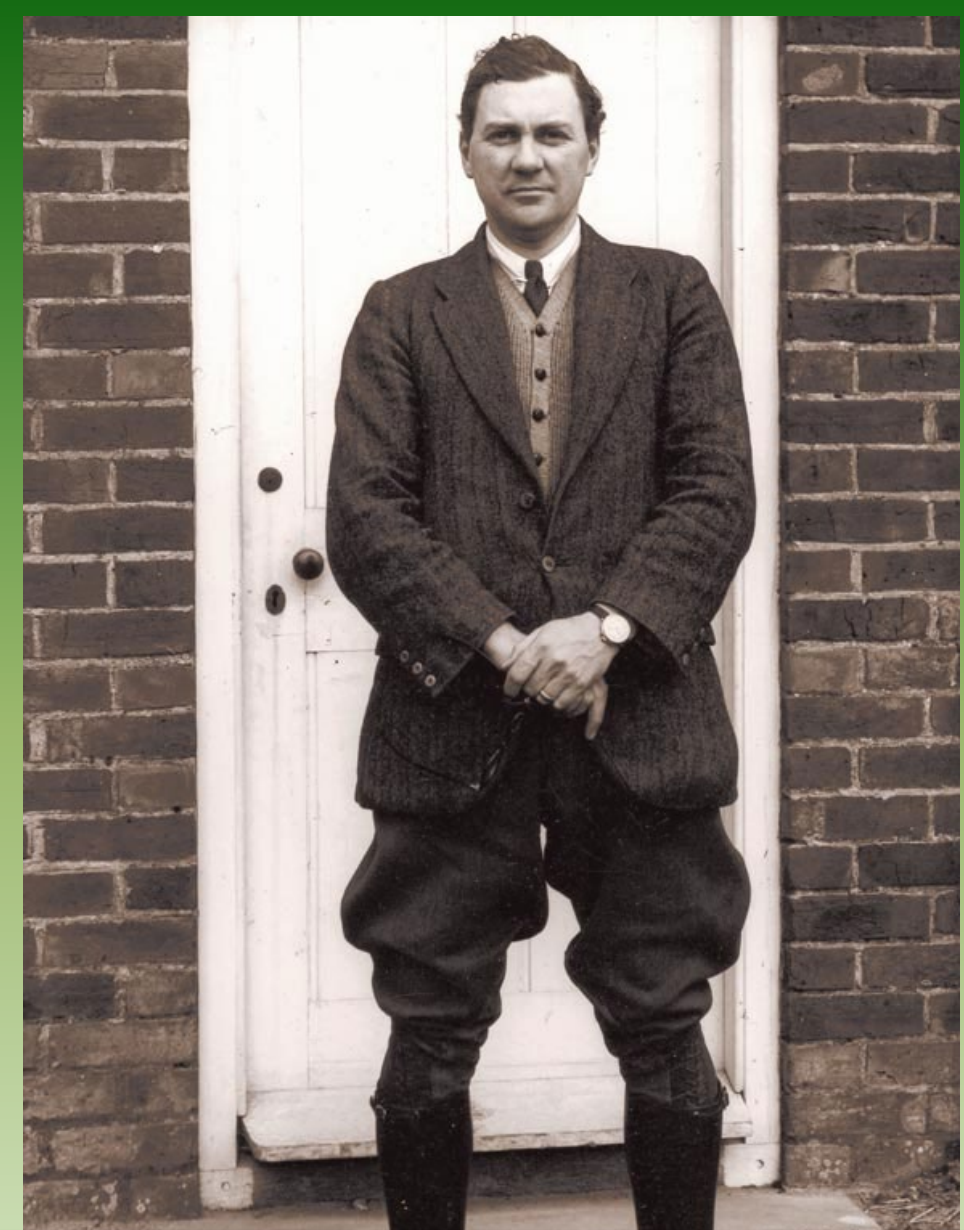


United States Department of Agriculture
Agricultural Research Service

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



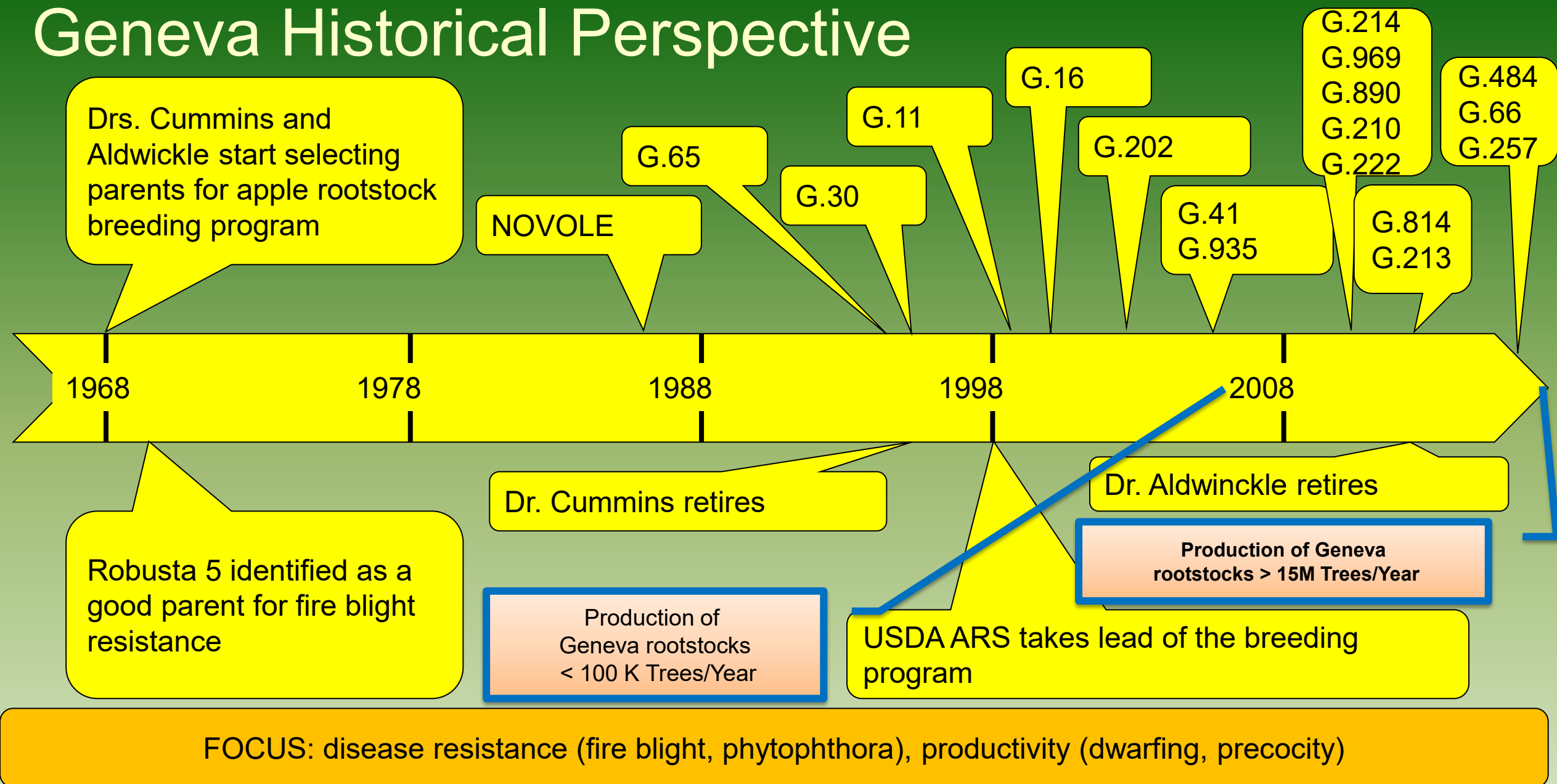
FROM WIKIPEDIA: From about 1912, Ronald Hatton and his colleagues rationalised, standardised and catalogued the various rootstocks in use in Europe at the time under names such as Doucin and Paradise.[1][2] Their first list had nine rootstock varieties, assigned the "type" numbers I–IX.[3] The list later grew to twenty-four, and the Roman numerals gave way to Arabic numerals with the prefix "Malling" or "M."



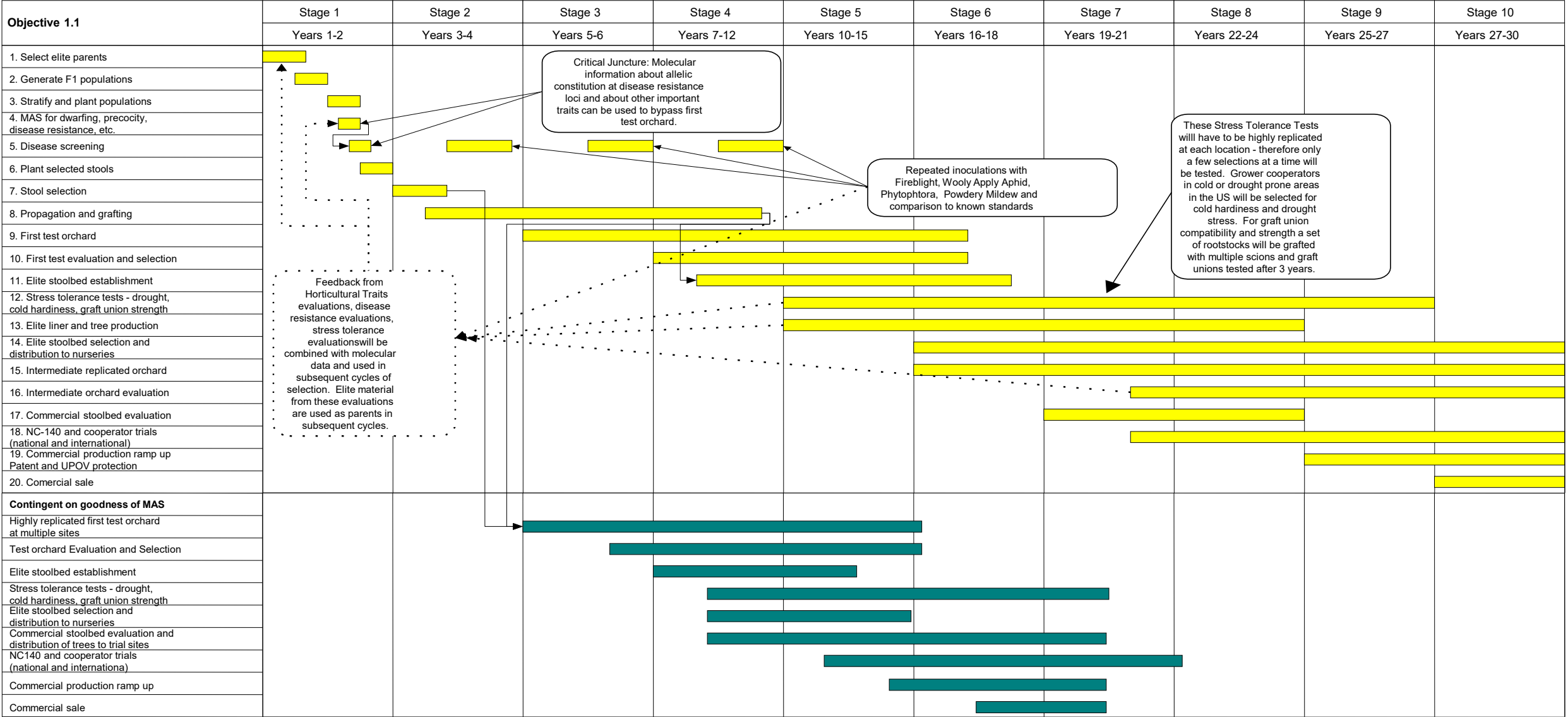
<https://applesandpeople.org.uk/stories/paradise/>



Geneva Historical Perspective



Apple Rootstock Breeding and Selection Protocols



Designer Traits for Precision Management

- Increase in productivity/ha
- Branch angle modification
- Replant disease tolerance
- Woolly apple aphid resistance
- Fire blight resistance
- Unique nutrient uptake
- Alternate bearing management

Value to Growers



	FUJI	GALA	HONEYCRISP
Characteristics that could use improvement	Too much vigor Biennial Color	Fruit Size Productivity Color/Maturity Fire blight	Weak vigor Biennial Fruit disorders
Rootstocks that have shown to improve Biennial Bearing	G.935, G.214, CG.5257, G.41, CG.4004, CG.4011		G.935, B.10, G.814, G.41TC, G.202, CG.4003
Rootstocks that have shown to improve Potassium/Calcium ratio in fruit	CG.5257, G.222, G.935, G.814, G.214		CG.4003, G.214, G.16, G.814, G.969, CG.6001, CG.6976
Rootstocks that have shown to influence Fruit Size	G.257, G.222, G.935, G.484, CG.3001	G.814, G.41, G.257	
Rootstocks with improved Productivity	G.11, G.41, G.214, G.935, G.4011, G.814	G.41, G.214, G.814, G.935, G.11, G.484	G.890, G.41, G.935, G.814, G.969

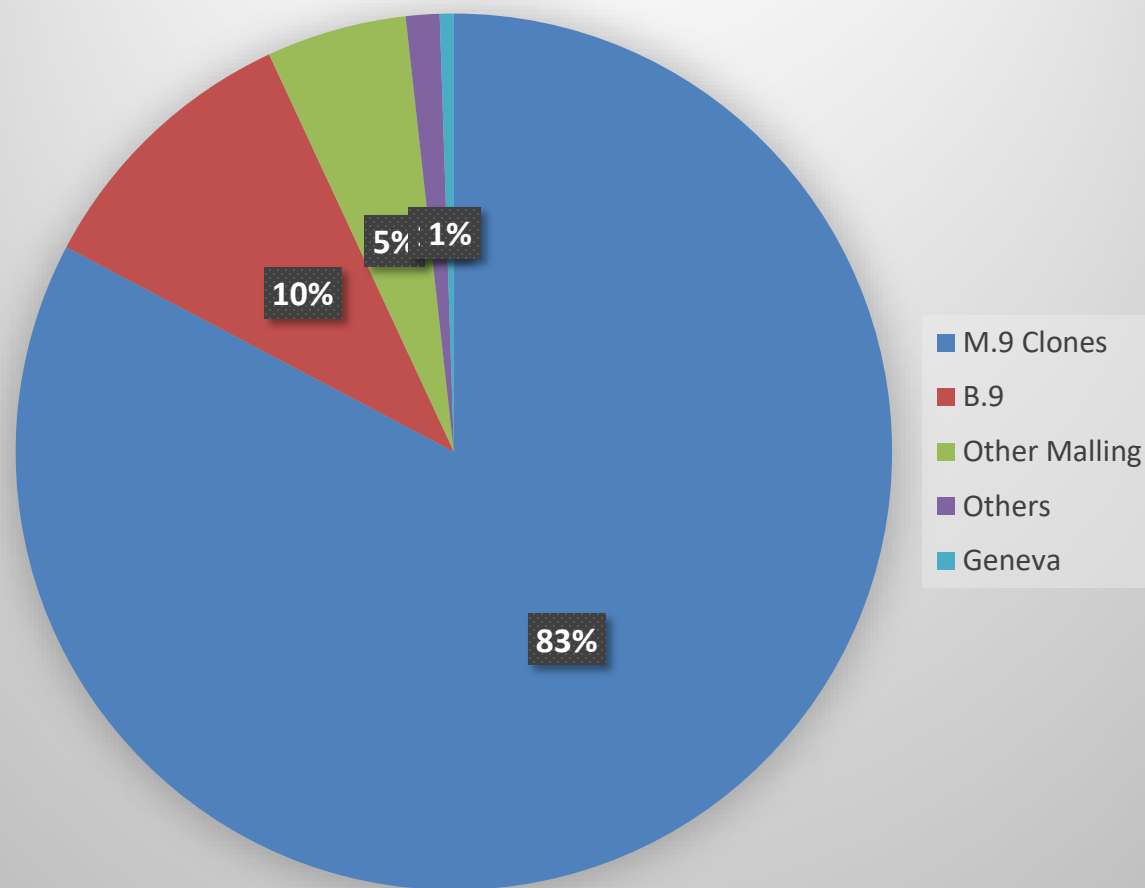


Diverse rootstocks can support different training system dynamics: fruiting wall vs V trellis, single vs multi axes.

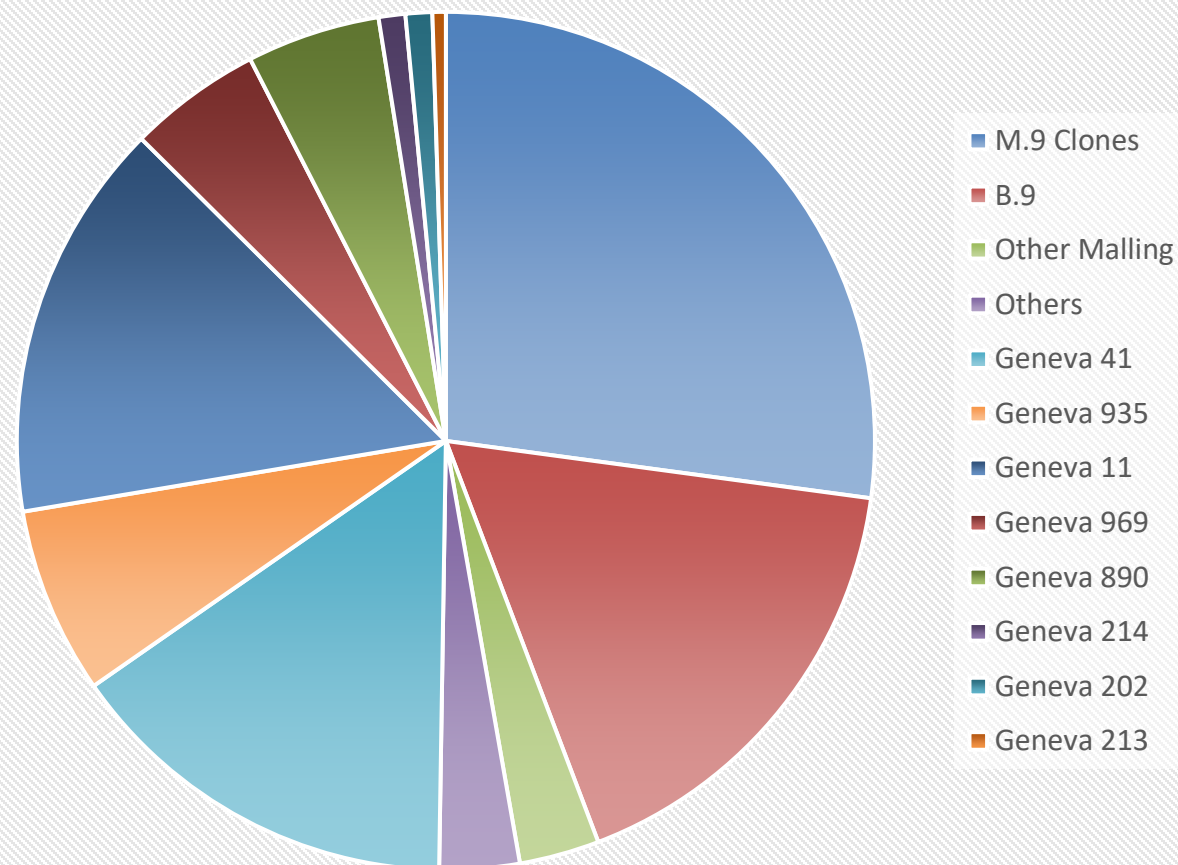


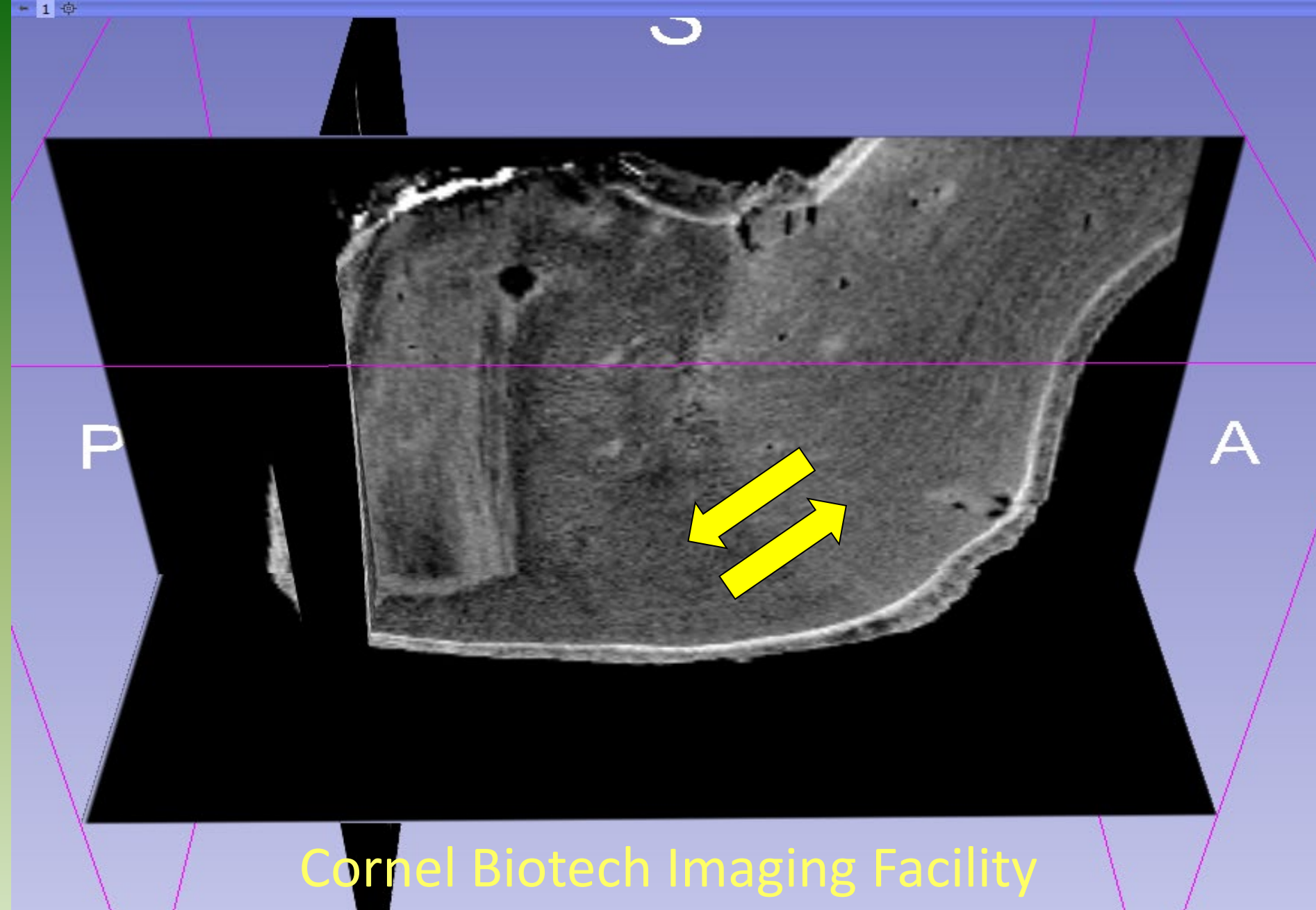
Genetic (Phenotypic) Diversity is the Key!

Estimate of U.S. Rootstock Sales
Composition 2001 (%)



Estimate of U.S. Rootstock Sales
Composition 2019 (%)





D:\Genna...DICOM
ID: Synt...taset
,, O
2008-01-01
2:00:24 PM
Xradia
Xradia, Inc
HFS
S: 11.027mm
B: 1: Xradia
10 mm

Y R: -11.398mm
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G A: -22.859mm
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Cornel Biotech Imaging Facility



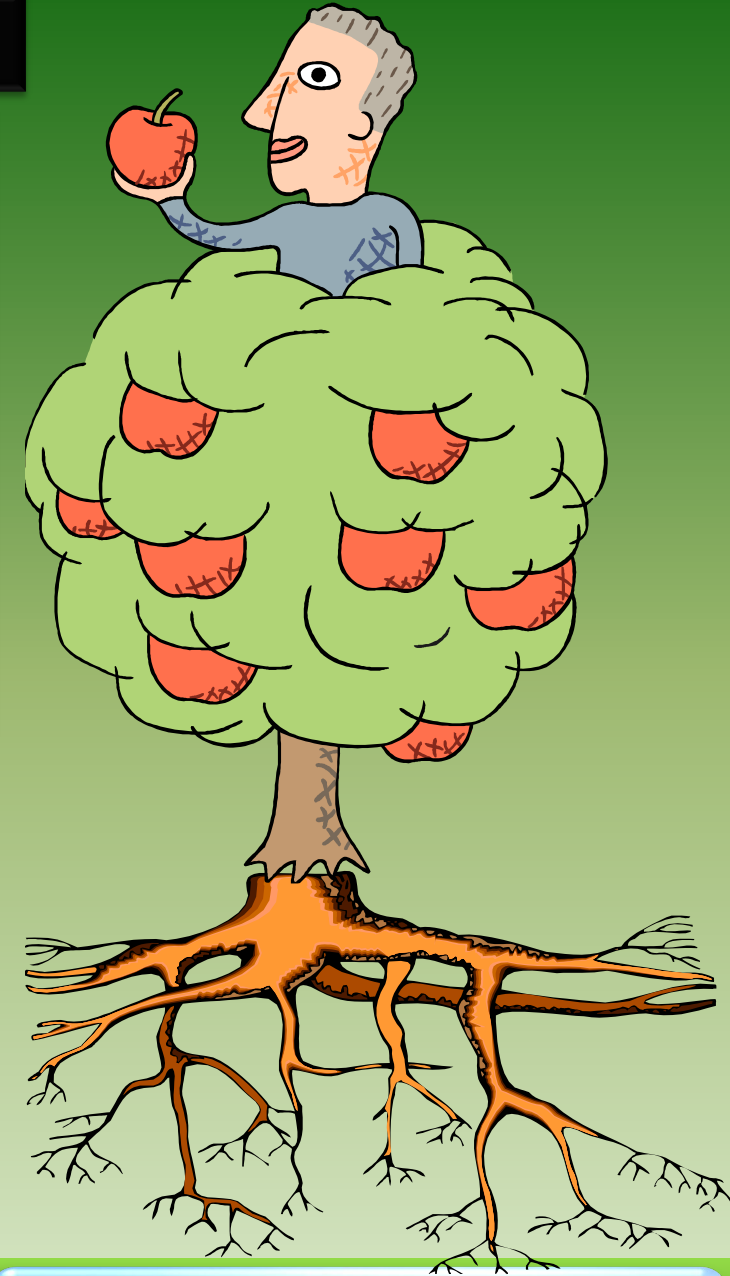
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Apple Rootstock Breeding Program
Plant Genetic Resources Unit, Geneva, NY



Efficiencies achieved by grafting

- Ability to discern root(stock) dependent traits
- Ability to discern root-scion interactions
- Ability to generate large number of clonal replicates
- Increased breeding efficiency:
 - Combining 15 traits in the same plant is harder than combining 7 traits in roots and 8 traits in scion.
 - Simplified environment interactions: soil microbes vs areal microbes.....
 - Ability to breed graft-transmissible traits

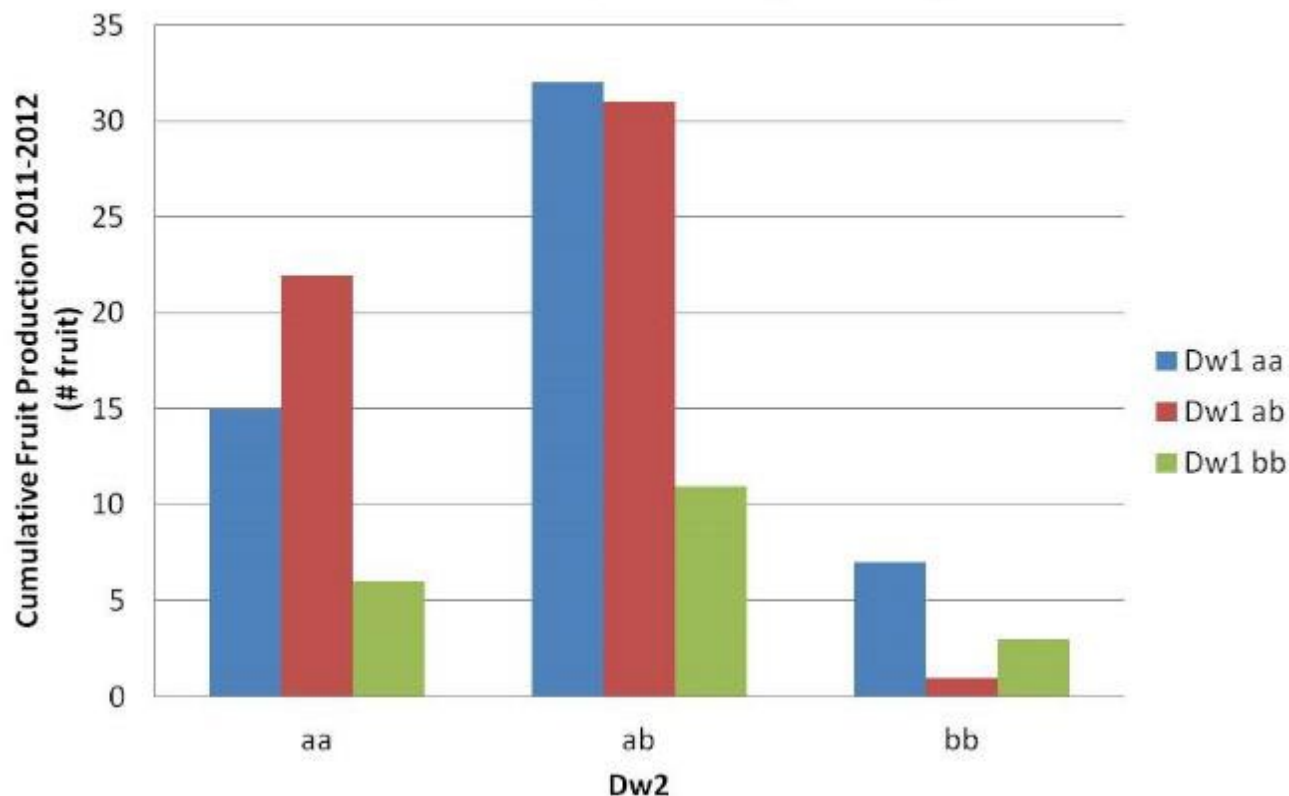


Examples of root(stock) induced traits on the scion

- 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



Cumulative Fruit Production
Least Square Means Dw1*Dw2
Wilks lambda=.48548, F(20, 166.78)=2.0300, p=.00827



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 Fazio¹

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

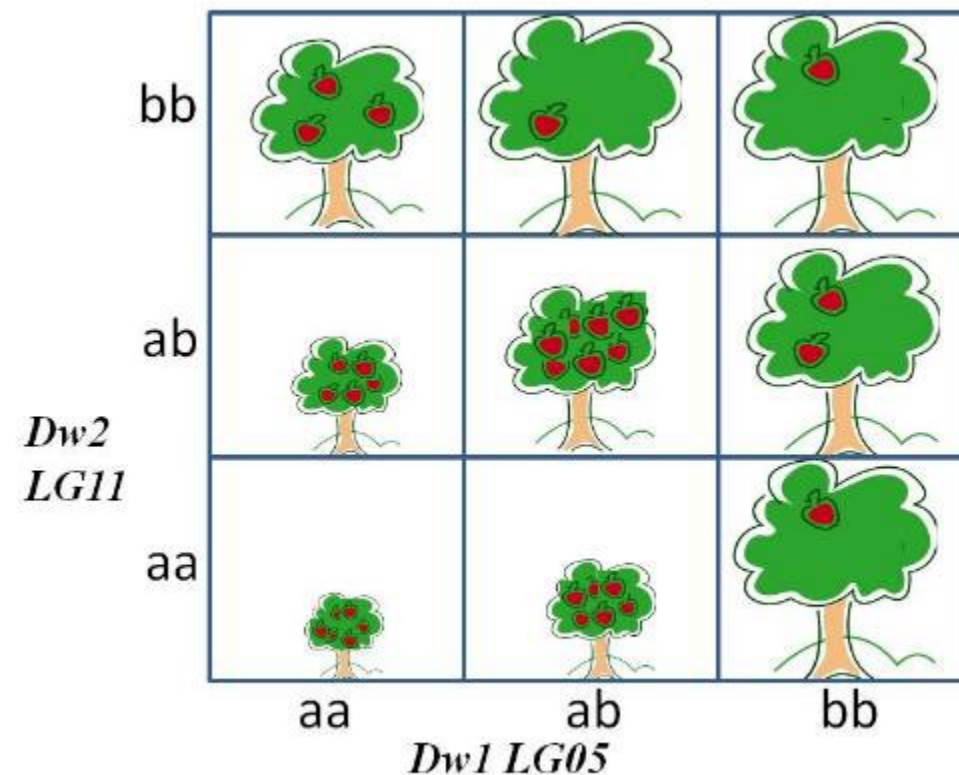
Willow Drive Nursery, 3539 RD 5 NW, Ephrata, WA 98823

David Strickland

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

Terence Robinson

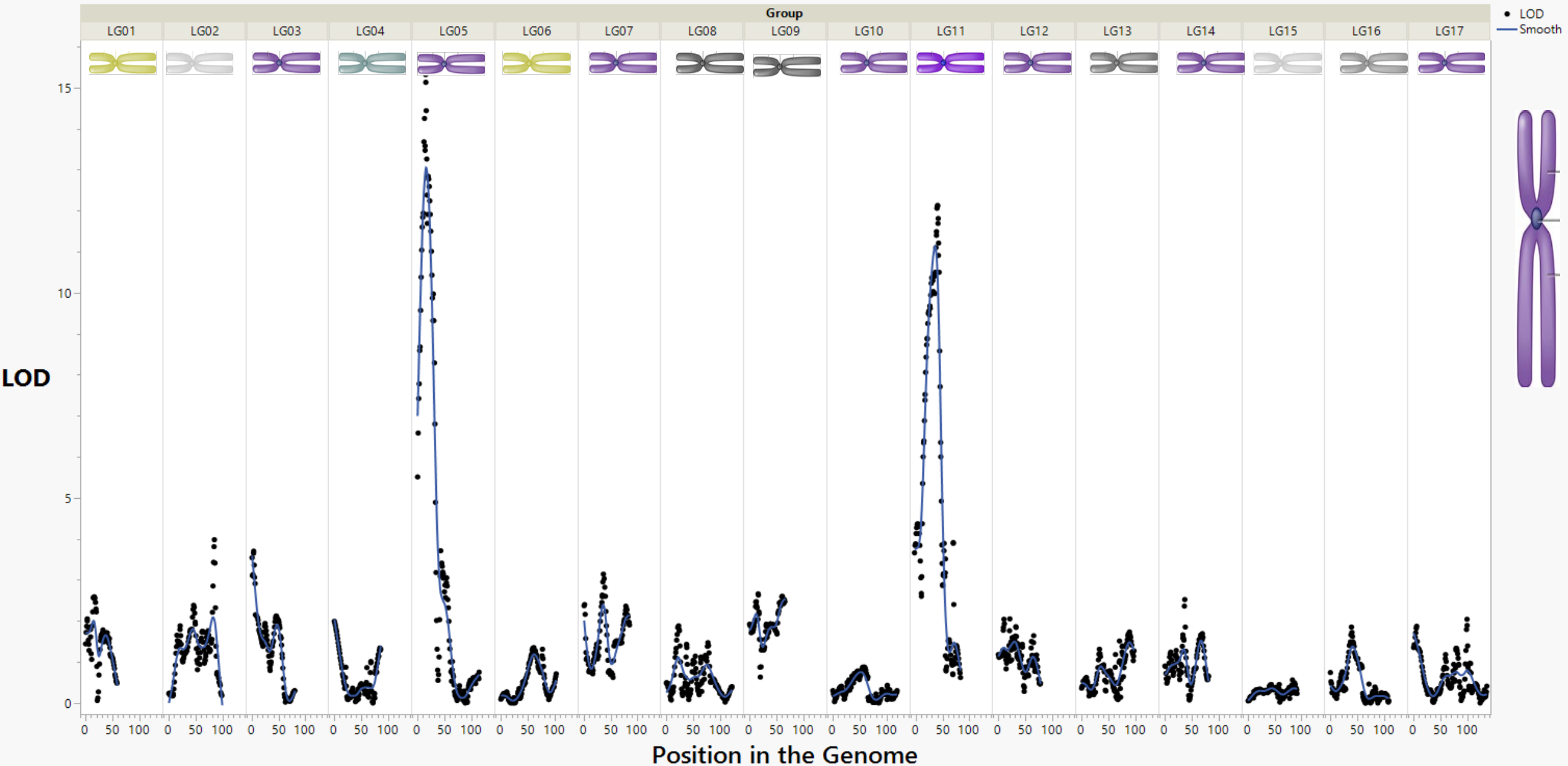
Department of Horticulture, NYSAES, Cornell University, Geneva, NY 14456



Highest fruit
 production in
 heterozygous
 plants

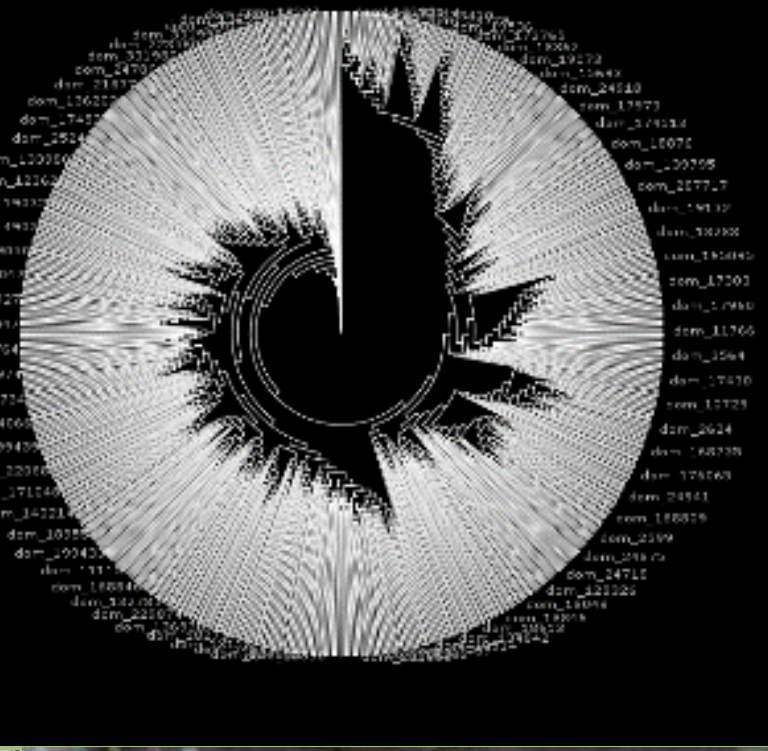
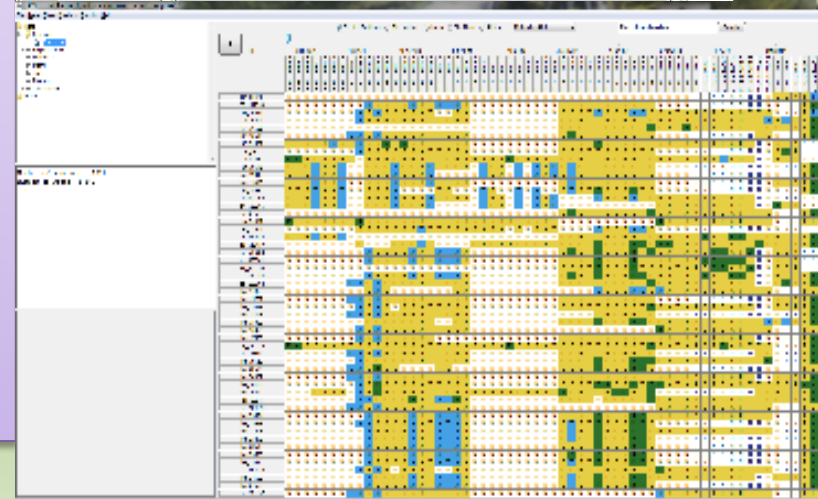
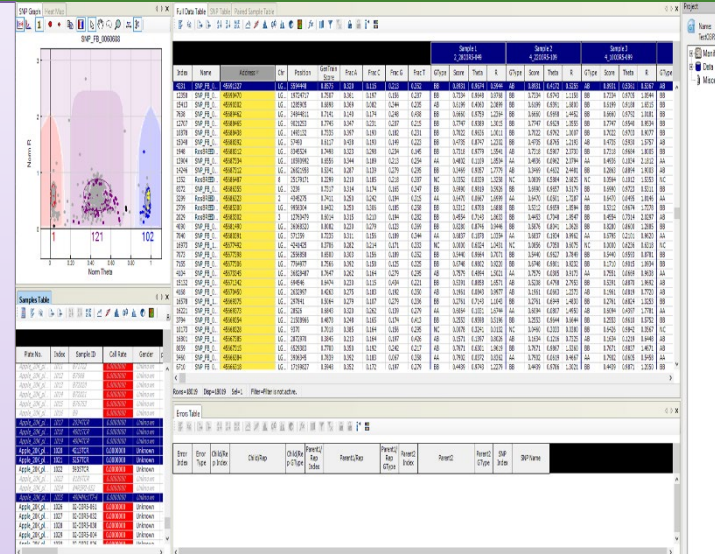


Mean Tree Diameter

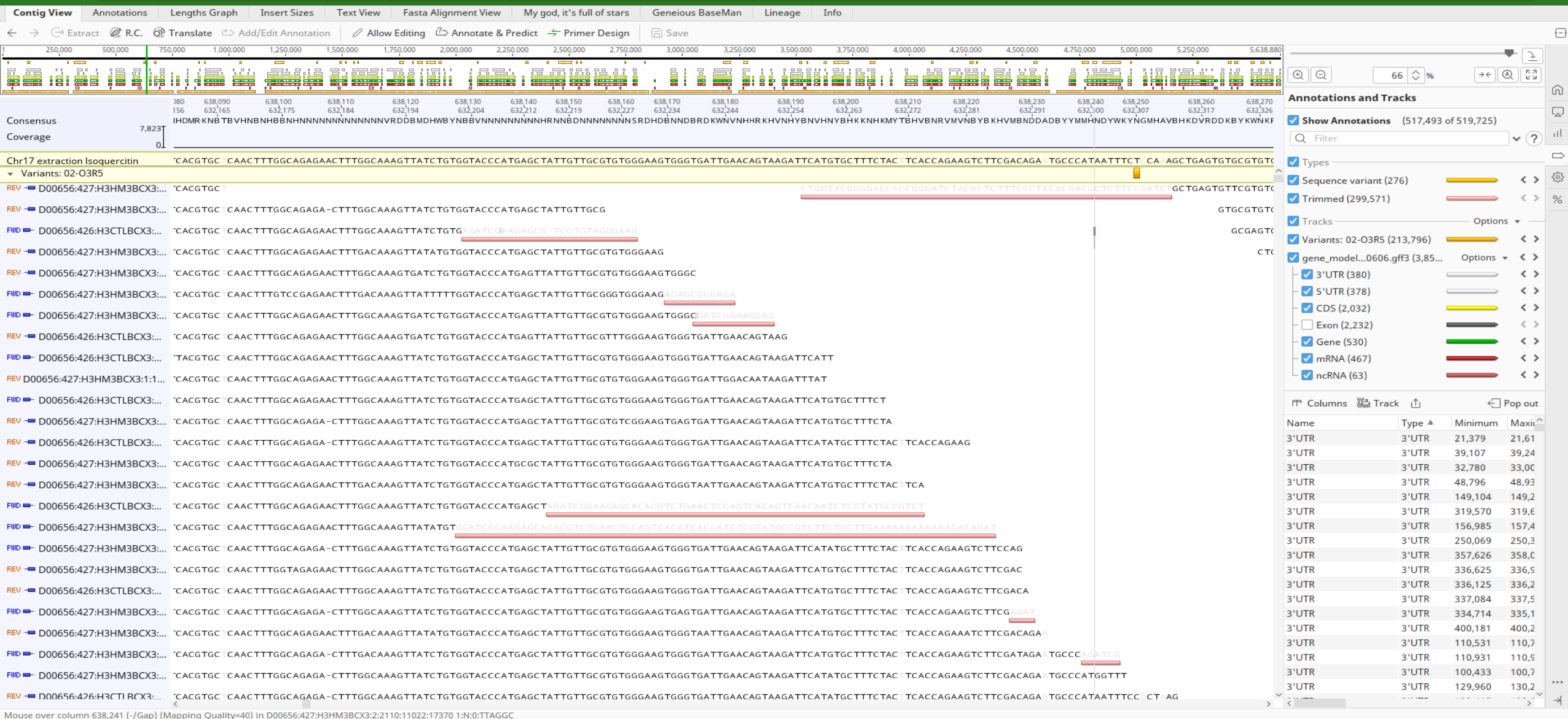


Genomic Resources for Breeding

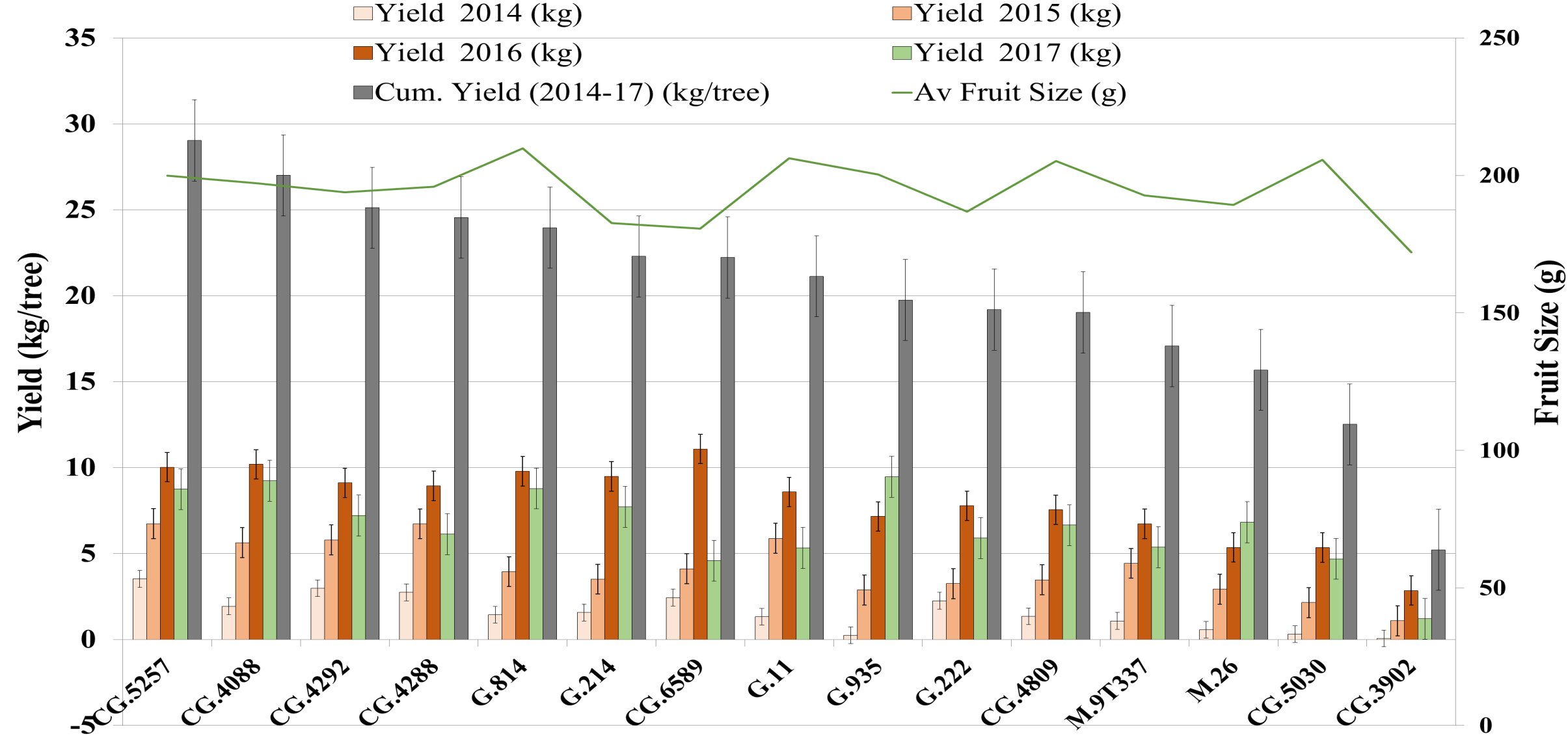
- Next-Gen Sequences of Parental Lines and Genome assemblies
- GBS data on PGRU Diversity Panel
- Genomes (various species)
- Gene Expression Markers
- Extensive RNAseq data
- Genetic Maps
- RosBREED 9K and 20K Infinium SNP Chips



RNAseq differential expression and variant analysis of diverse apple roots

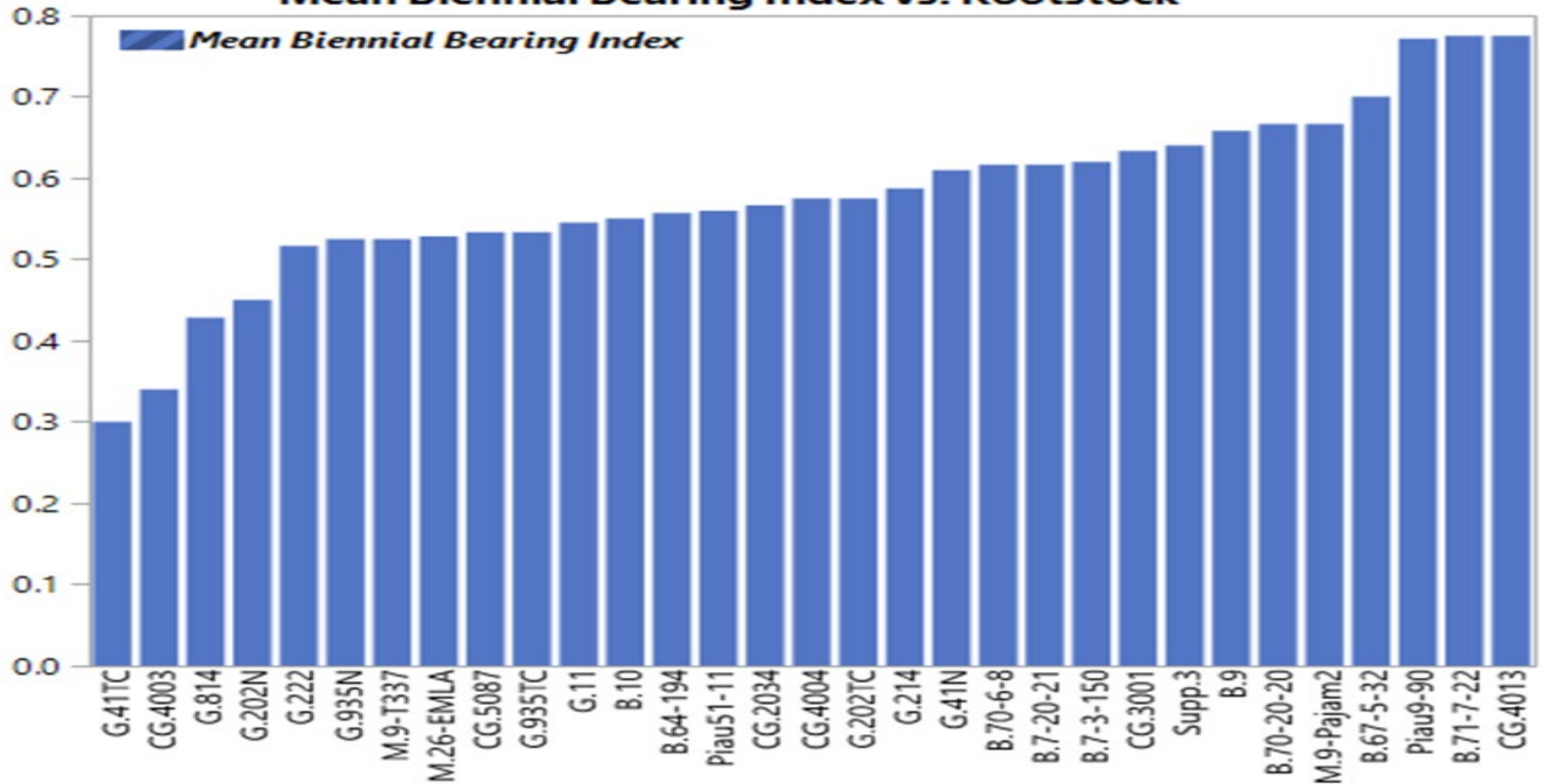


Performance of SnapDragon on Geneva Rootstocks



Mean Biennial Bearing Index vs. Rootstock

Mean Biennial Bearing Index



Rootstock ordered by Mean Biennial Bearing Index (ascending)



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G. 41

M.9

**Courtesy Betsy Beers
WSU Wenatchee**



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

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



Ongoing research in Geneva featuring all released and elite rootstocks and breeding populations. European research shows a new woolly apple aphid ecotype overcoming deployed resistance in G.41.



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



2007 UT Field Trial turned into a Fire Blight Trial



GALA on M.26 planting with Geneva rootstocks interspersed randomly through the planting.



Two years later most M.26 trees had died from fire blight, 100% of Geneva rootstocks survived. Orchard removed and the surviving trees moved into new orchard that still stands.



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



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

Low Chilling Comparison between Gala grafted on G.213 and M.9 in Brazil (2014)



Work of Dr. Tiago Afonso de Macedo & Dr. Rufato



United States Department of Agriculture
Agricultural Research Service

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



Productivity per hectare of cv. MaxiGala grafted on different rootstocks in **new area**

Rootstocks	Yield (t/ha)		cumulative
	2016	2017	t/ha
M.9	13,18	25,8	38,98
G.213	17,13	34,49	51,62
G.202	6,89	28,32	35,21
G.757	6,86	33,13	39,99
G.814	7,48	44,61	52,09

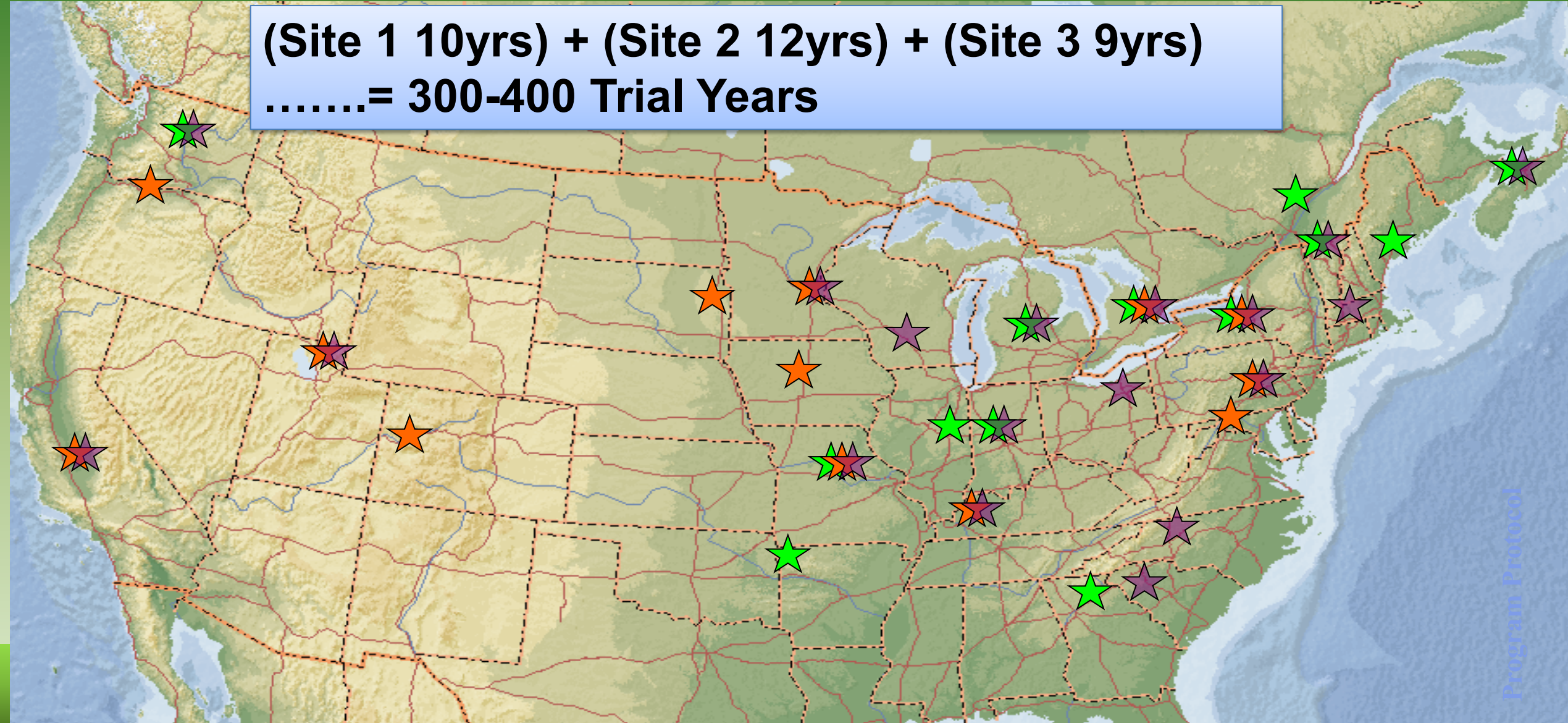
Planting density 3,571 plants per hectare (0,7 x 4,0 m)

Courtesy of Dr. Leo Rufato



Trials with NC-140 Collaborators and Advanced Growers – Stage 8

**(Site 1 10yrs) + (Site 2 12yrs) + (Site 3 9yrs)
.....= 300-400 Trial Years**



Volume 246, 27 February 2019, Pages 506-517



Gemma Reig ^{a, h} , Jaume Lordan ^{b, h}, Mario Miranda Sazo ^c, Stephen Anthony Hoying ^a, Michael J. Fargione ^d, Gabino Hernan Reginato ^e, Daniel J. Donahue ^f, Poliana Francescato ^b, Gennaro Fazio ^{b, g}, Terence Lee Robinson ^b



Volume 244, 26 January 2019, Pages 277-293



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



Figure 1 displays 12 scatter plots (a-l) showing the relationship between tree density (tree ha⁻¹) and various growth and yield parameters for 12 different tree species (B9, G20, G21, G22, G23, G24, G25, G26, G27, G28, G29, G30). The plots are arranged in a 4x3 grid. The x-axis for all plots is Tree density (tree ha⁻¹), ranging from 700 to 2500. The y-axis for each plot represents a different parameter: (a) PI (kg cm⁻²), (b) PI (kg cm⁻²), (c) PI (kg cm⁻²), (d) PI (kg cm⁻²), (e) PI (kg cm⁻²), (f) PI (kg cm⁻²), (g) PI (kg cm⁻²), (h) PI (kg cm⁻²), (i) PI (kg cm⁻²), (j) PI (kg cm⁻²), (k) PI (kg cm⁻²), and (l) PI (kg cm⁻²). Each plot includes data points for the 12 species and a linear regression line. The regression equations and R-squared values are provided for each plot.

Plot (a): PI (kg cm⁻²) vs Tree density (tree ha⁻¹)

Regression equations and R-squared values:

- G10: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G11: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G12: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G13: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G14: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G15: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G16: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G17: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G18: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G19: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G20: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G21: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$

Plot (b): PI (kg cm⁻²) vs Tree density (tree ha⁻¹)

Regression equations and R-squared values:

- G10: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G11: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G12: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G13: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G14: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G15: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G16: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G17: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G18: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G19: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G20: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G21: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$

Plot (c): PI (kg cm⁻²) vs Tree density (tree ha⁻¹)

Regression equations and R-squared values:

- G10: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G11: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G12: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G13: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G14: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G15: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G16: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G17: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G18: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G19: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G20: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G21: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$

Plot (d): PI (kg cm⁻²) vs Tree density (tree ha⁻¹)

Regression equations and R-squared values:

- G10: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G11: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G12: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G13: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G14: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
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- G19: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G20: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G21: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$

Plot (e): PI (kg cm⁻²) vs Tree density (tree ha⁻¹)

Regression equations and R-squared values:

- G10: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G11: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G12: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G13: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G14: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G15: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G16: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G17: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G18: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G19: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G20: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G21: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$

Plot (f): PI (kg cm⁻²) vs Tree density (tree ha⁻¹)

Regression equations and R-squared values:

- G10: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G11: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G12: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G13: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G14: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G15: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G16: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G17: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G18: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G19: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G20: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G21: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$

Plot (g): PI (kg cm⁻²) vs Tree density (tree ha⁻¹)

Regression equations and R-squared values:

- G10: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G11: $Y = 0.002 + 0.0001X$, $R^2 = 0.01$
- G



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Authors: Gemma Reig¹, Jaume Lordan², Stephen Hoving³, Michael Fargione⁴, Da...

View More +

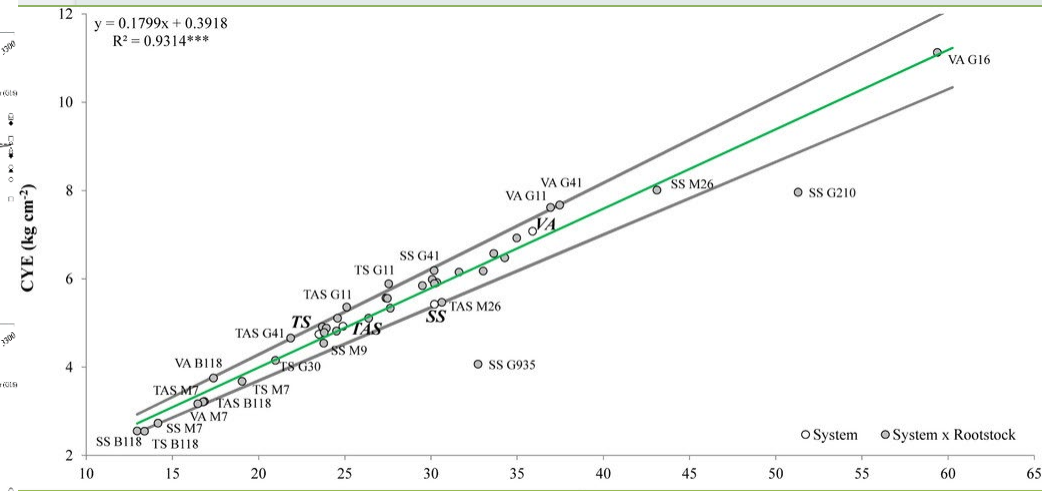
DOI: <https://doi.org/10.21273/HORTSCI14904-20>

Article Category: Research Article

Page Count: 1538–1550

Online Publication Date: 21 Aug 2020

Volume/Issue: Volume 55: Issue 10



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.

Apple Rootstock Breeding Program

Plant Genetic Resources Unit, Geneva, NY



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

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



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

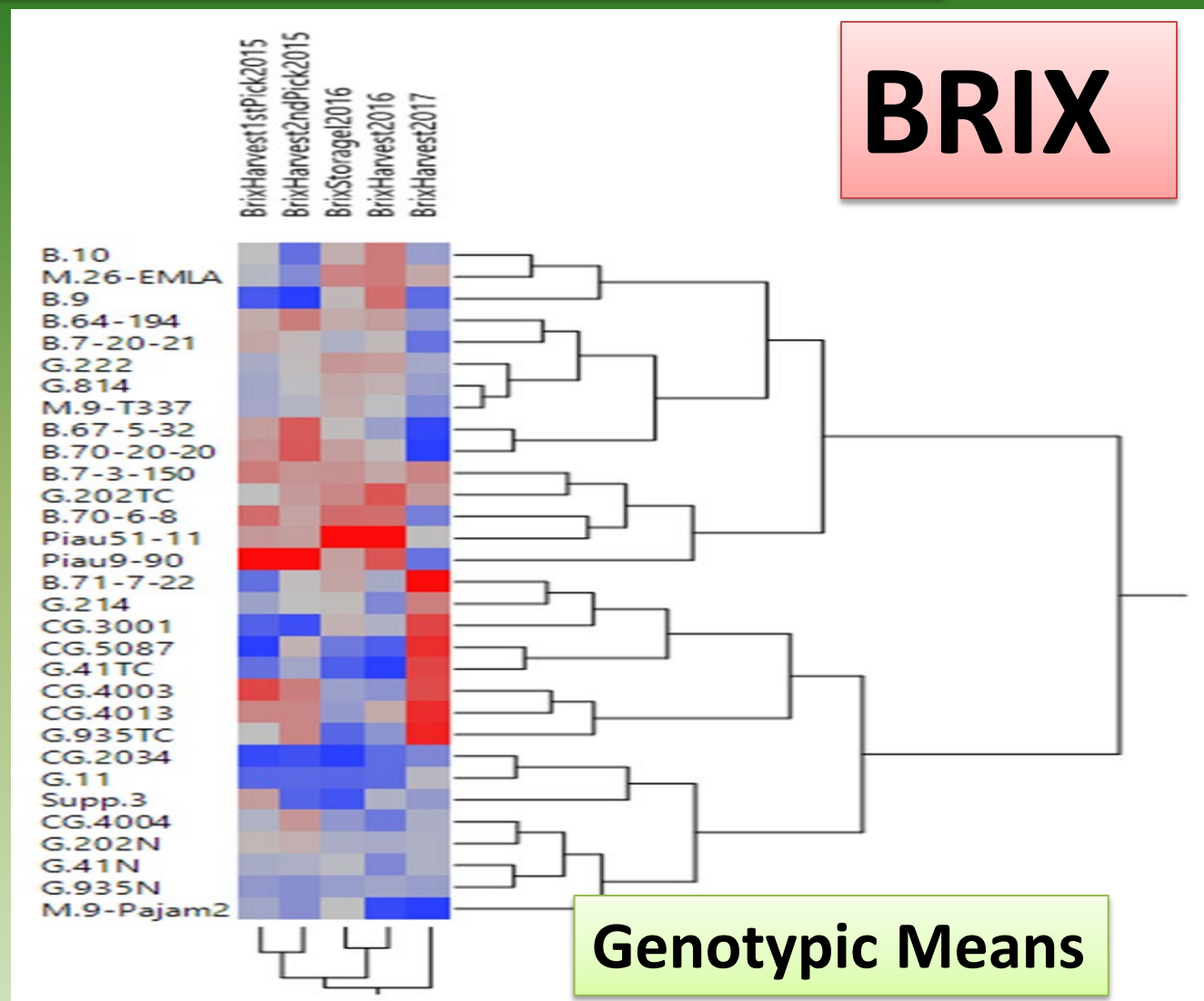
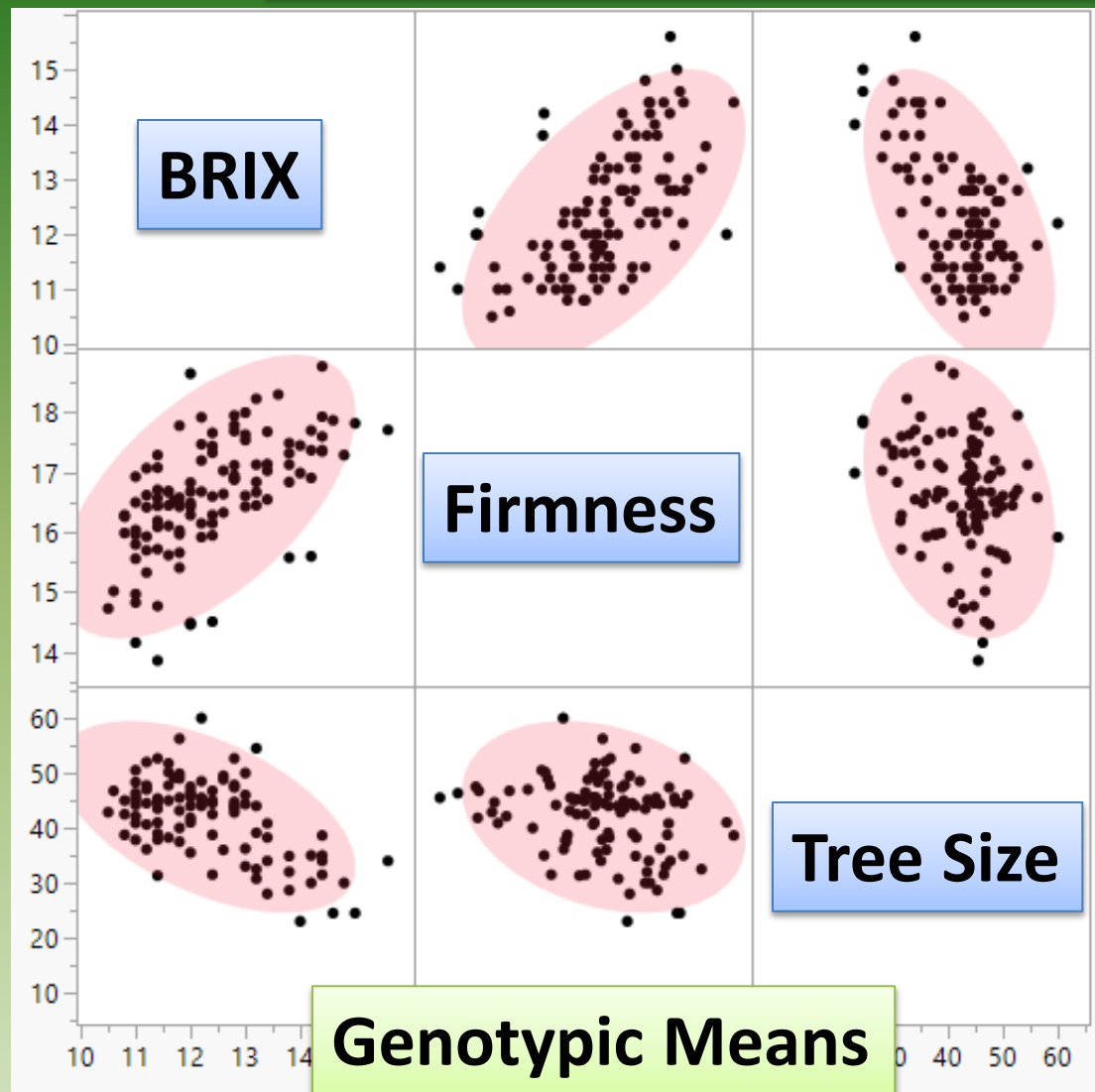
Nicola Dallabetta, Andrea Guerra, and Jonathan Pasqualini
FEM-IASMA, Technology Transfer Center, San Michele a/A, TN, Italy

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

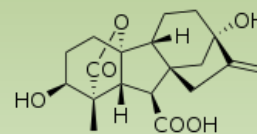
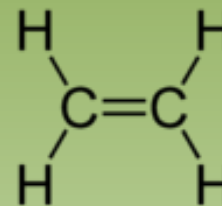
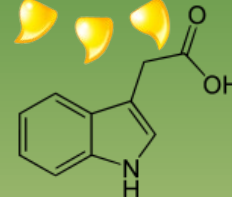
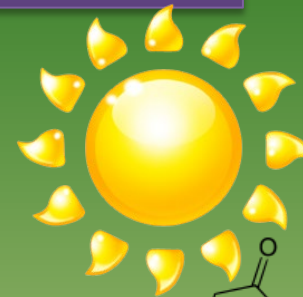
Additional index words. fruit size, fruit quality, yield efficiency, planar training system, mechanical pruning, crop value

Fruit Quality is Affected by Rootstocks



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....



K

P

Fe

Cu

Mg

Mn

Mo

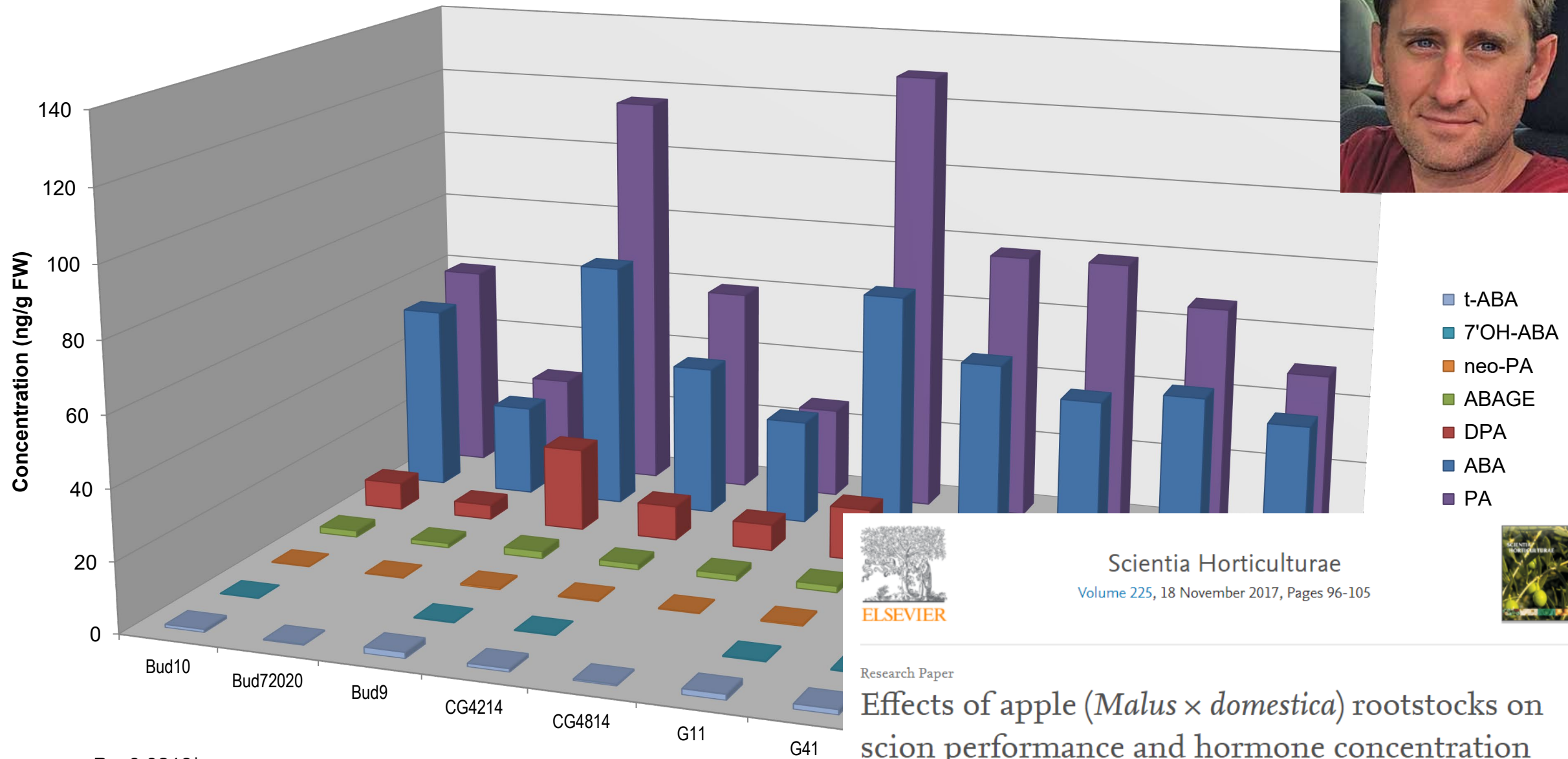
Na

Zn

Ca



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



Scientia Horticulturae

Volume 225, 18 November 2017, Pages 96-105

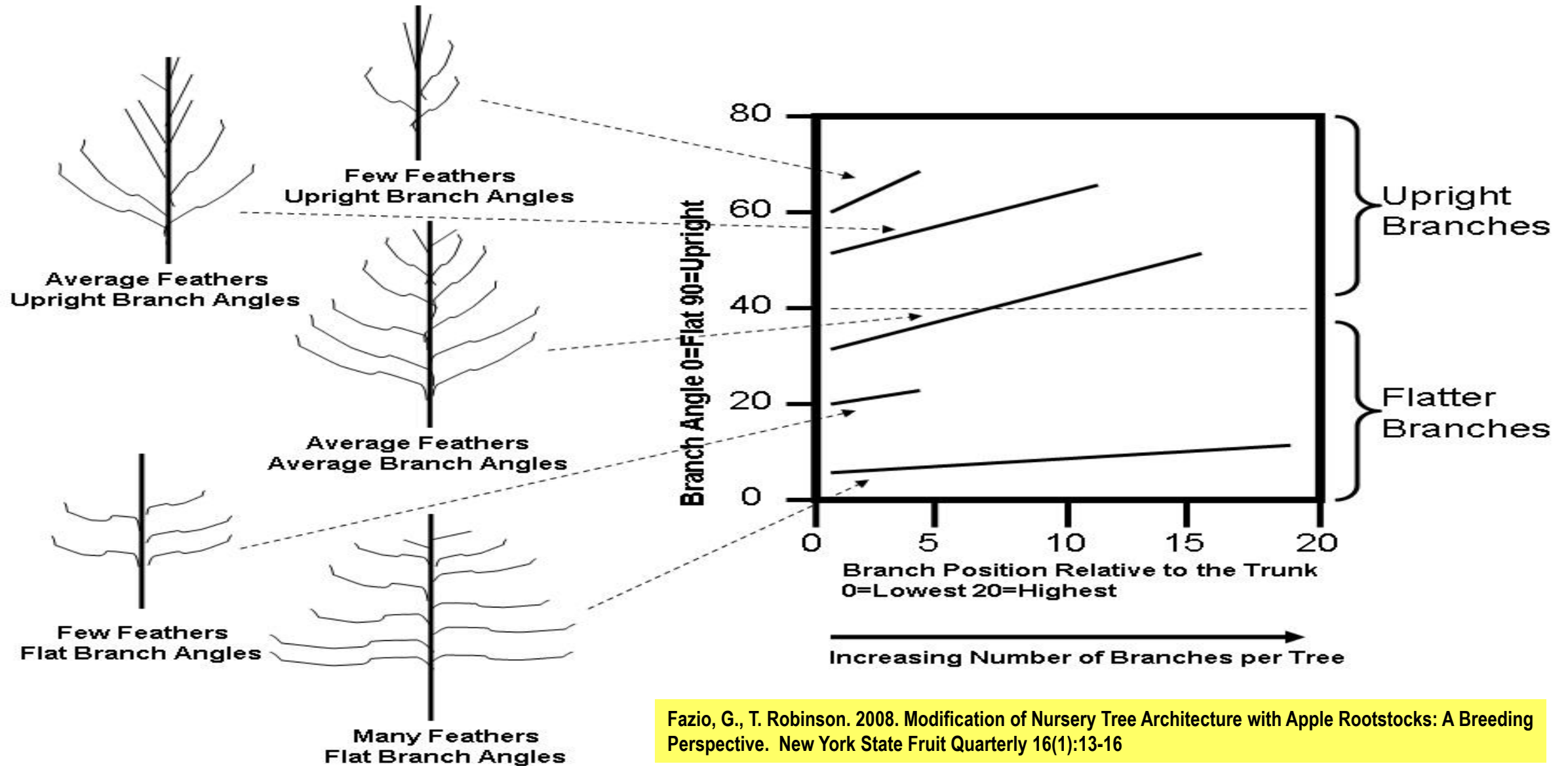


Research Paper

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

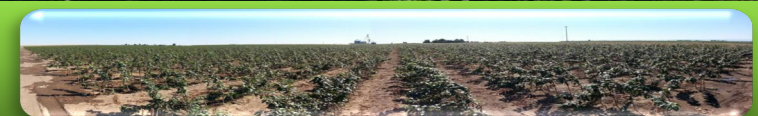
J. Lordan ^a, G. Fazio ^{a, b}, P. Francescato ^a, T. Robinson ^a

Some rootstocks can induce more feathers, modify branch angles





ANNA WALLIS

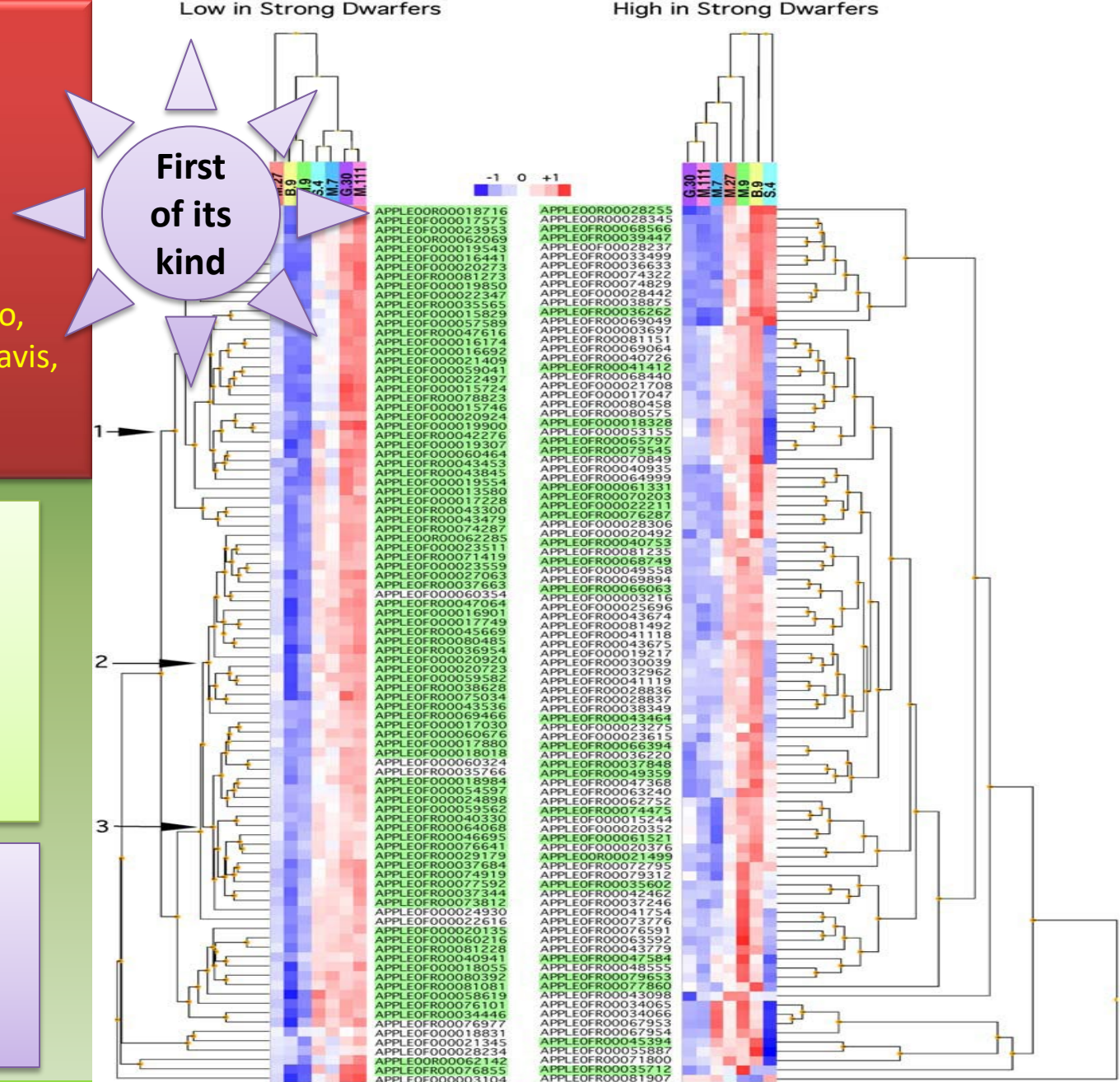


Rootstock-regulated gene expression patterns in apple tree scions

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

- 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



Apple Trees and Woodpeckers



Clemson, SC



Monhegan Island, ME



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



United States Department of Agriculture
Agricultural Research Service

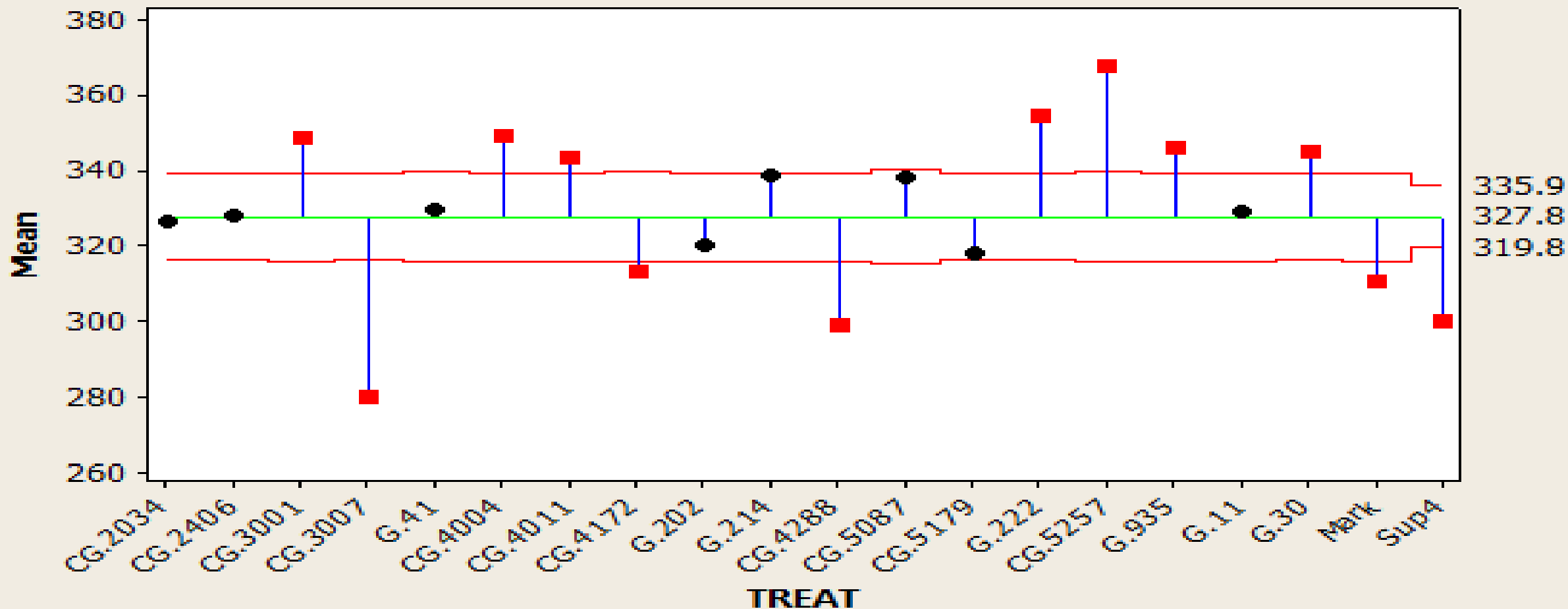
Apple Rootstock Breeding Program
Plant Genetic Resources Unit, Geneva, NY



2012 Fruit Size Data, Auvil Fruit Farm Vantage, WA

Aztec Fuji Mean Fruit Weight (Grams)

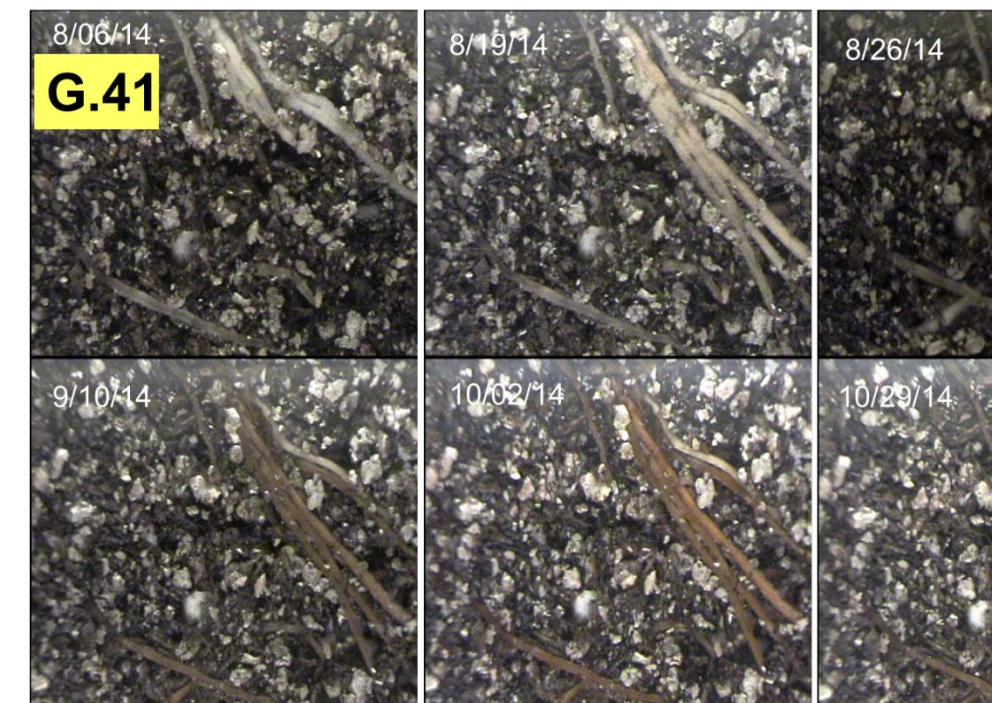
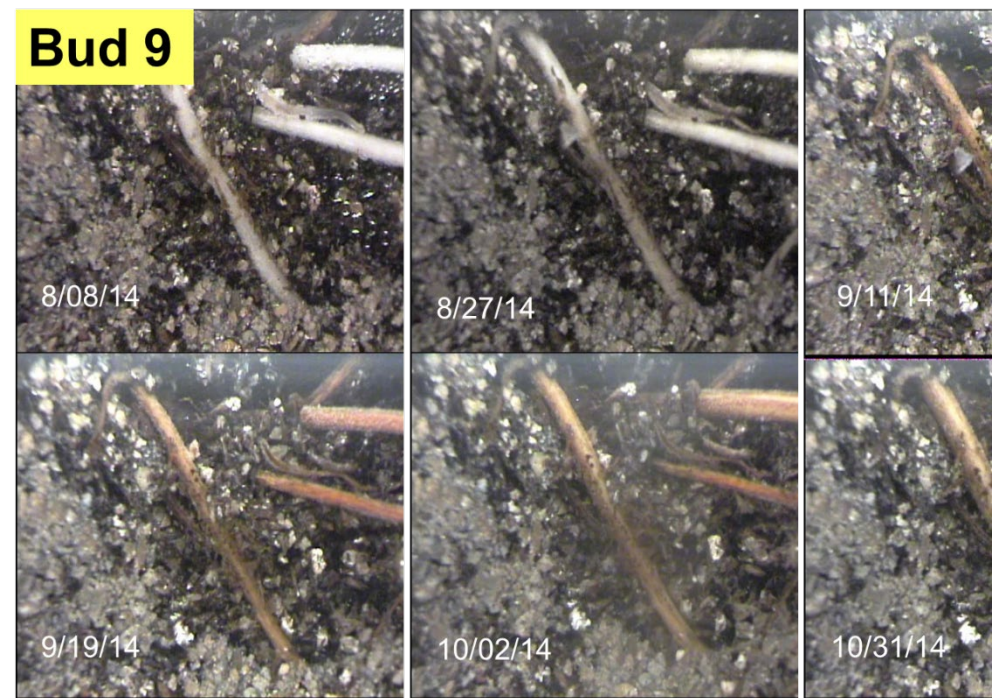
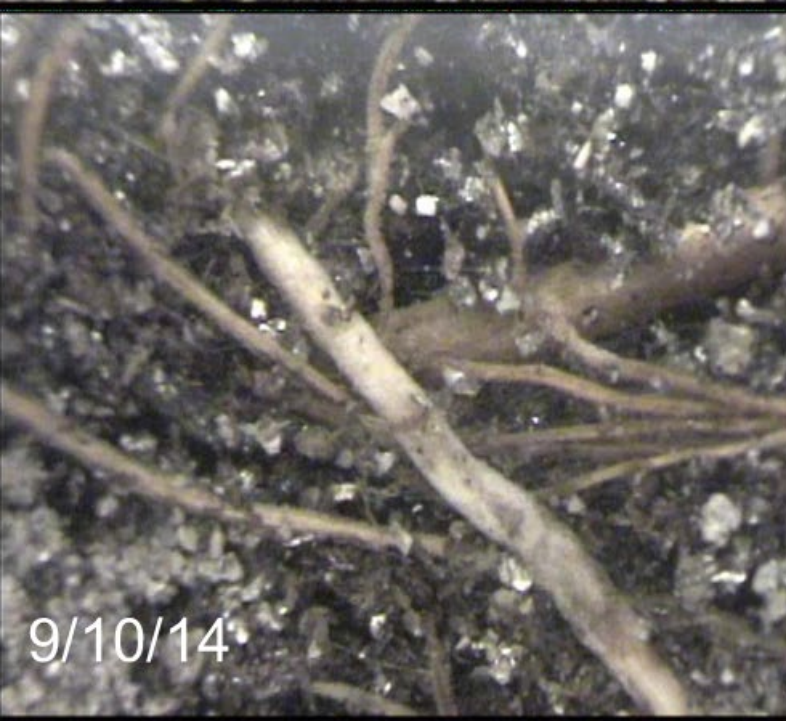
Alpha = 0.05



What About Root Research?

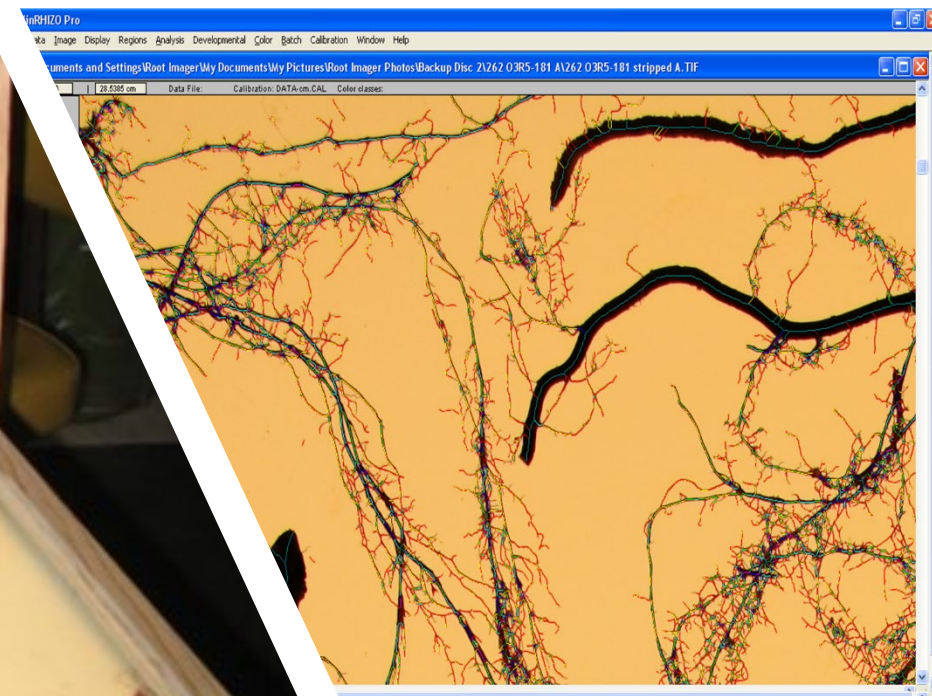
- “Underground” research often gets ignored.
- Yet root systems perform most of the “heavy lifting” in rootstocks.
- Employed traditional and “modern” shovelomics to understand connection between root phenotypes and tree performance.
- Experiments include pH effects on root systems, metabolomics and transcriptomics.





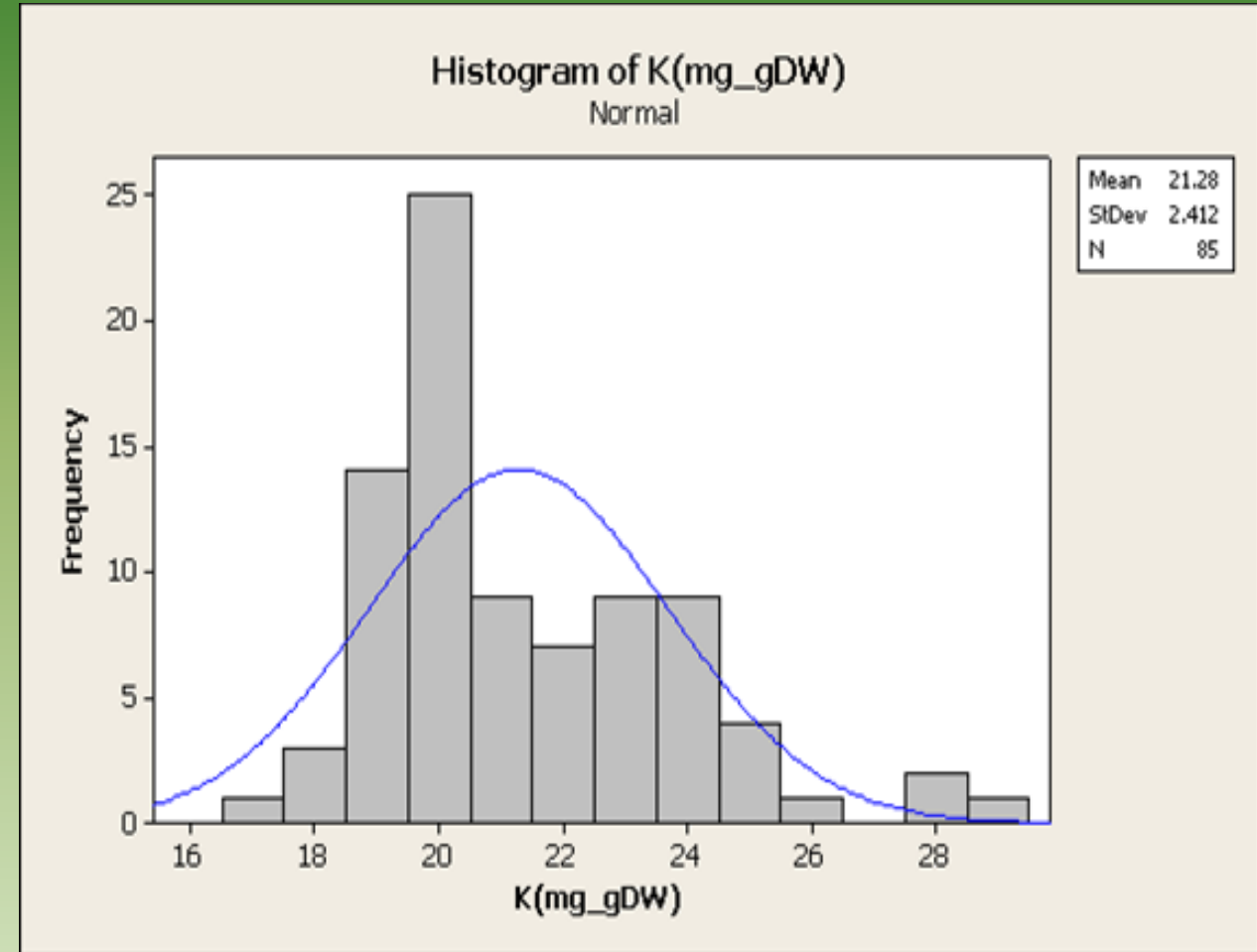
The background of the slide is a large grid composed of many small, individual images. Each image shows a cross-section of soil with thin, light-colored roots growing through it. The roots vary in direction and density across the different images, illustrating the growth patterns of apple roots. The text is overlaid on the lower-left portion of this grid.

Hand stitching 67,000 images to
make sense of the how apple roots
grow – not a pleasant experience.....



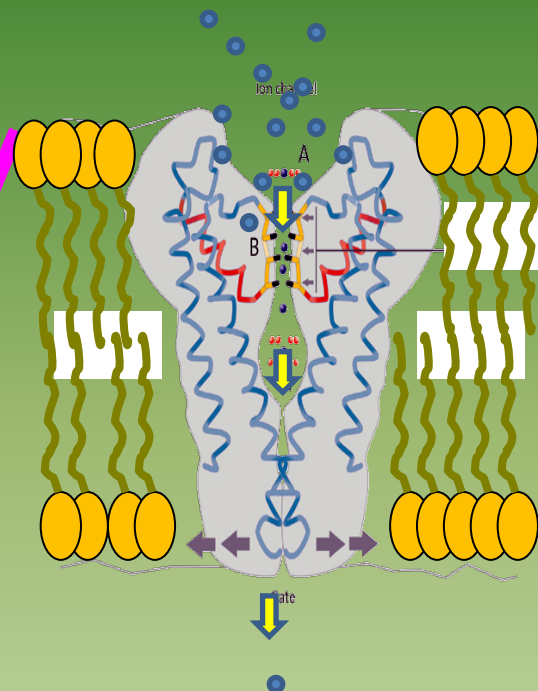
What sparked our interest in root mediated ionomics?

- 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

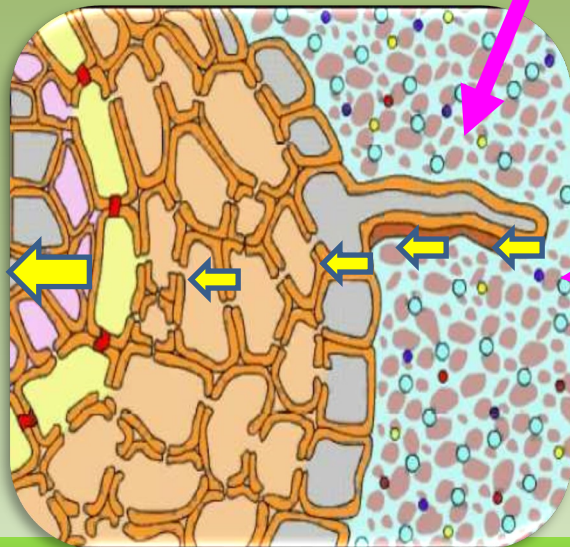
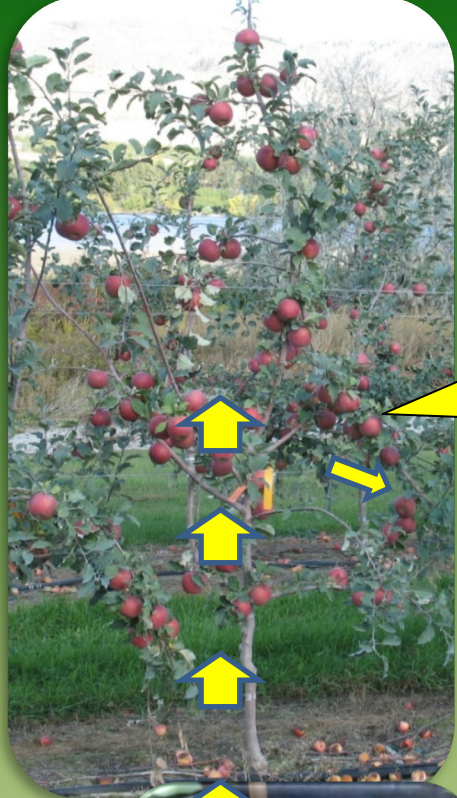


Journey of nutrients from soil to scion

Different sinks competing for same resources



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



Some factors influencing “specific” absorbance and conductance (transport)

- Absorbance

- Co-absorption
- Root exudates
- Root structure
- Root turnover
- Root half-life
- Root exploration index
- Root symbiotic and pseudo-symbiotic associations (mycorrhizae)

- Conductance

- Applies to any substance transported in vascular tissues
- Channels
- Chaperones
- Active vs. passive
- Vessel size, shape
- Pressure
- Gradient
- Co-transport



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

By GENNARO FAZIO¹, DARIUS KVIKLYS², MICHAEL A GRUSAK³
and TERENCE ROBINSON⁴

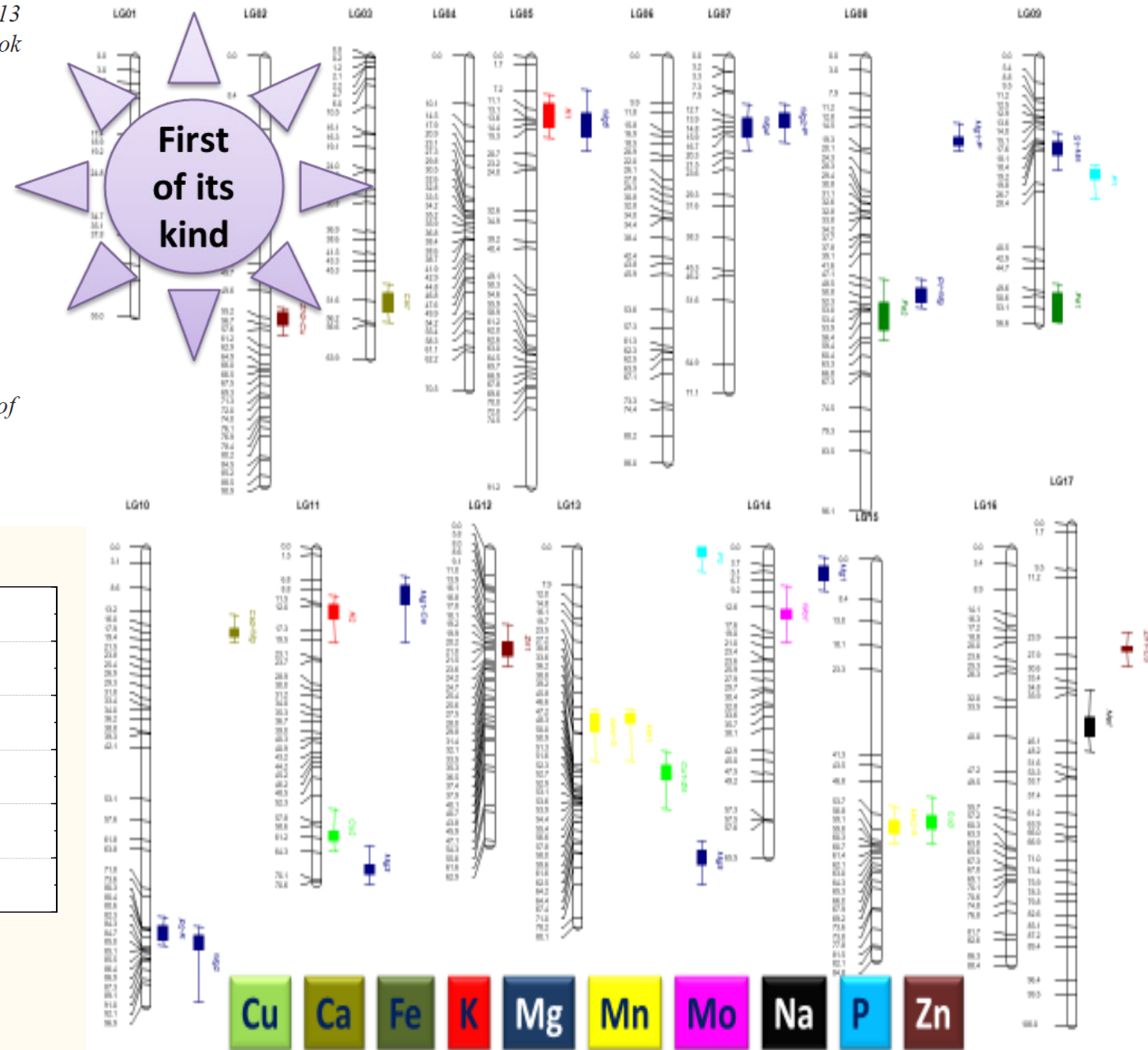
¹Plant Genetics Resources Unit, USDA-ARS, Geneva, NY

²Institute of Horticulture, Lithuanian Research Center for Agriculture and Forestry, Babtai,
Lithuania

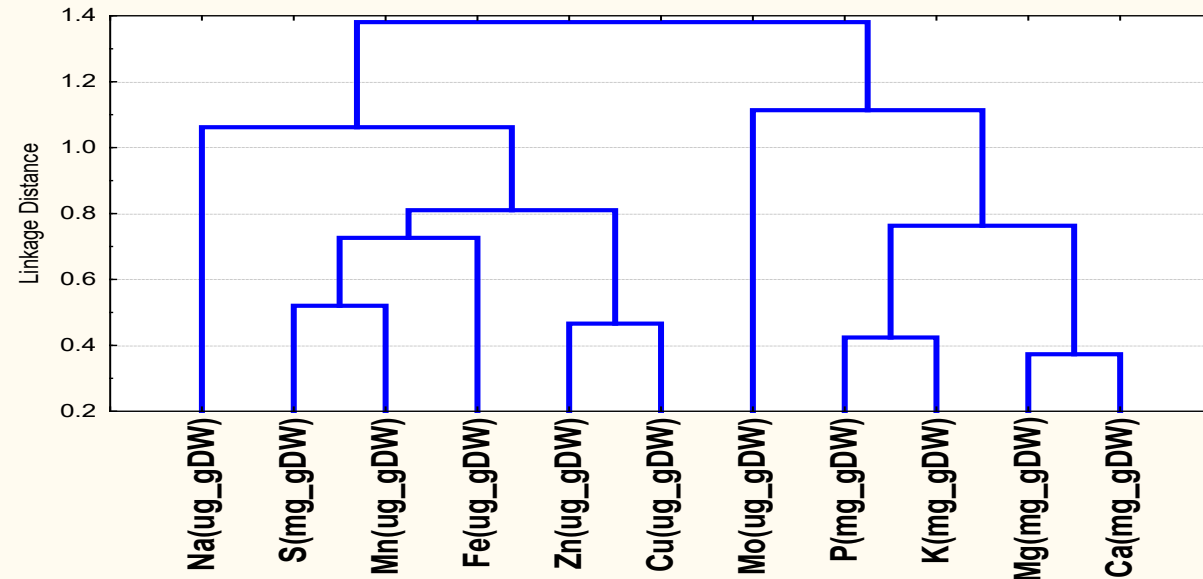
³USDA-ARS Children's Nutrition Research Center, Department of Pediatrics, Baylor College of
Medicine, Houston, Texas

⁴Dept of Horticultural Sciences, NYSAES, Cornell University, Geneva, New York

Corresponding Author Email: gennaro.fazio@ars.usda.gov



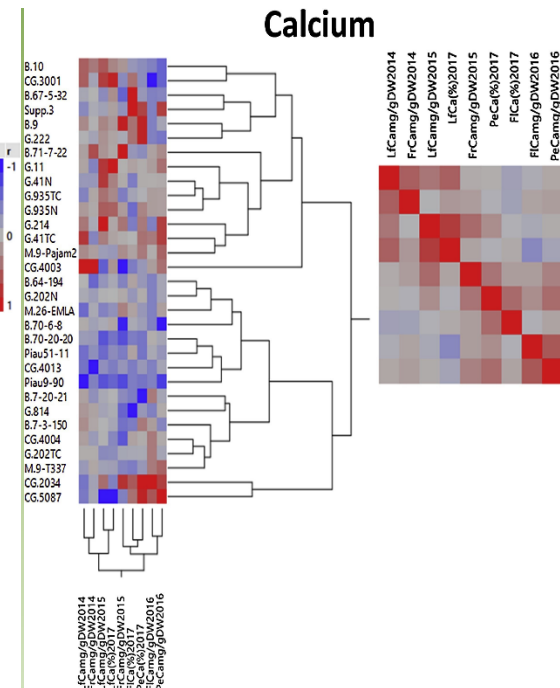
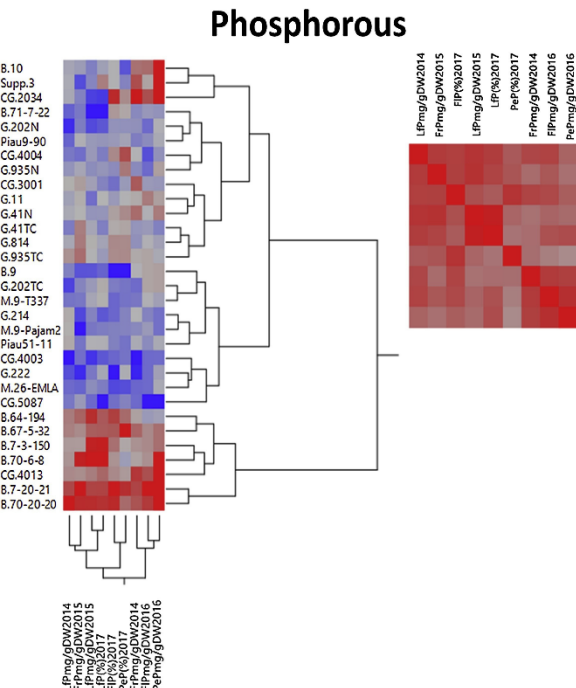
Relationships for Nutrient Concentrations (Complete Linkage)
1-Pearson r



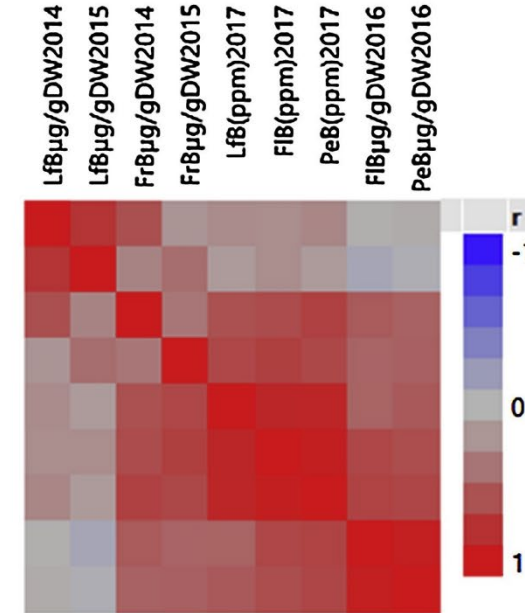
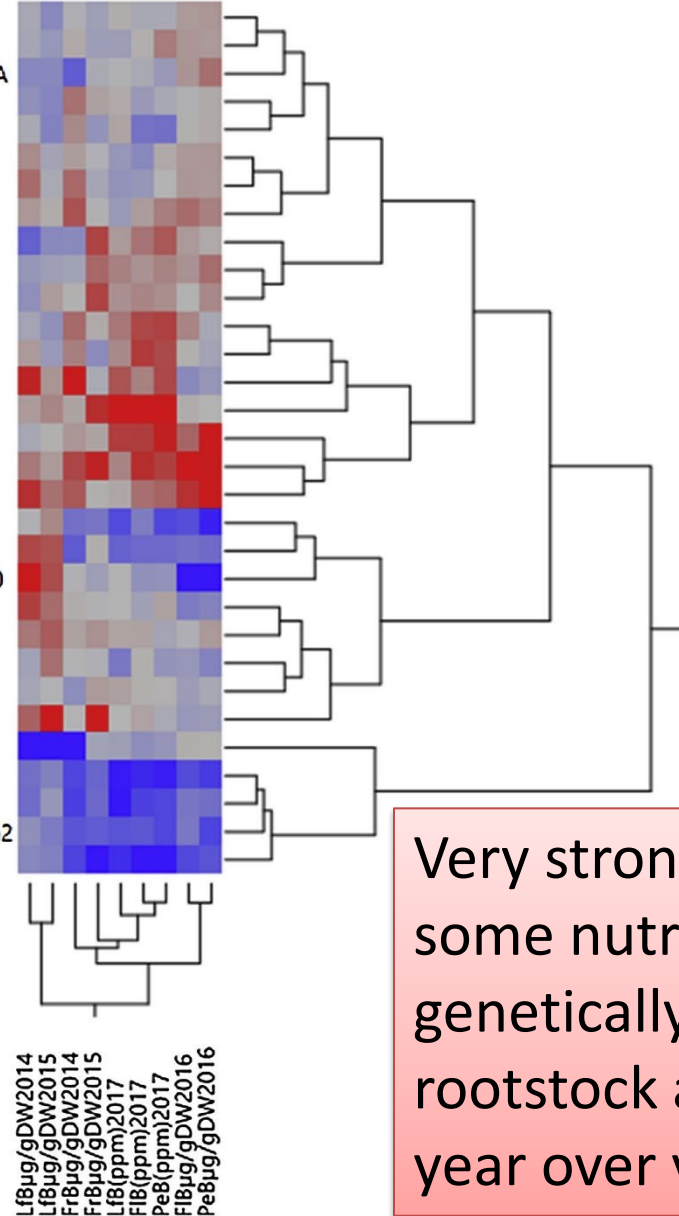


I. Mineral nutrient profiles and relationships of ‘Honeycrisp’ grown on a genetically diverse set of rootstocks under Western New York climatic conditions

Gennaro Fazio ^{a, b, c}, Jaime Lordan ^{b, c}, Michael A. Grusak ^d, Poliana Francescato ^b, Terence L. Robinson ^b

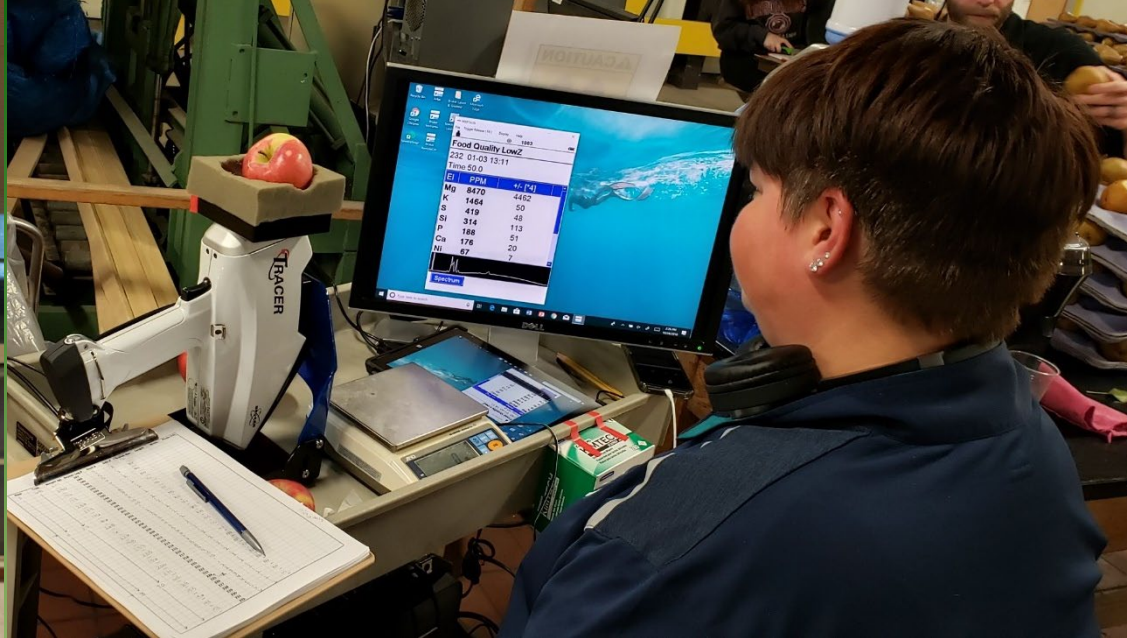


B.10
G.11
M.26-EMLA
G.202N
Supp.3
CG.3001
G.214
G.41N
CG.4003
G.41TC
Piau9-90
CG.2034
CG.4004
CG.4013
CG.5087
G.222
G.935N
G.935TC
B.64-194
B.7-20-21
B.70-20-20
B.67-5-32
B.7-3-150
G.202TC
G.814
B.70-6-8
B.71-7-22
B.9
M.9-T337
M.9-Pajam2
Piau51-11

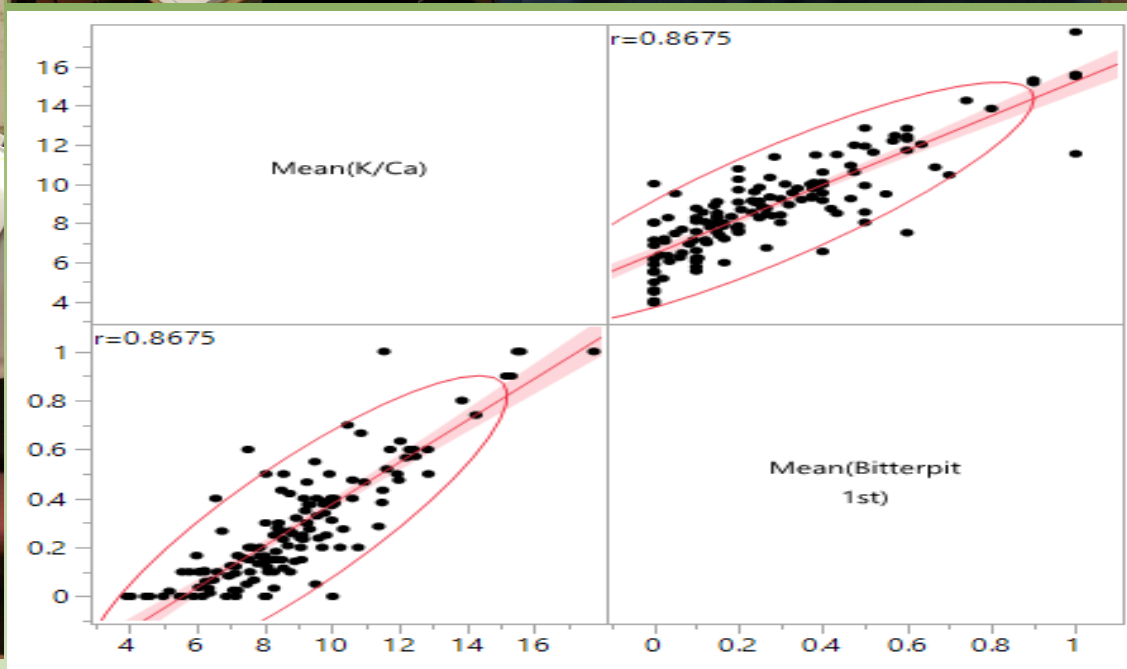


Very strong evidence that some nutrient profiles are genetically controlled by the rootstock and consistent year over year.





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.

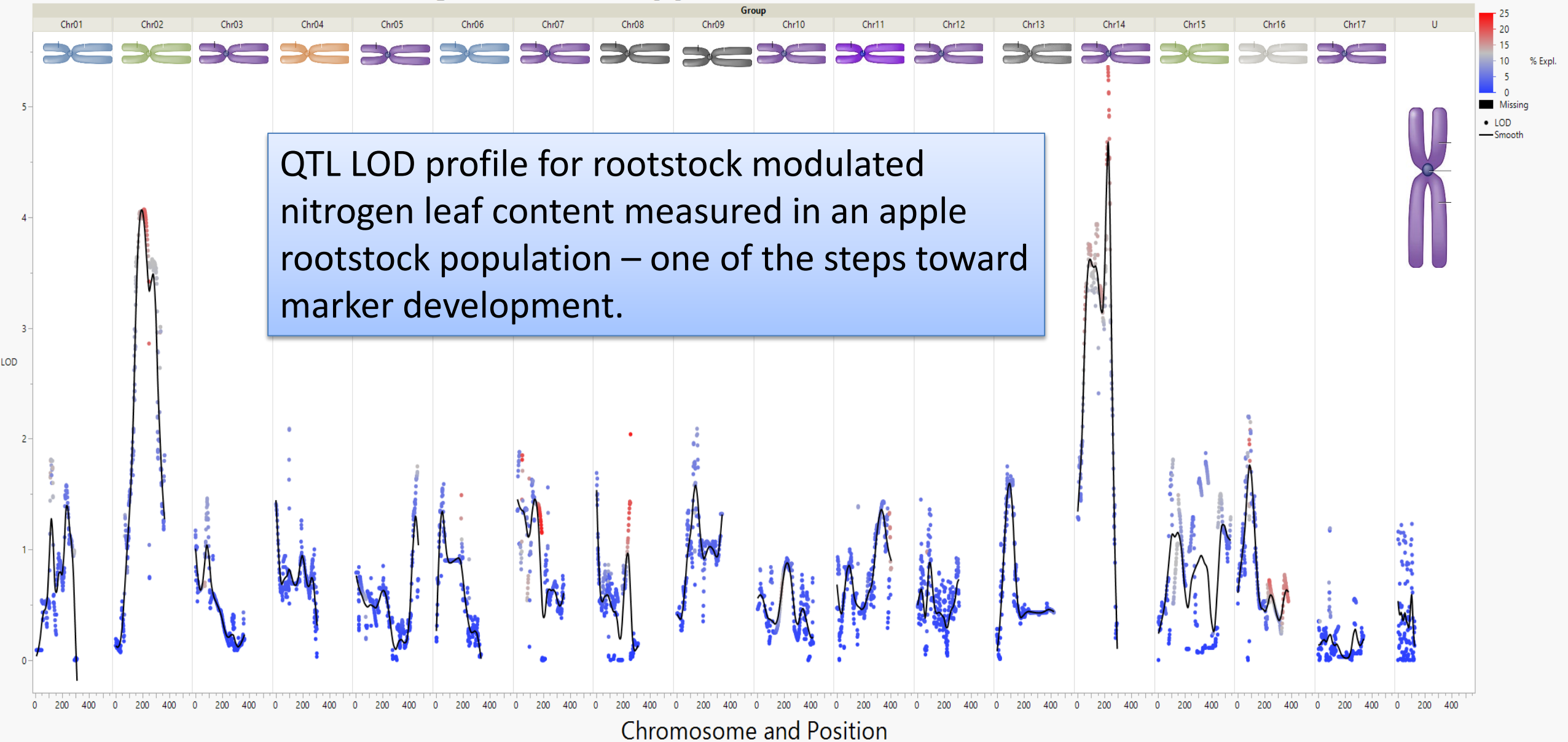


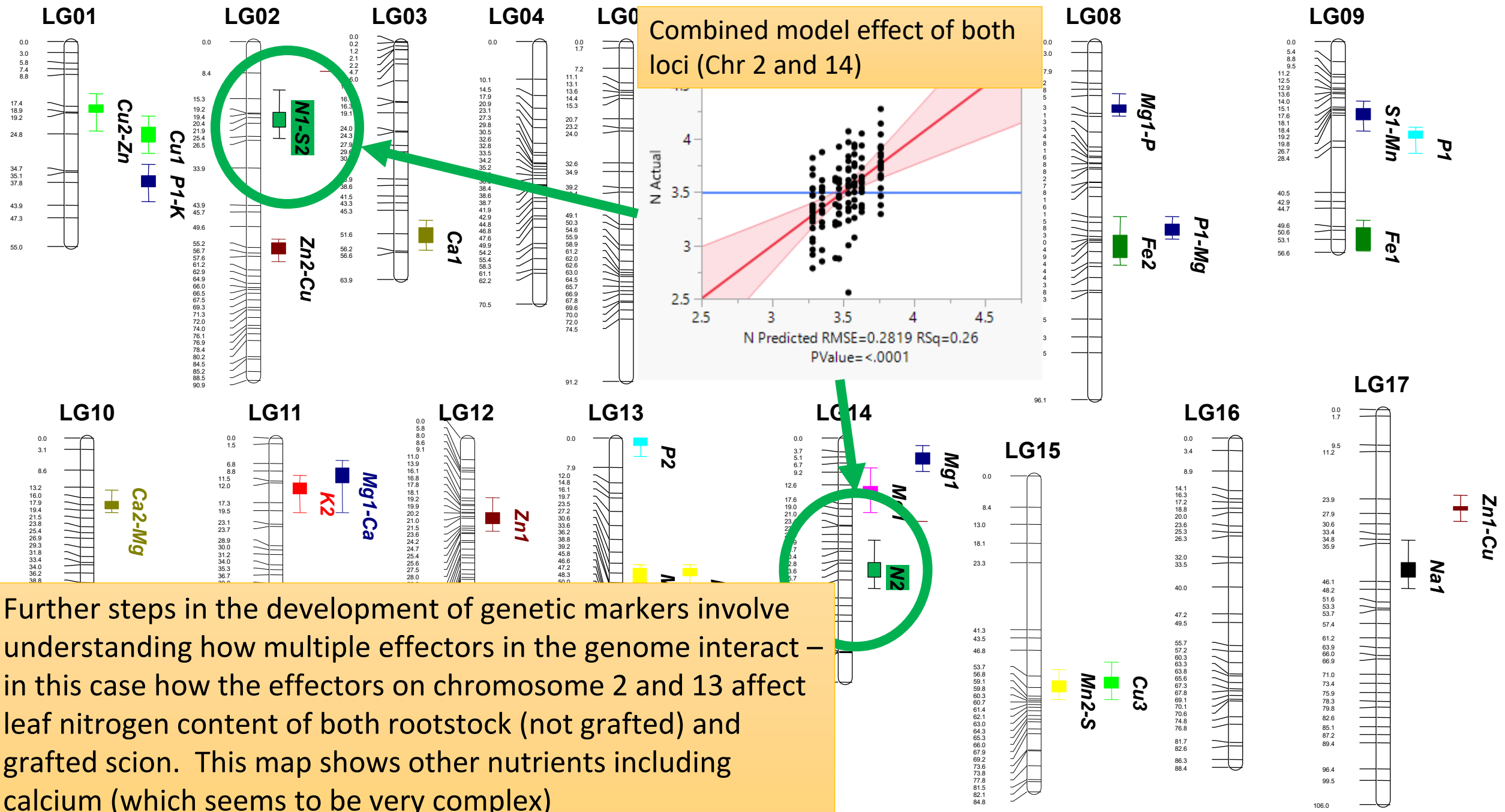
United States Department of Agriculture
Agricultural Research Service

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



Nitrogen QTLs in Apple Rootstock Chromosomes

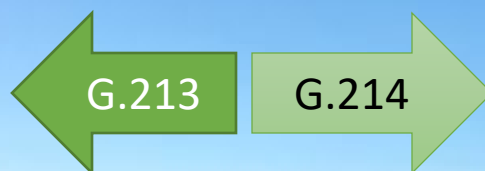


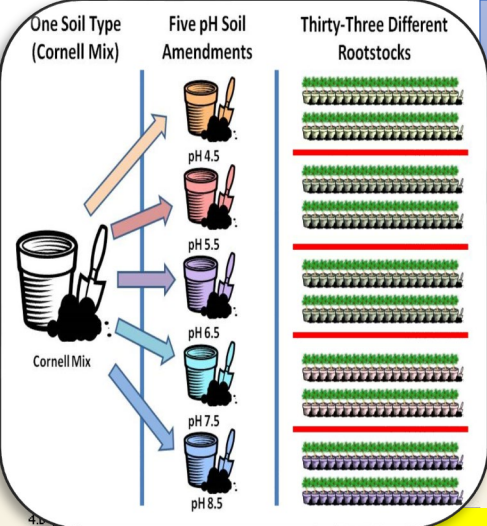


Further steps in the development of genetic markers involve understanding how multiple effectors in the genome interact – in this case how the effectors on chromosome 2 and 13 affect leaf nitrogen content of both rootstock (not grafted) and grafted scion. This map shows other nutrients including calcium (which seems to be very complex)

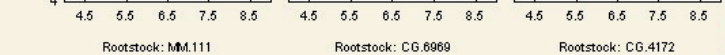
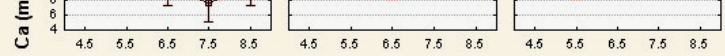
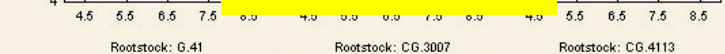
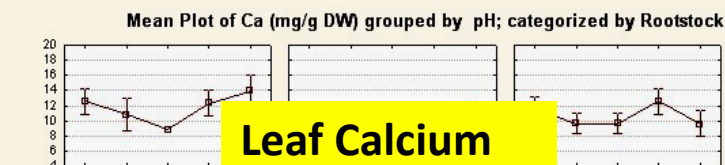
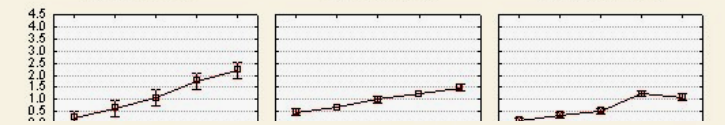
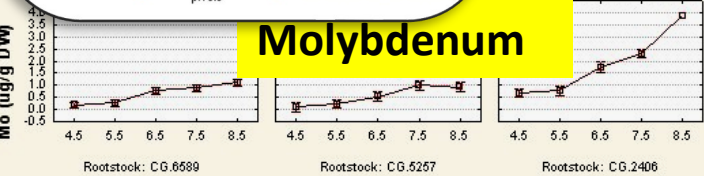
Geneva 213 and Geneva 214 at Cameron Nursery in Eltopia, WA

G.214 is a low nitrogen rootstock

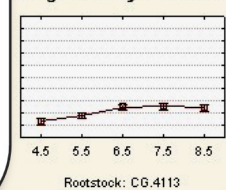




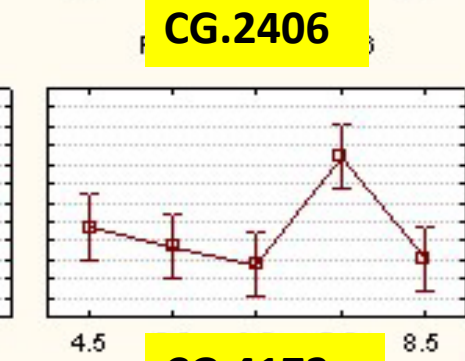
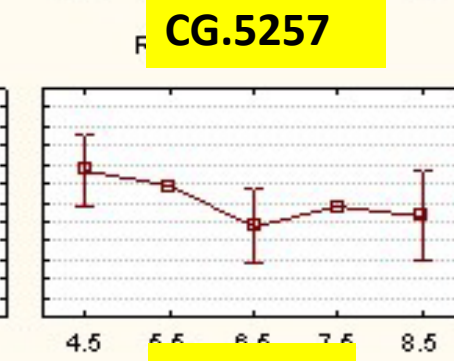
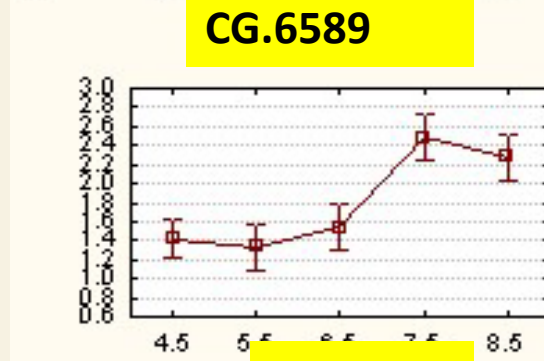
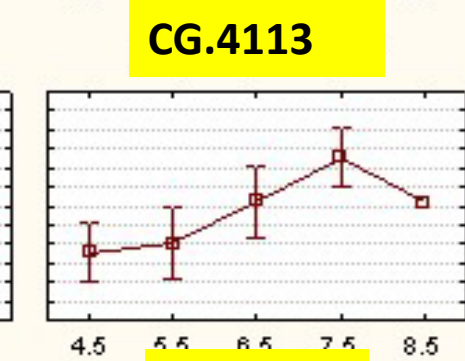
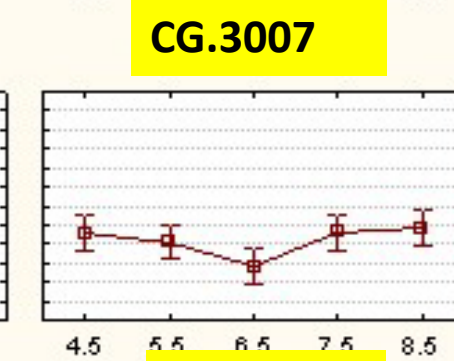
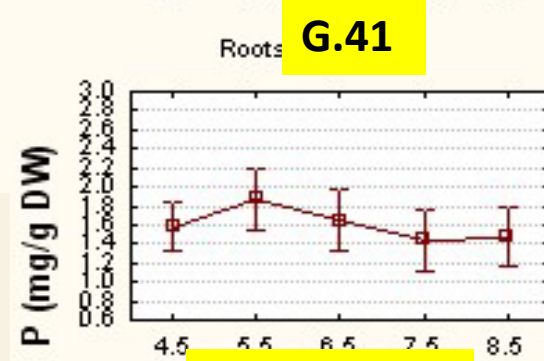
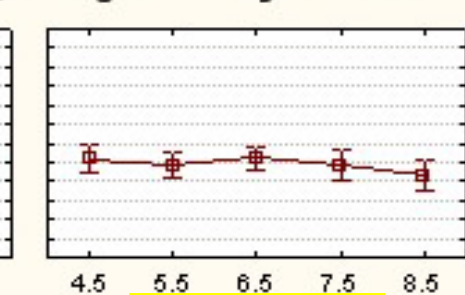
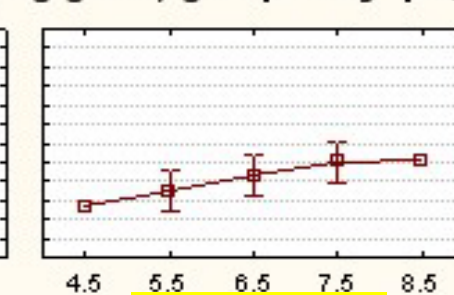
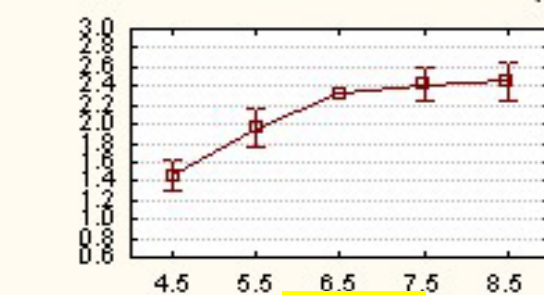
Rootstocks have unique interactions with soil pH and nutrient absorption and translocation



categorized by Rootstock

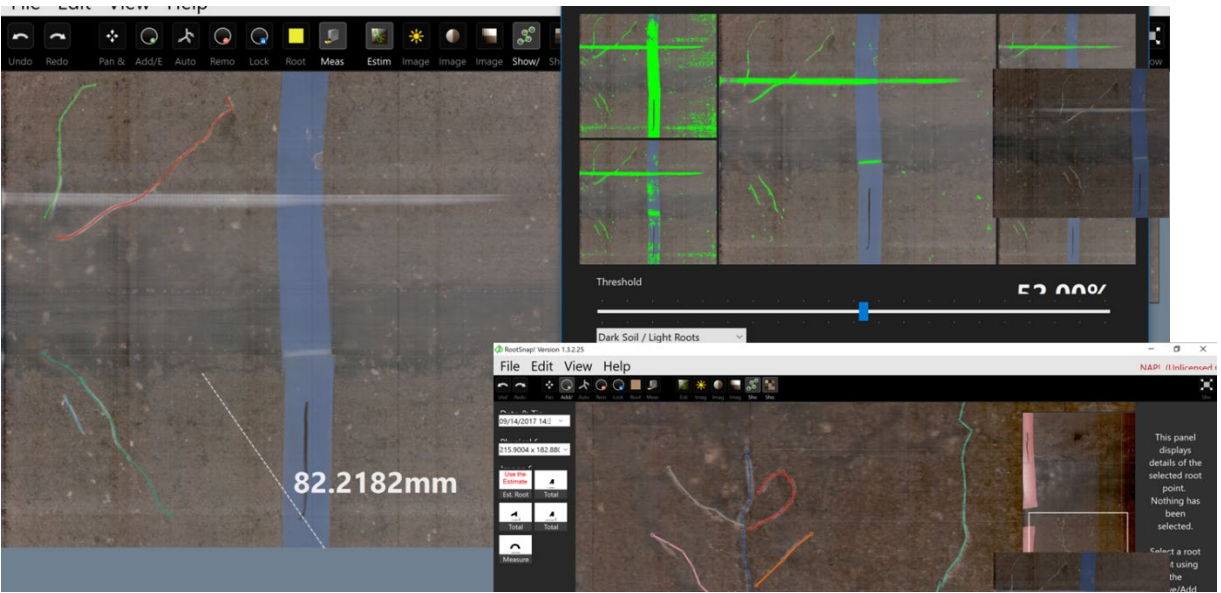


Mean Plot of P (mg/g DW) grouped by pH; categorized by Rootstock



Mean
Mean±SE

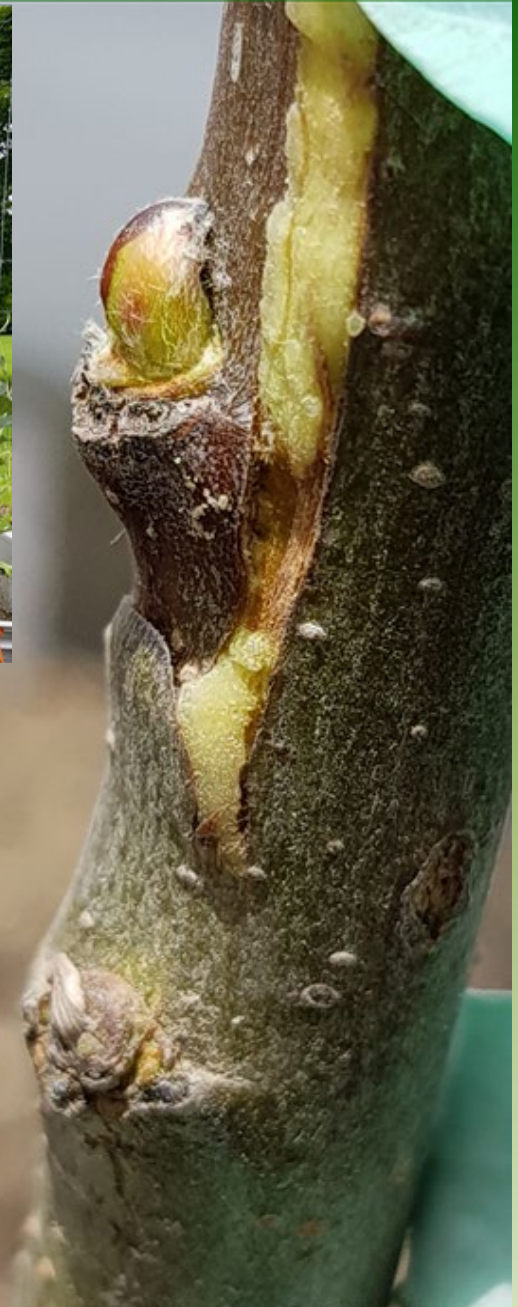
Mean
Mean±SE

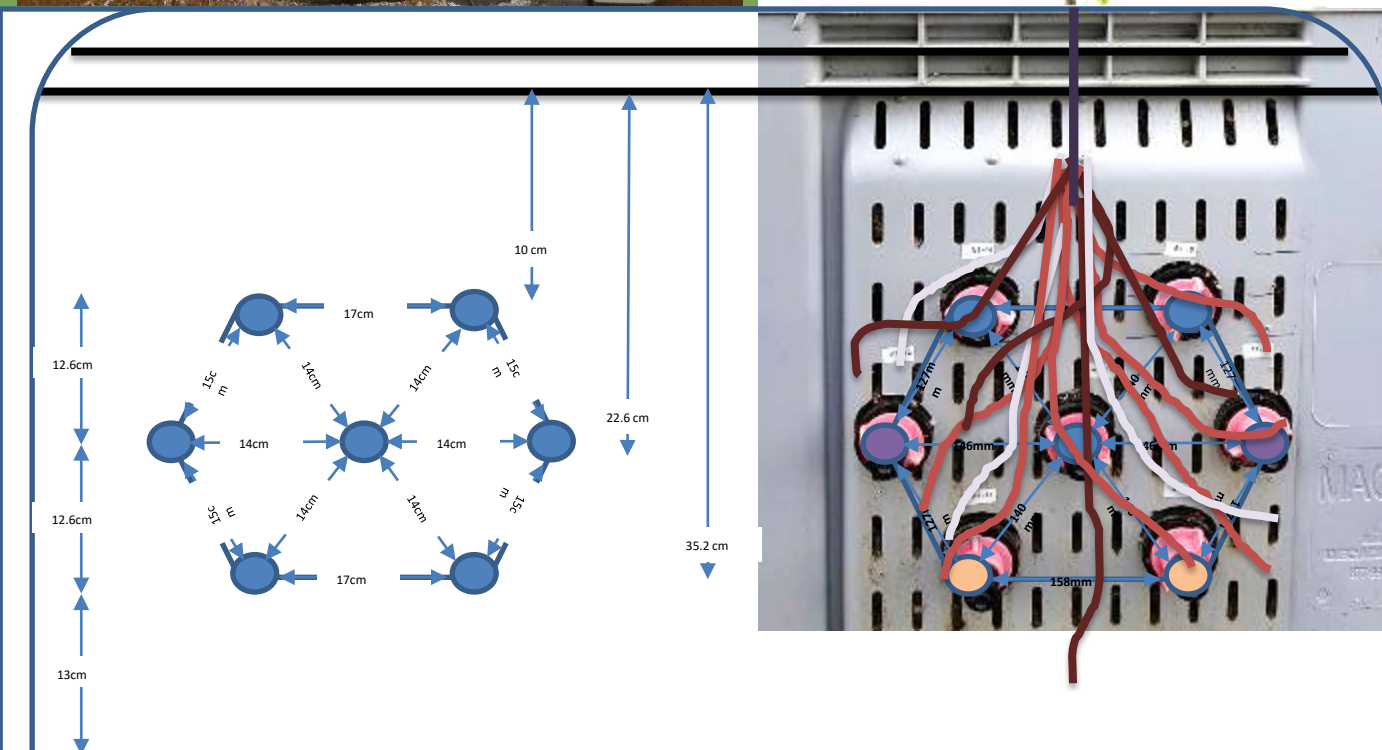
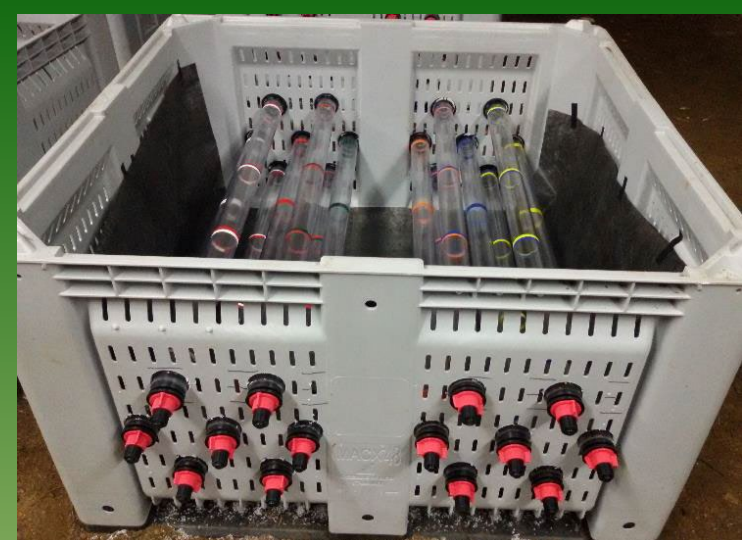


Apple Rootstock Minirhizotron pH Experiment Honeycrisp Grafted on 4 rootstocks.



Dr. Ali Farqani





- 4months
- +4months
- +4months



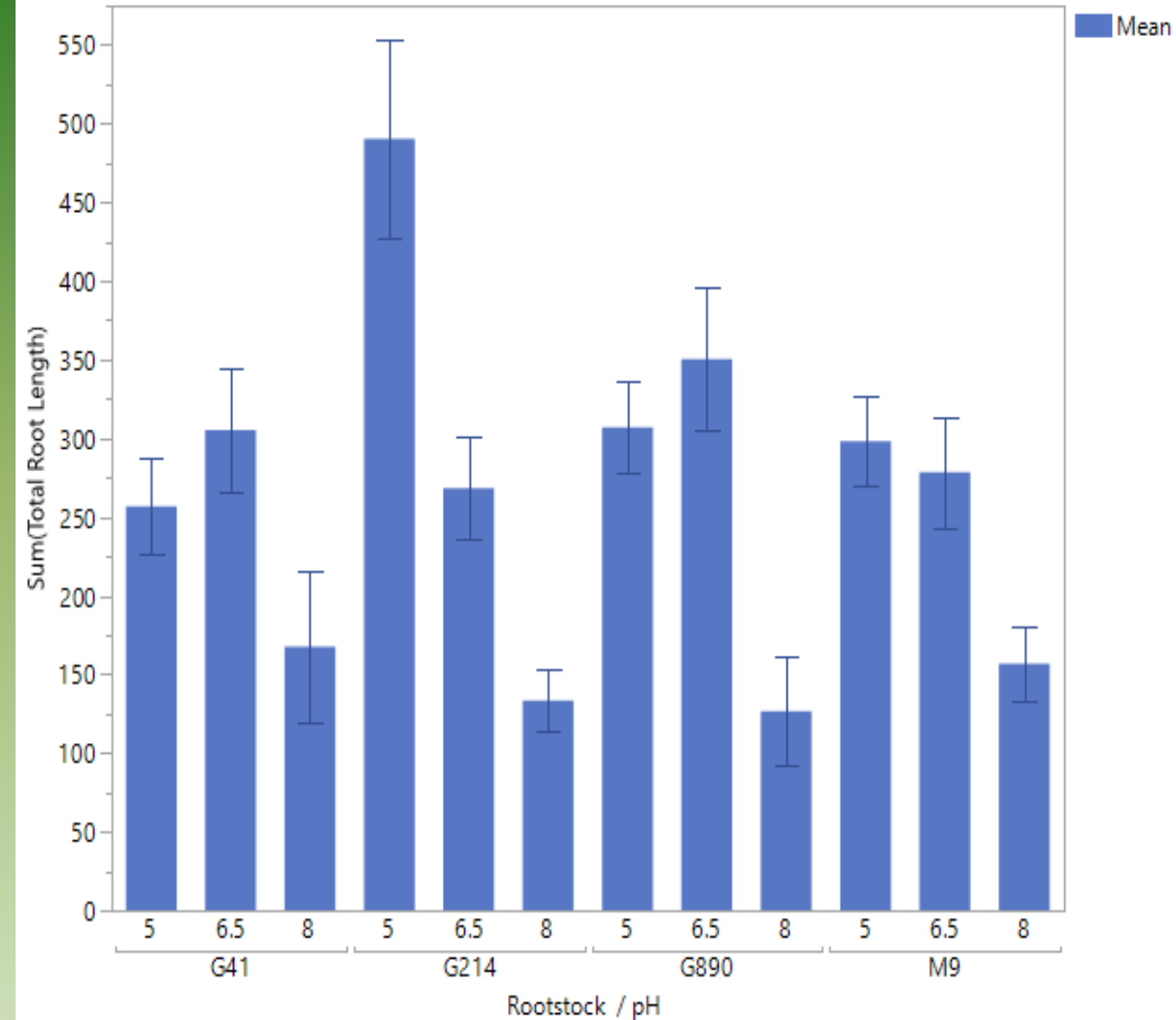
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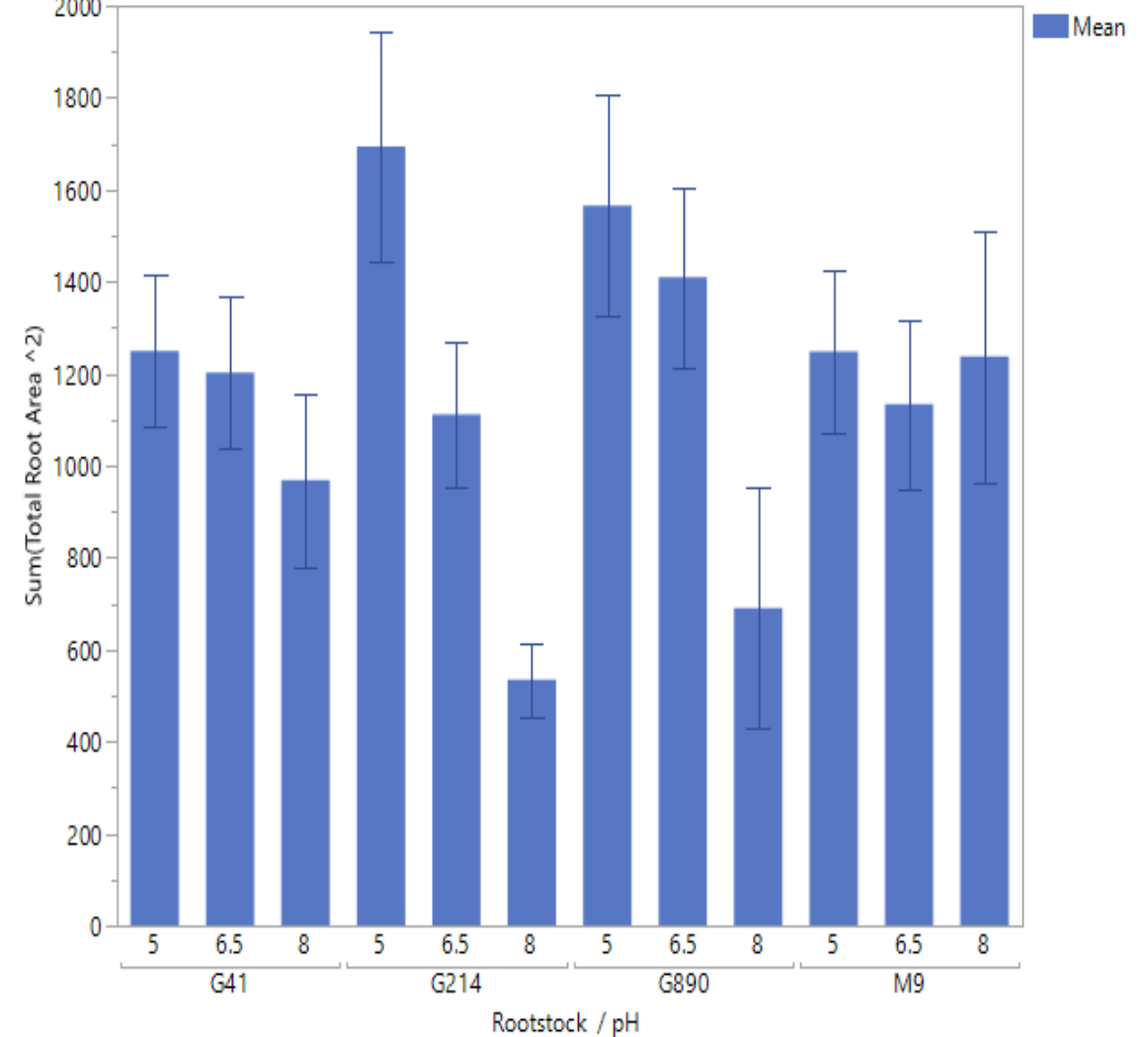


Minirhizotron (Response to soil pH)

Mean(Sum(Total Root Length)) vs. Rootstock & pH

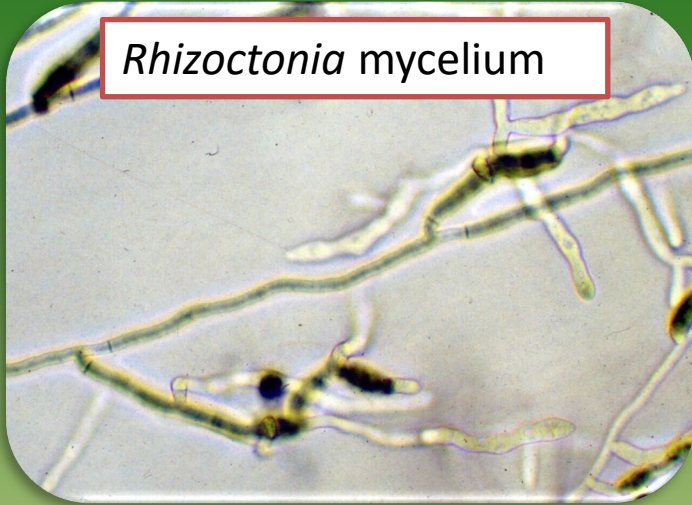


Mean(Sum(Total Root Area ^2)) vs. Rootstock & pH

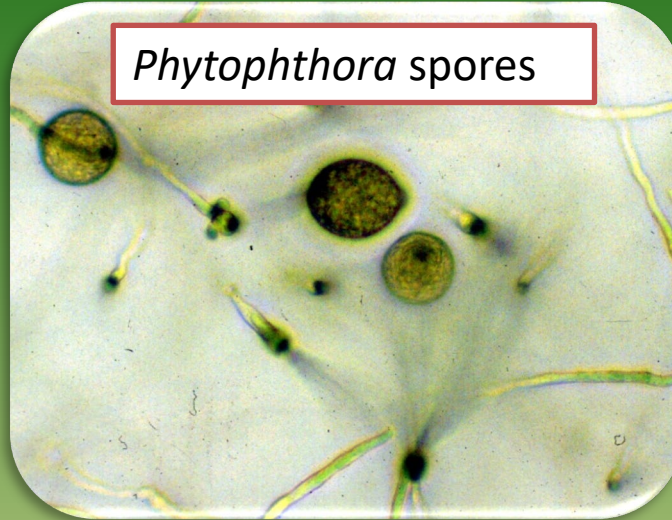


Replant Disease Tolerance of Geneva Rootstocks

Rhizoctonia mycelium



Phytophthora spores



Apple Replant Disease: Role of Microbial Ecology in Cause and Control

Mark Mazzola¹ and Luisa M. Manici²

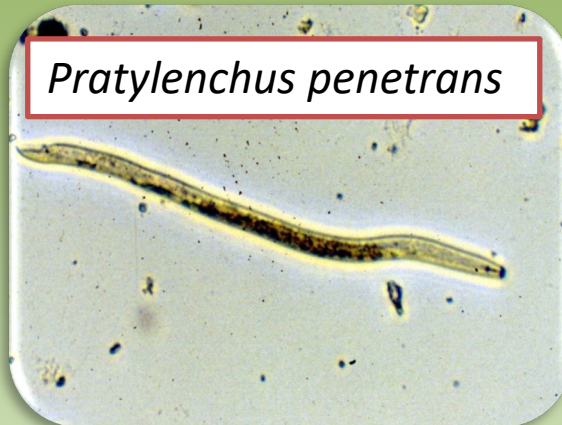
¹Tree Fruit Research Lab, U.S. Department of Agriculture, Agriculture Research Service, Wenatchee, Washington 98801; email: mark.mazzola@ars.usda.gov

²Agricultural Research Council (CRA), Research Centre for Industrial Crops, 40129 Bologna, Italy; email: luisa.manici@entecra.it

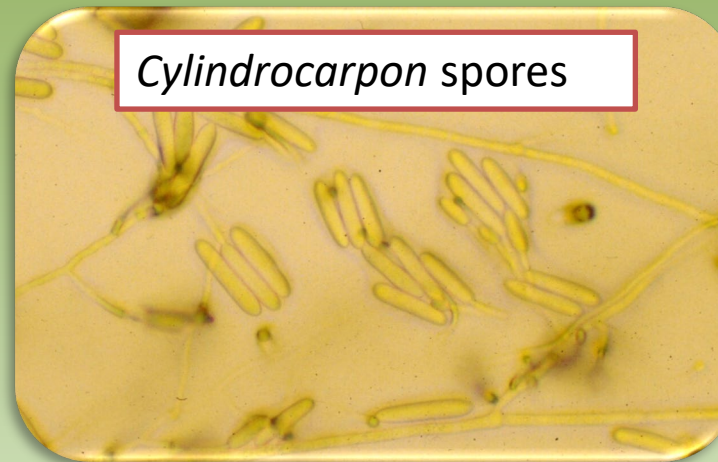
Pythium



Pratylenchus penetrans

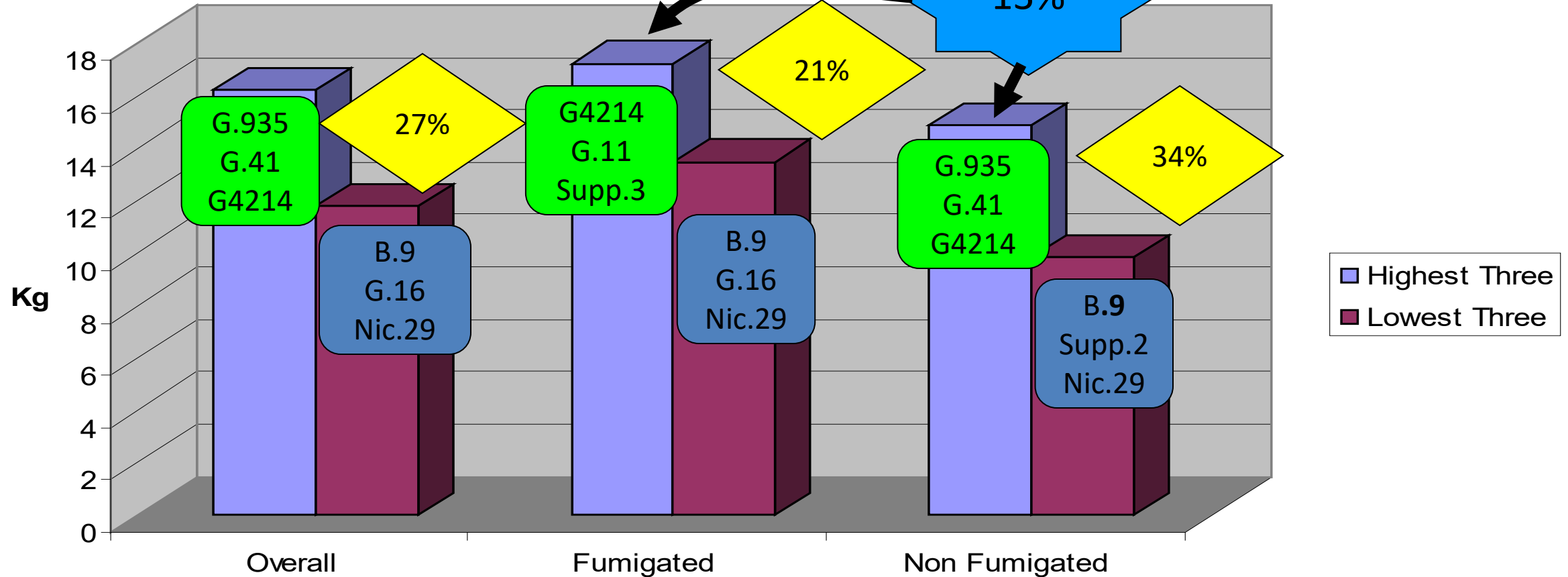


Cylindrocarpon spores



WAPATO REPLANT TRIAL LOCATION

Mean Cumulative Yield Per Tree for the Three Highest and Lowest Yielding Rootstocks

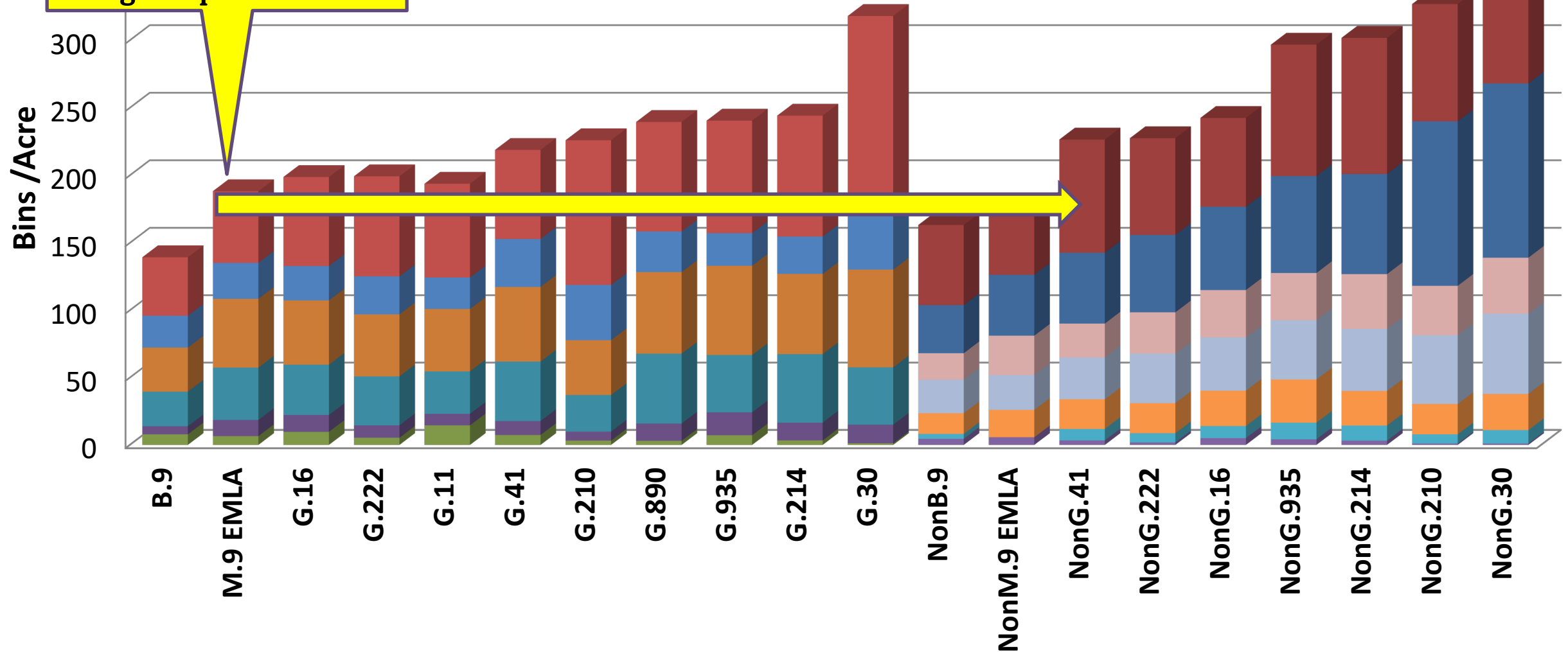


'06 Wapato Gala Geneva Rootstock Trial

Cumulative yield 2007-2013



Replant resistant Geneva rootstocks in non-fumigated plots yield more than M.9 EMLA in fumigated plots.



Replant tolerance seems to apply in many apple growing regions worldwide



Productivity per hectare of cv. MaxiGala grafted on different rootstocks in **replanting area**

Rootstocks	Yield (t/ha)		cumulative
	2016	2017	t/ha
M.9	11,21	32,63	43,84
G.213	19,52	52,76	72,28
G.202	5,19	36,55	41,74
G.757	7,79	37,43	45,22
G.814	5,8	47,81	53,61

Planting density 3,571 plants per hectare (0,7 x 4,0 m)



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



Apple Replant Disease: Role of Microbial Ecology in Cause and Control

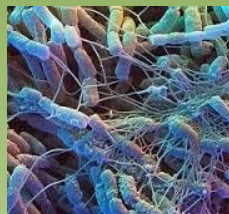
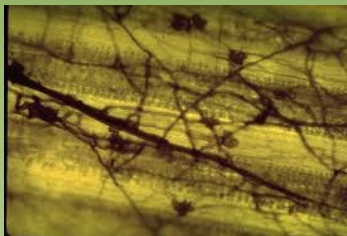
Annual Review of Phytopathology

Vol. 50: 45-65 (Volume publication date September 2012)

First published online as a Review in Advance on May 1, 2012

DOI: 10.1146/annurev-phyto-081211-173005

Mark Mazzola¹ and Luisa M. Manici²



Relationship between soil microbes and rootstocks

Plant and Soil
July 2004, Volume 264, Issue 1-2, pp 247-260

Rootstock genotype and orchard replant position rather than soil fumigation or compost amendment determine tree growth and rhizosphere bacterial community composition in an apple replant soil

Angelika Rumberger, Shengrui Yao, Ian A. Merwin, Eric B. Nelson, Janice E. Thies



Elucidating the molecular responses of apple rootstock resistant to ARD pathogens: challenges and opportunities for development of genomics-assisted breeding tools

Yanmin Zhu, Gennaro Fazio & Mark Mazzola





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 Rudell² and Mark Mazzola²

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 and validates the contribution of vegetative activity to rhizodeposit quantity. Primary

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

Rachel Leisso^{*}, David Rudell, Mark Mazzola

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

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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

ARTICLE

Open Access

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

Yanmin Zhu¹, Jonathan Shao², Zhe Zhou³ and Robert E. Davis²



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.

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

Stefan Weiß¹ · Melanie Bartsch¹ · Traud Winkelmann¹



Received: 15 August 2016 / Accepted: 23 March 2017 / Published online: 19 April 2017
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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 detected. Verification of MACE data, candidate via RT-qPCR and a strong positive correlation of both datasets was observed. Comparing roots cultivated in ARD soil or γ-irradiated suggests that typical defense reactions to take place in ARD affected plants but responding to the biotic stressors attack to the observed growth depressions in A

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

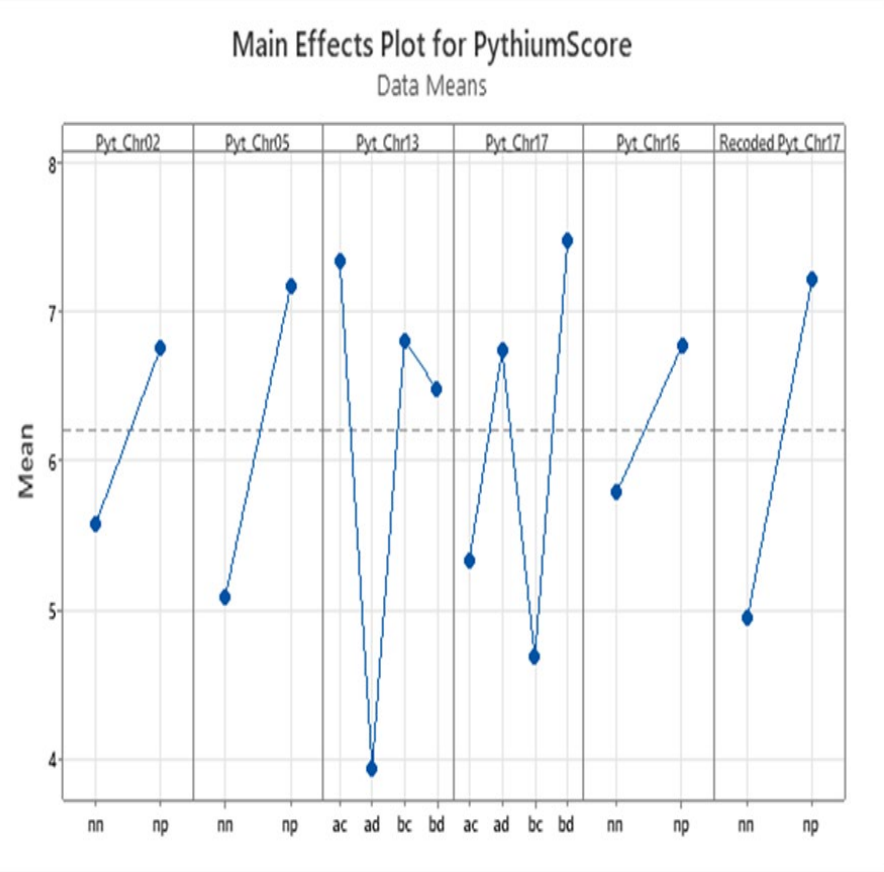


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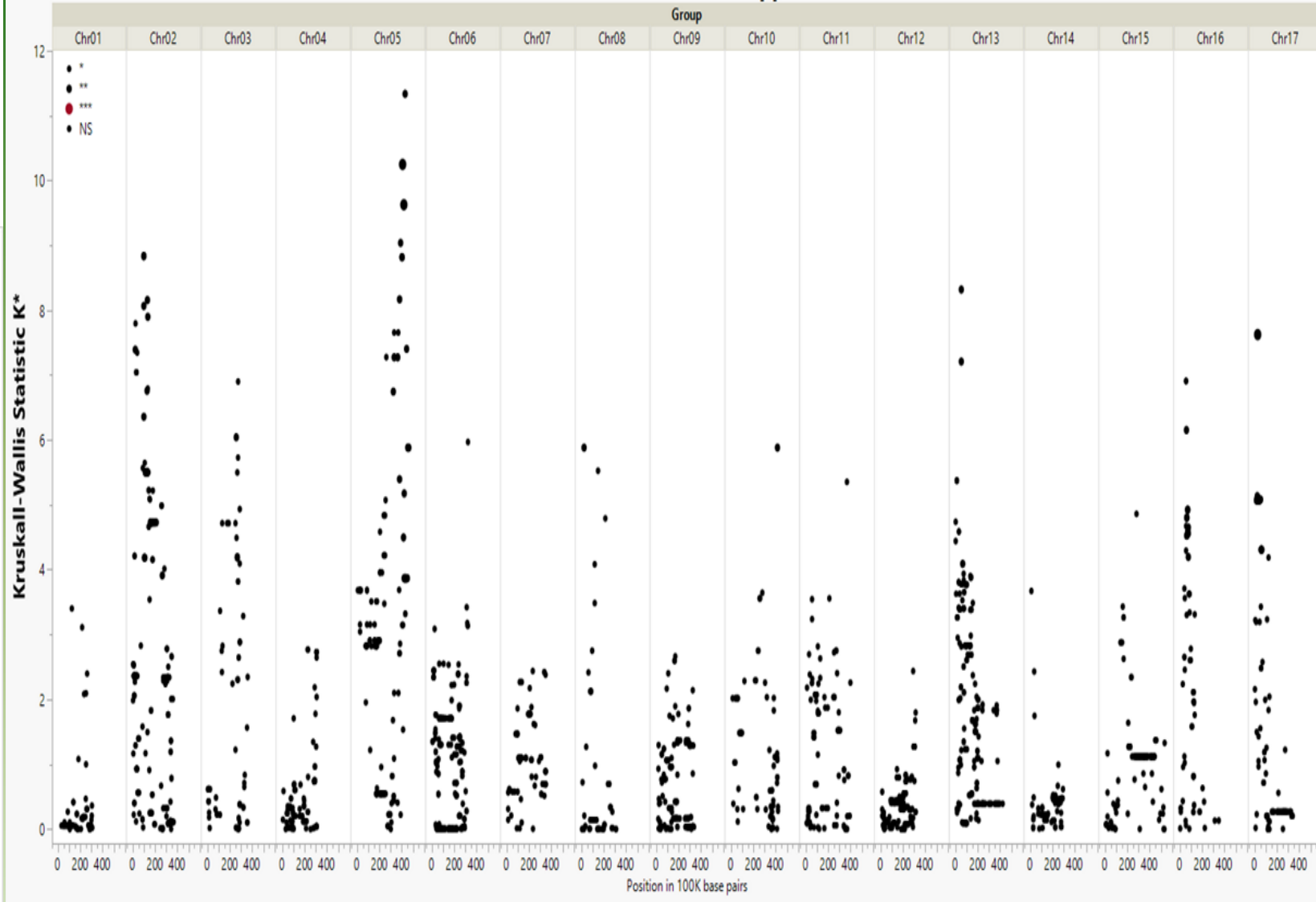
Genetic Analysis of Resistance to Pythium ultimum a Major Component of Replant Disease in Apple Rootstocks

GENNARO FAZIO¹, MARK MAZZOLA^{2,3}, YANMIN ZHU²

Additional index words: apple root, soilborne pathogens, quantitative trait loci, plant resistance, allelic contribution



K* vs. Position in the GDD-H13 Apple Genome



Sub-experiment 2. Assessment of bacterial populations in the rhizosphere in combination with leaf area measurements

Primary experiment. Determining the quantity and composition of apple rootstock rhizodeposits according to genotype

Sub-experiment 3. Rhizodeposit validation of tree metabolites with axenically grown tissue culture plants

rhizodeposits

Collection and metabolic profiling of rhizodeposits

pH measured

orchard soil treated with rhizodeposits

Sub-experiment 1. Assessment of rhizodeposits/ soil microbiome on next generation of trees

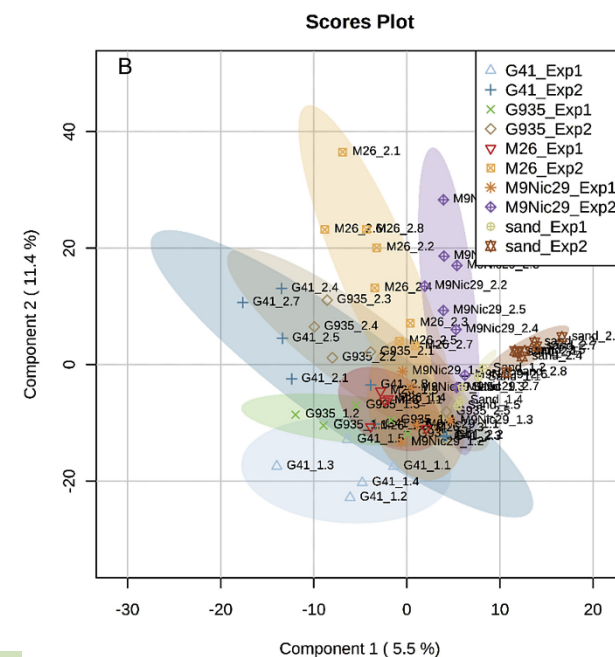
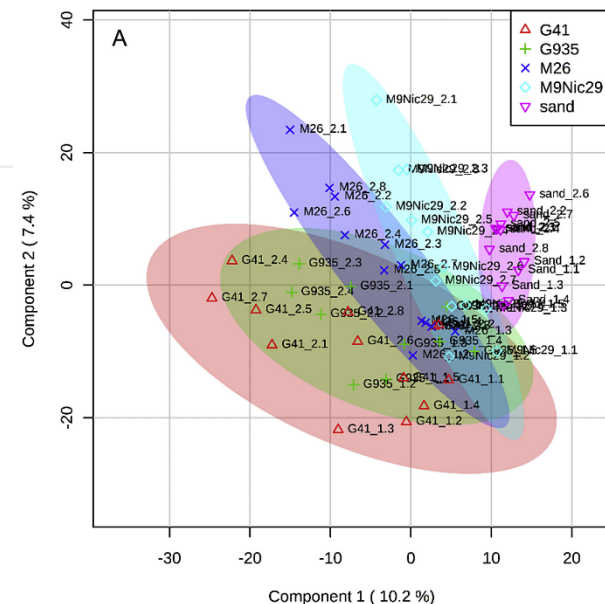
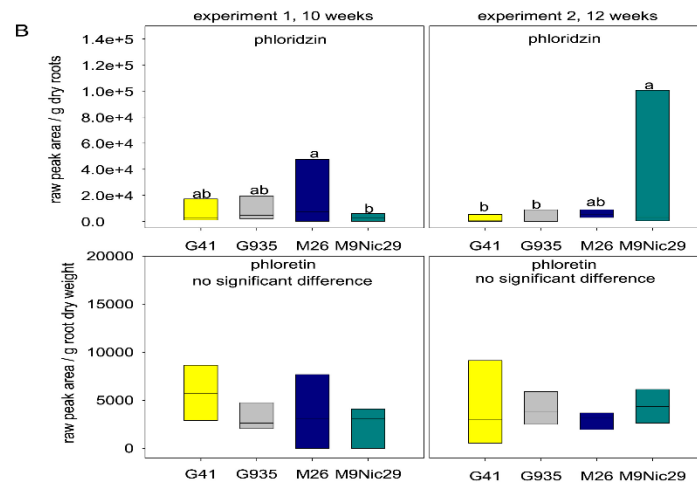
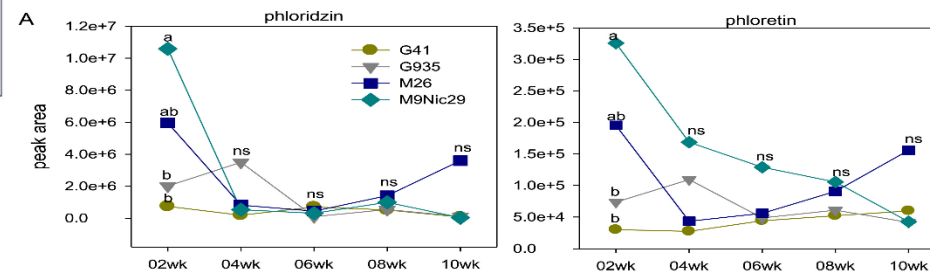


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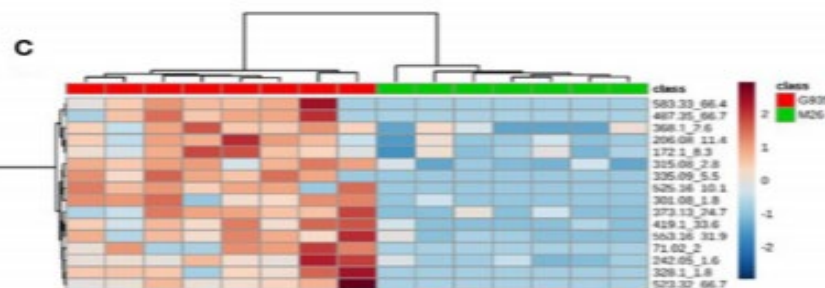
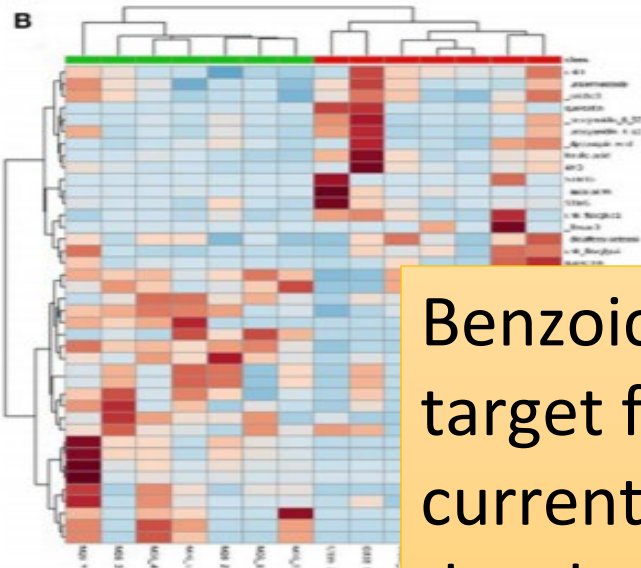
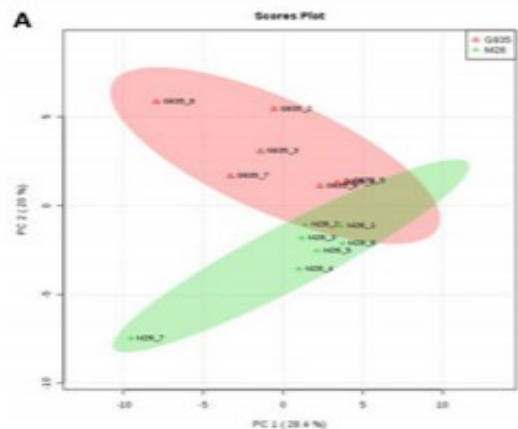
Apple Rootstock Breeding Program
Plant Genetic Resources Unit, Geneva, NY





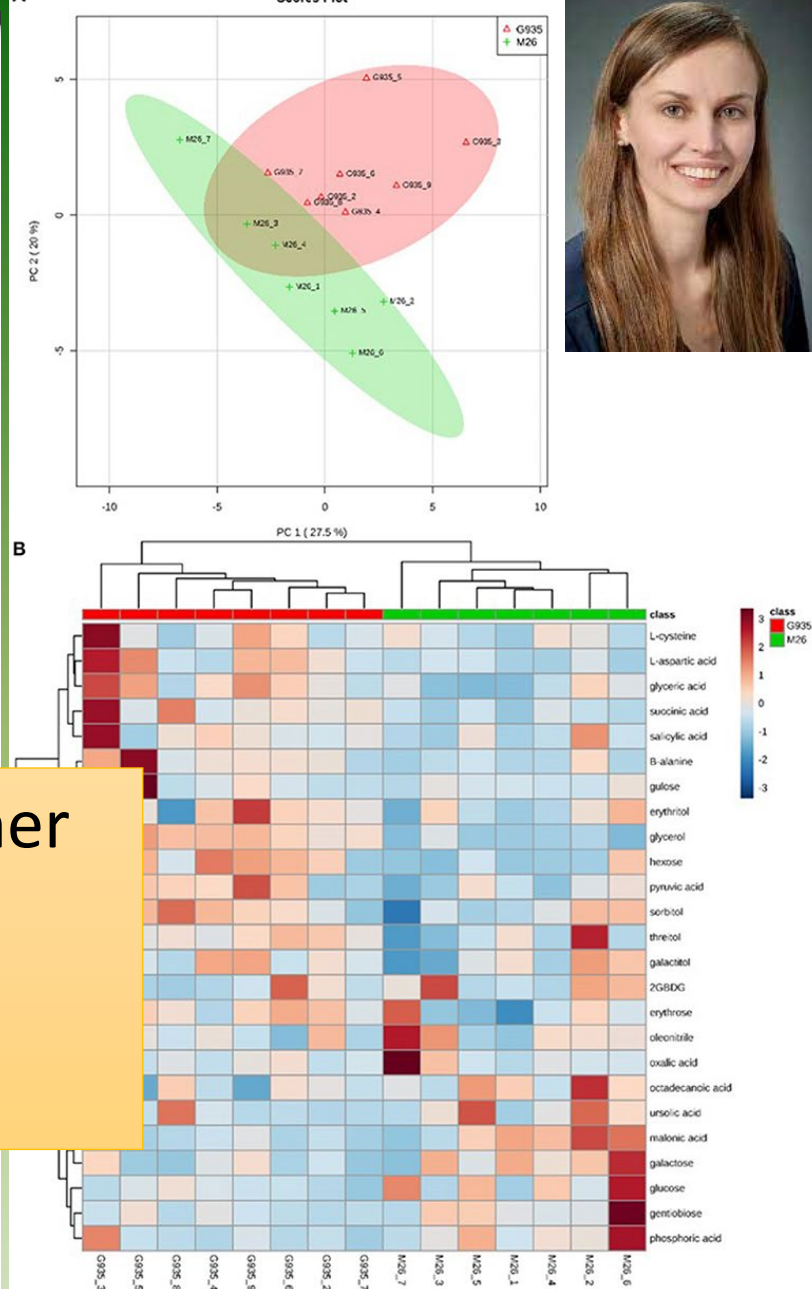
Targeted Metabolic Profiling Indicates Apple Rootstock Genotype-Specific Differences in Primary and Secondary Metabolite Production and Validate Quantitative Contribution From Vegetative Growth

Rachel Leisso^{1*}, Dave Rudell² and Mark Mazzola²

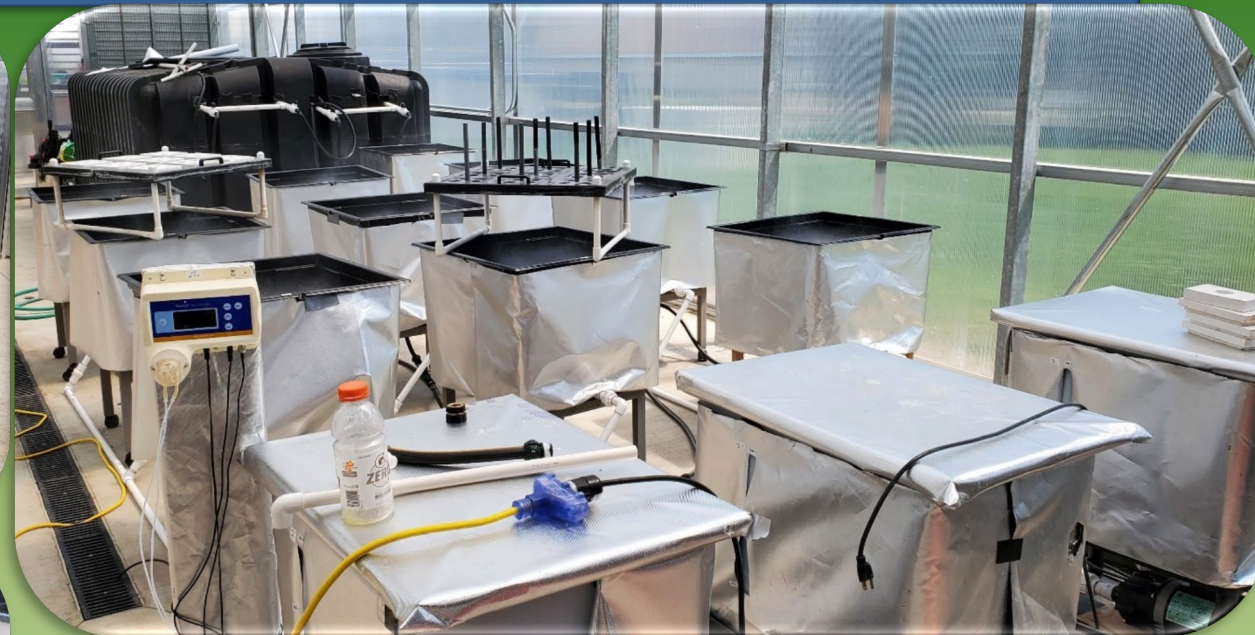


Benzoic acid has been identified as another target for marker development and currently is at the stage of genetic model development (next slide).

FIGURE 4 | Principal components analysis (A) of rhizodeposit phenolic compounds and heatmap showing top 40 identified compounds according to *t*-test significance (B) and unidentified compounds (C), also according to *t*-test significance, indicating separation of the cultivars according to genotype, as well as demonstrating the number of unidentified compounds differing between the genotypes in the LCMS method for phenolic compounds.



Aeroponics Systems to study apple roots

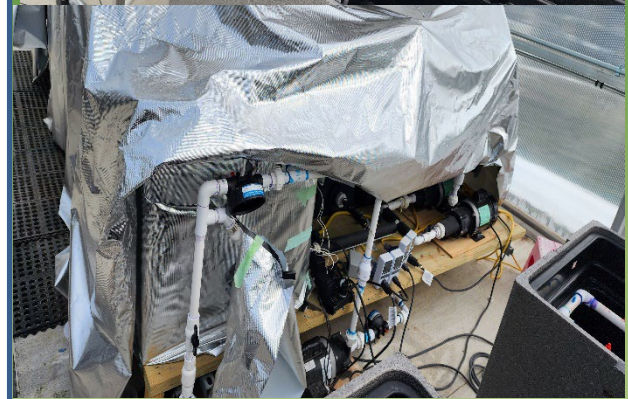
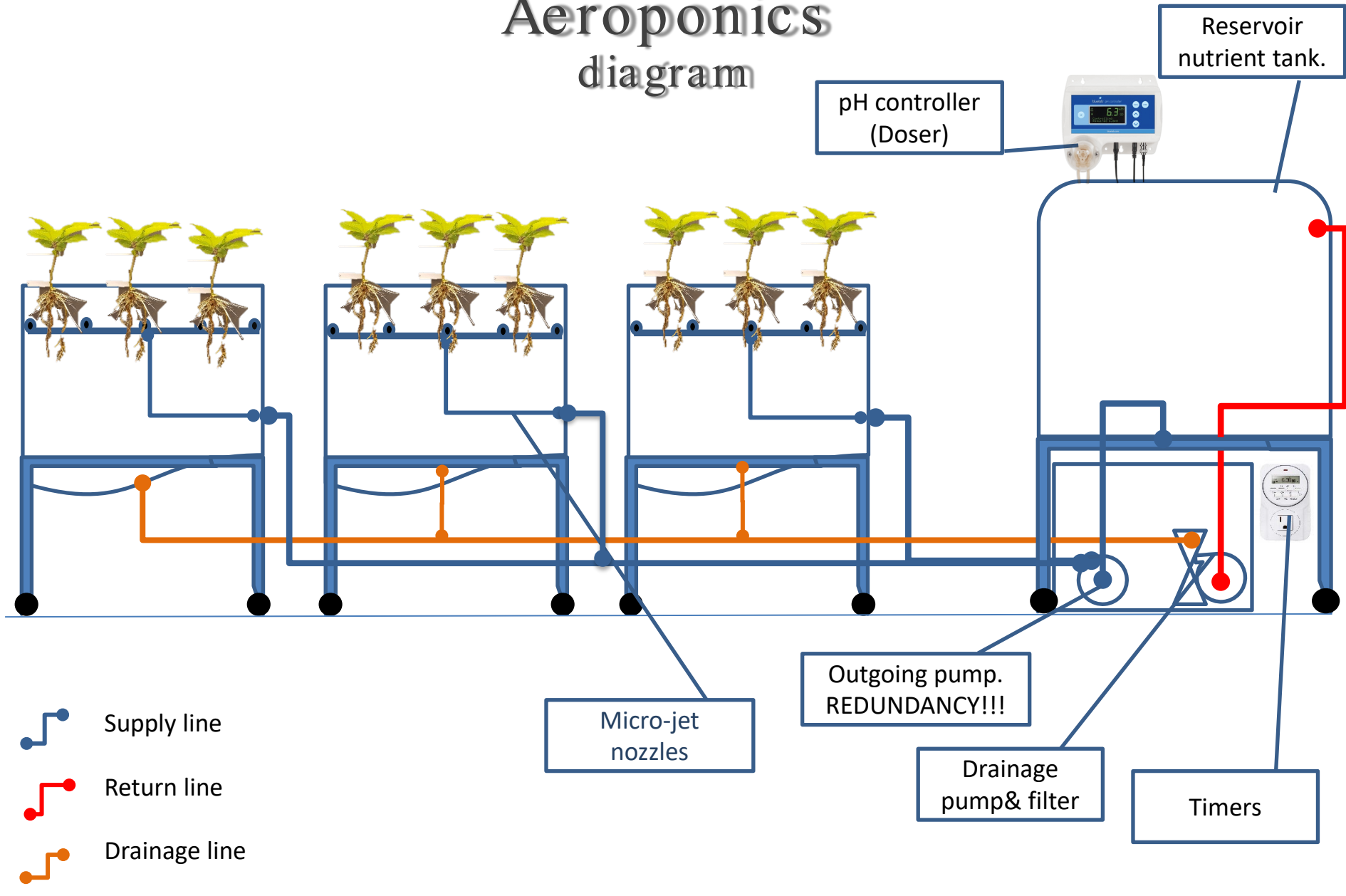


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Plant Genetic Resources Unit, Geneva, NY



Aeroponics diagram



Treatments and Diagnostics Possible with Aeroponics

Integration with robotics will allow multiple automated diagnostics and treatments

- Mineral nutrients
- pH
- Temperature (cold or heat shock) with the addition of a transducer
- Plant growth regulators
- Root pathogens
- Salinity
- Drought

- Easy access roots – RNA, gene expression
- Root growth
- Architecture
- Genotype specific root metabolites
- Disease resistance
- Nutrient induced architecture
- Root gas exchange and respiration





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Malling 9 → Ottawa 3 X Robusta 5



Apple root phenotypic diversity in aeroponics

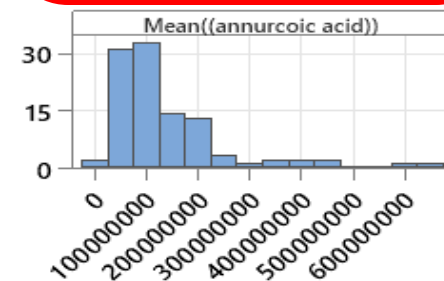
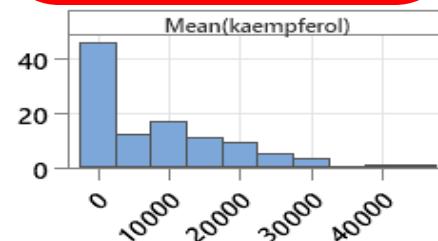
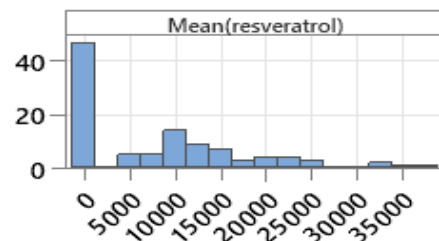
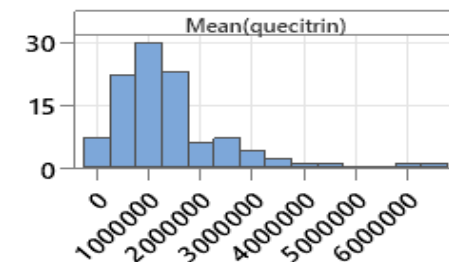
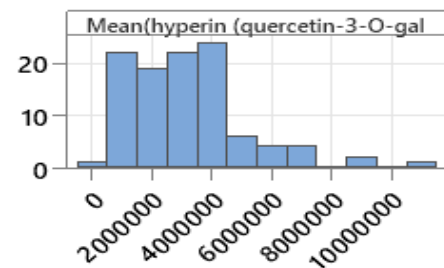
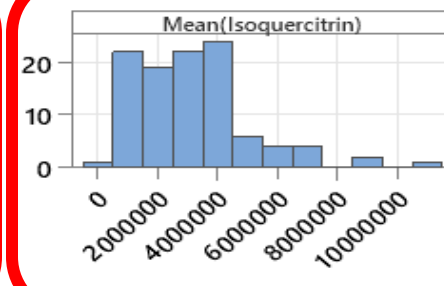
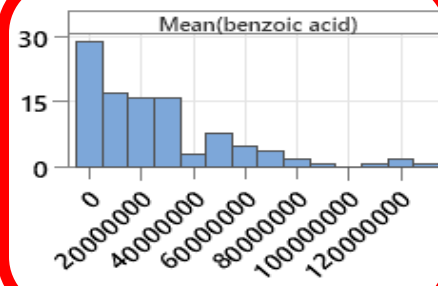
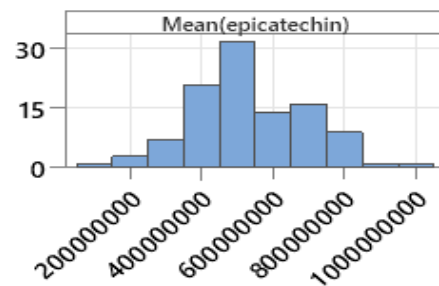
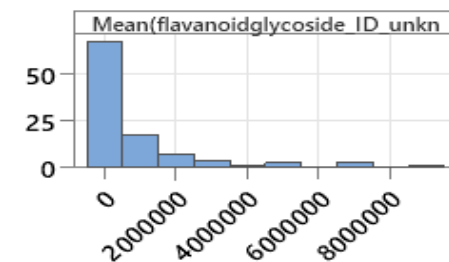
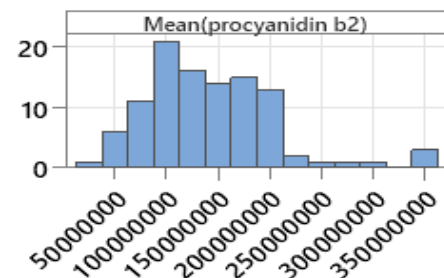
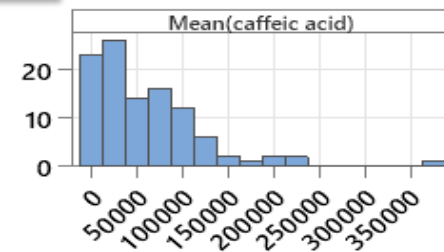
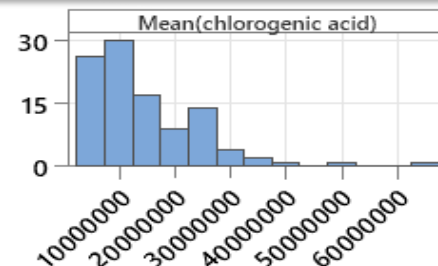
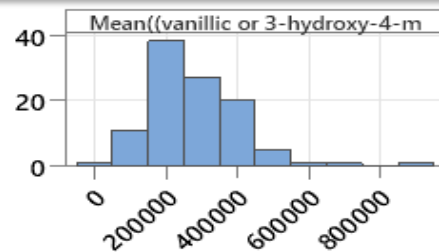
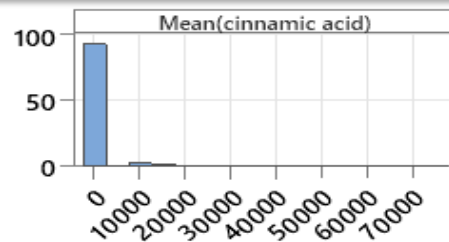
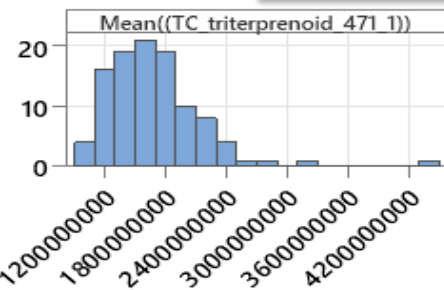
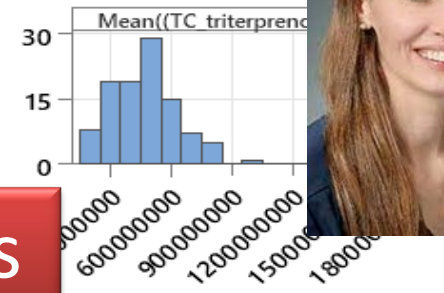
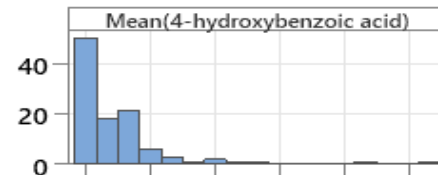
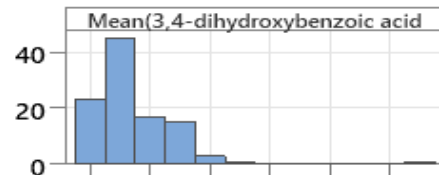
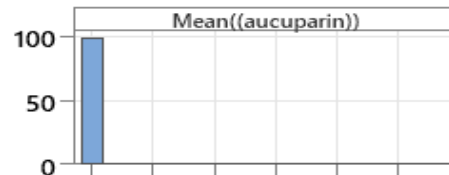
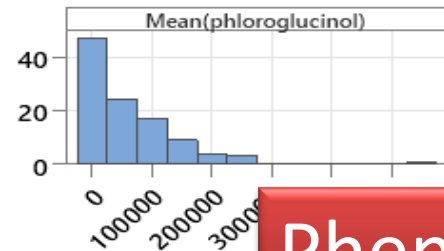


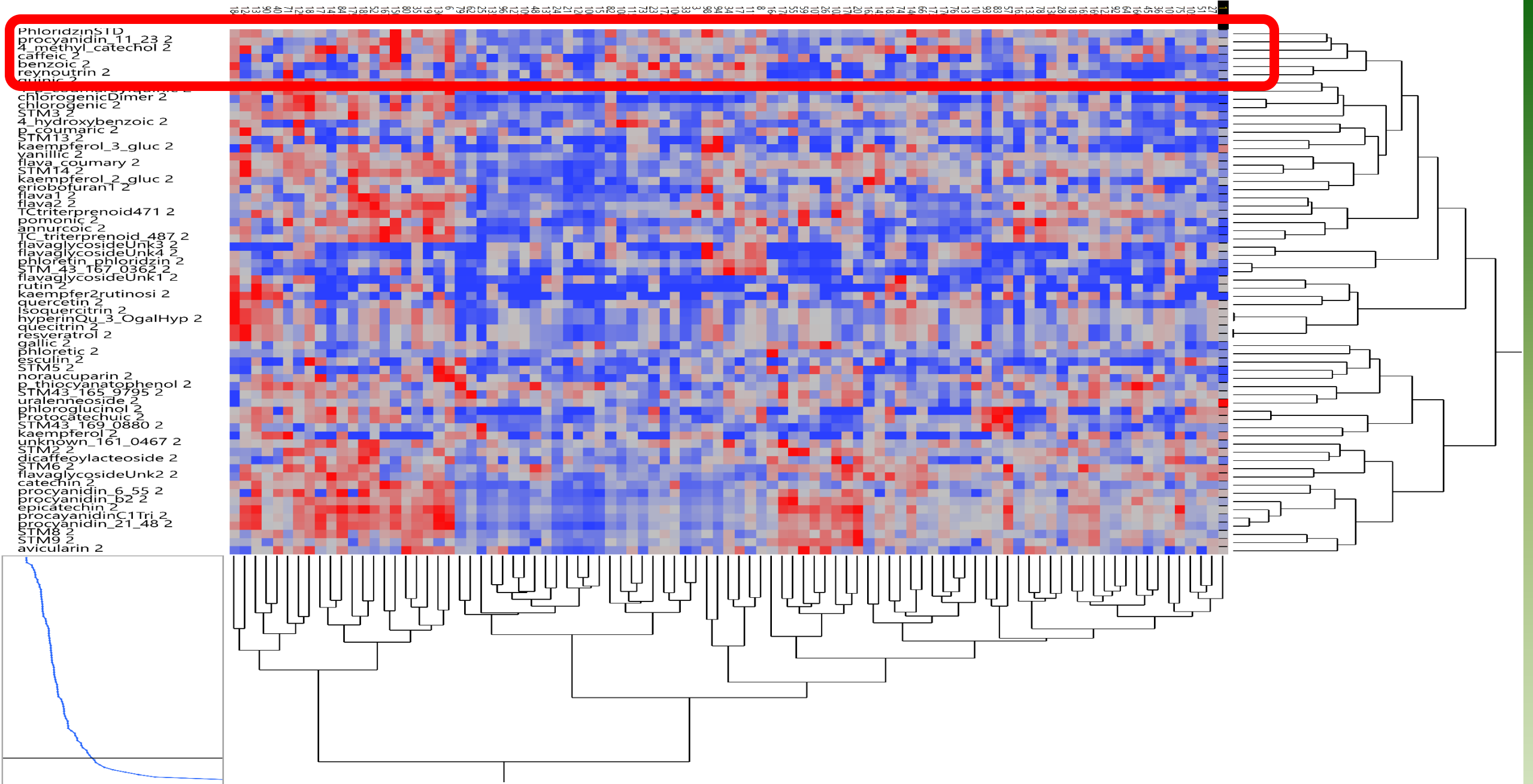
Histogram of Genotypic Means for Root Metabolites (Aeroponics)



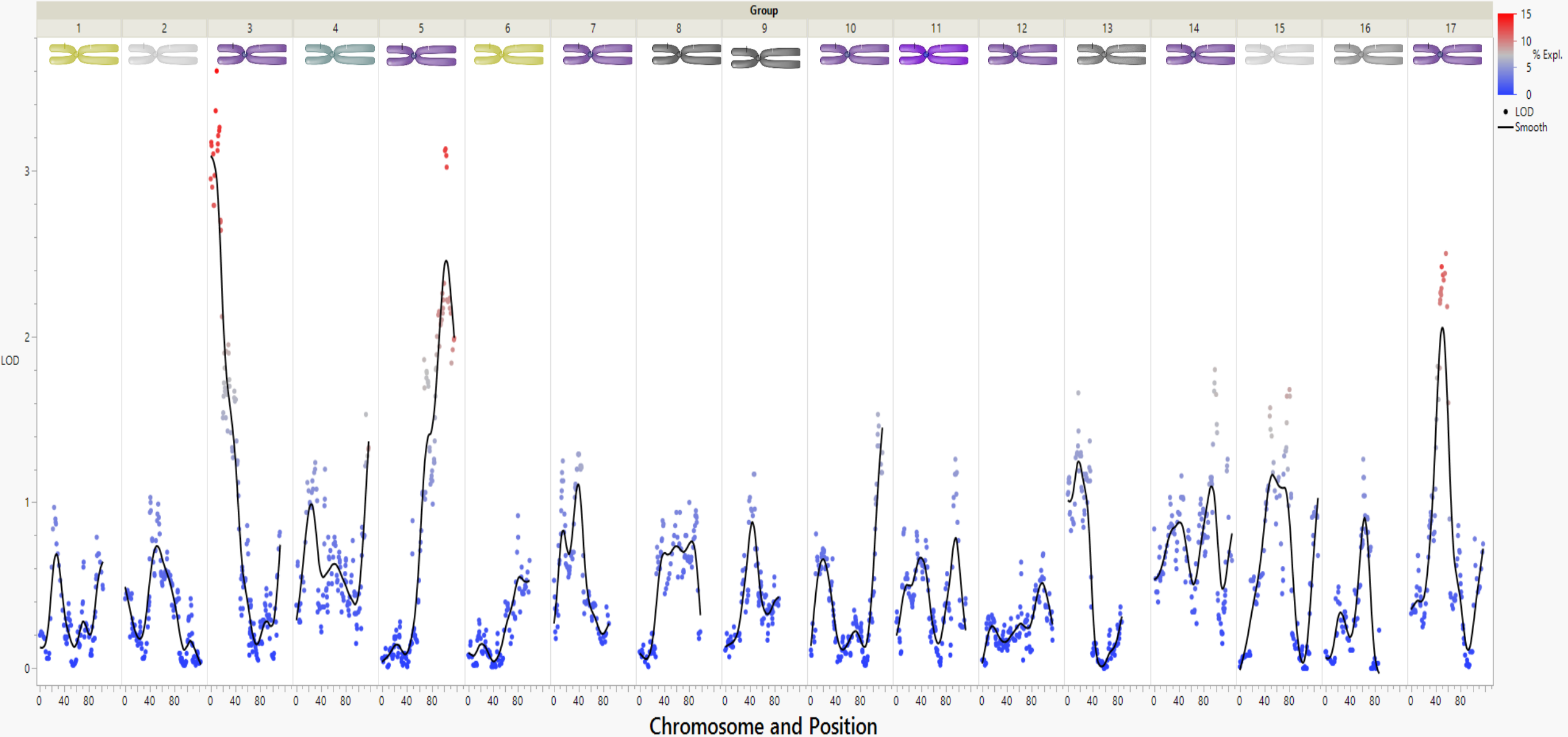
Phenotypic diversity in metabolic compounds

Frequency



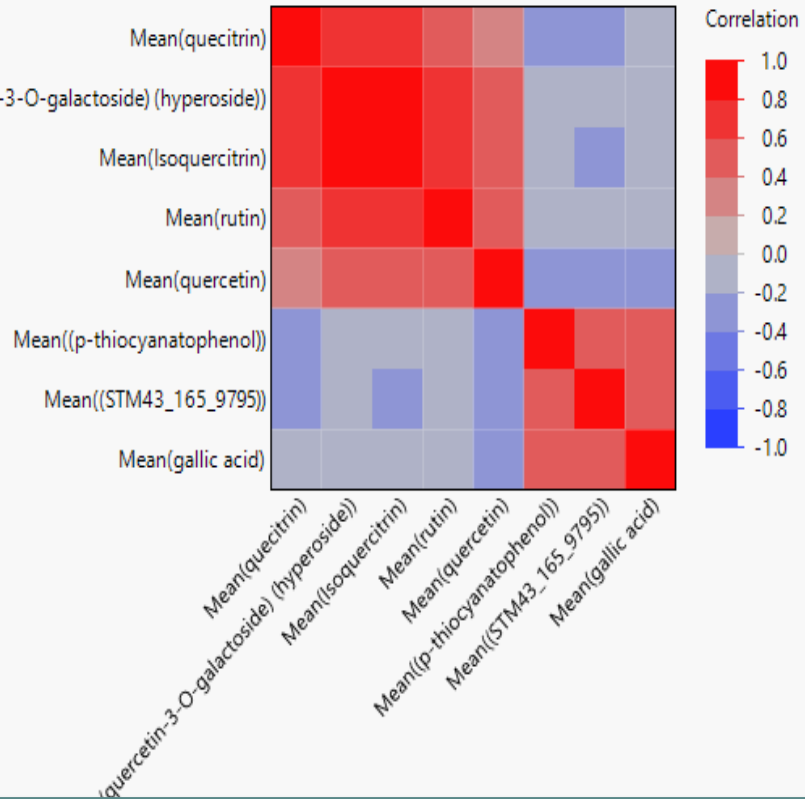


Benzoic Acid Marker Significance



Root Isoquercitrin relationships and pathways

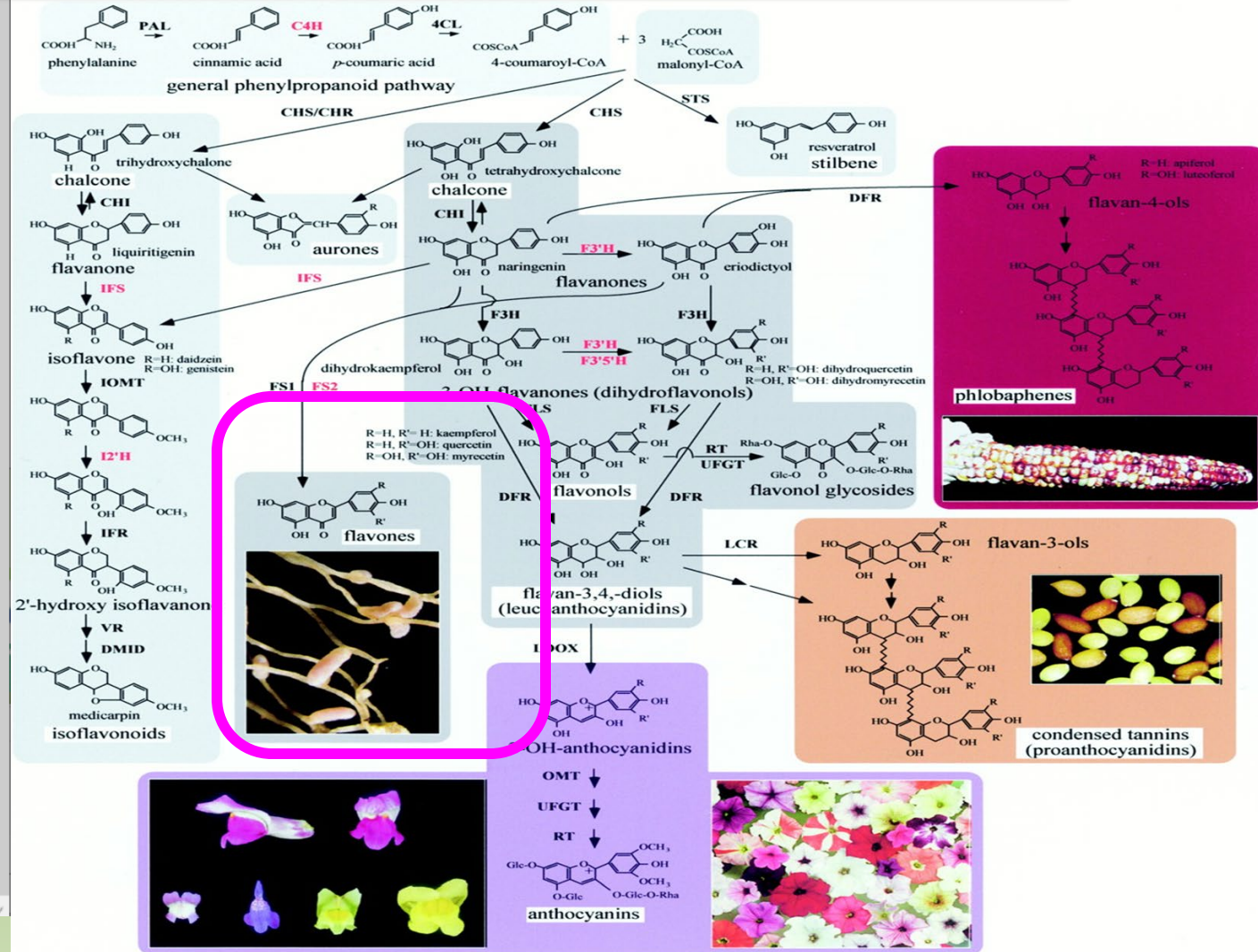
Cluster the Correlations



Quercetin 3-O-beta-D-glucufuranoside is a quercetin O-glucoside in which a glucufuranosyl 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 $\rightarrow$ H⁺ + UDP + quercetin-3-glucoside

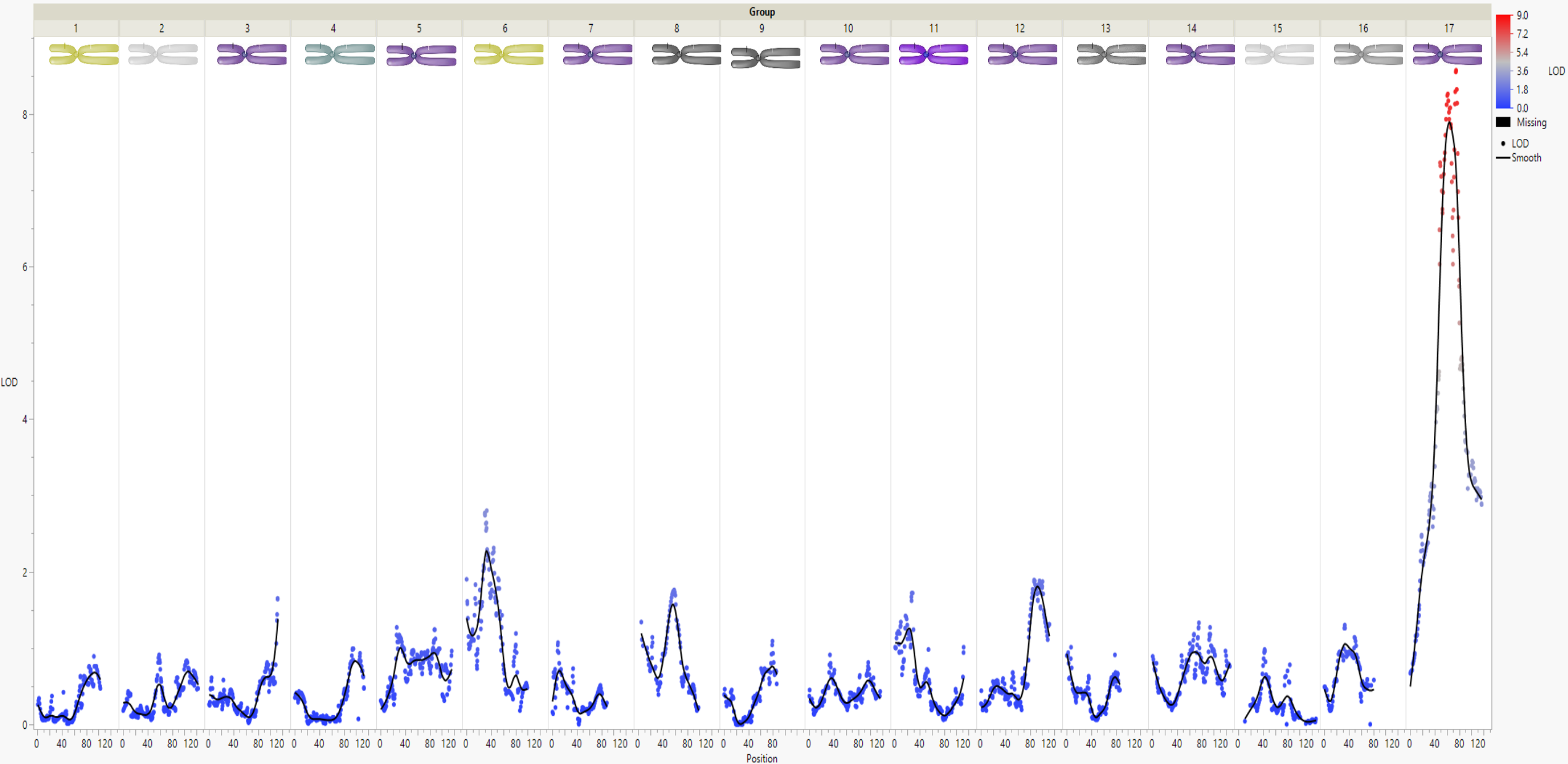
Source: <https://pubchem.ncbi.nlm.nih.gov/compound/5484006>



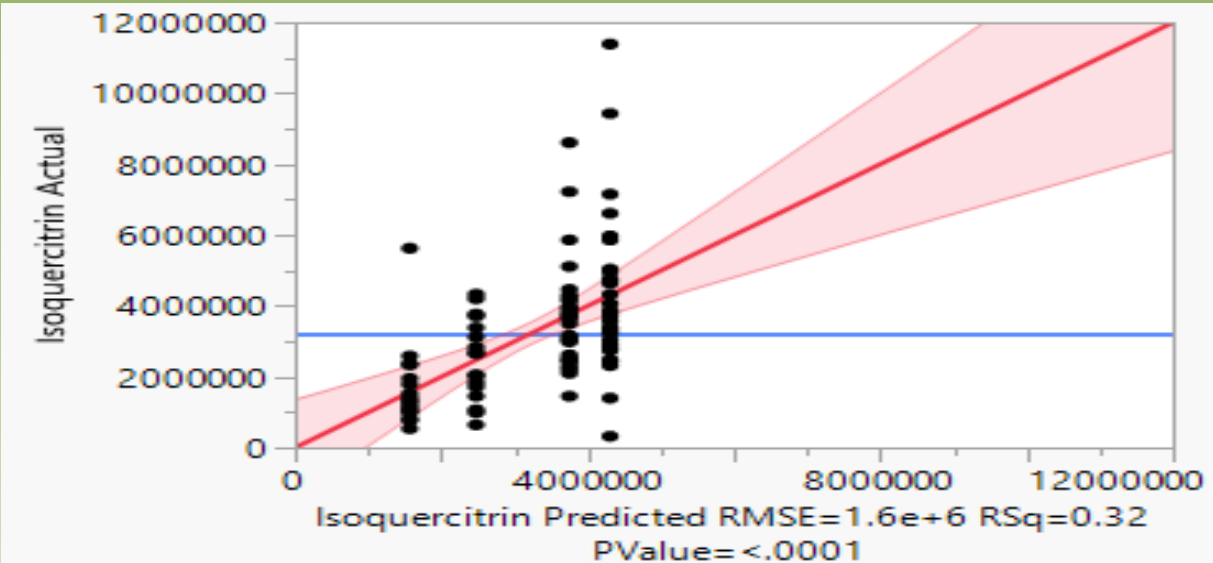
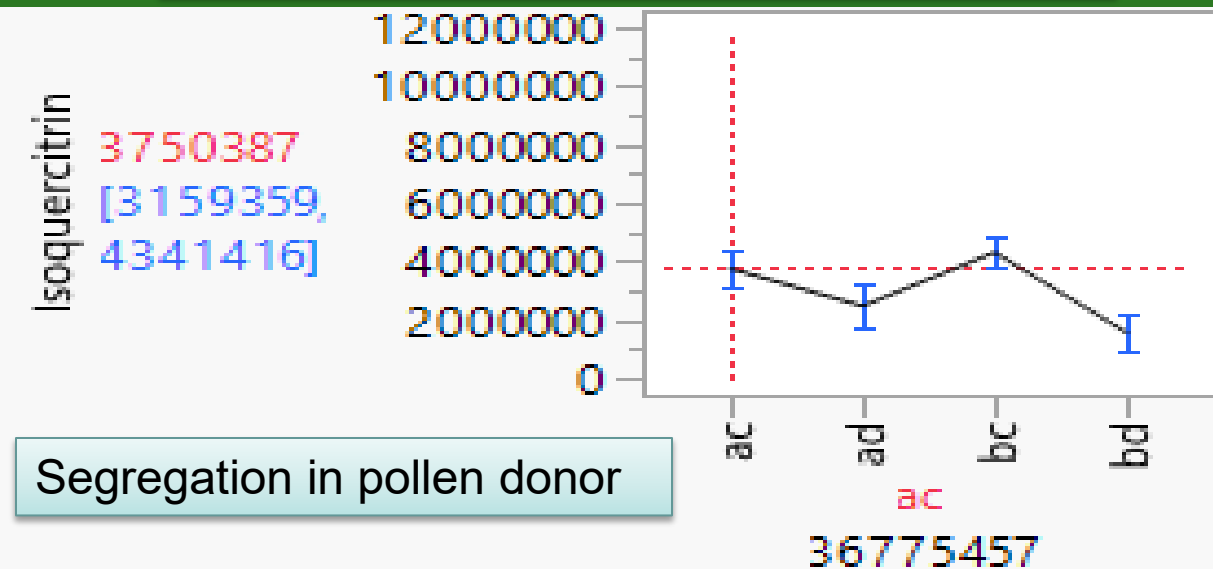
Plant Physiology June 2001 vol. 126 no. 2 485-493



Isoquercitrin LOD vs. LG Position



QTL Marker Effect Prediction

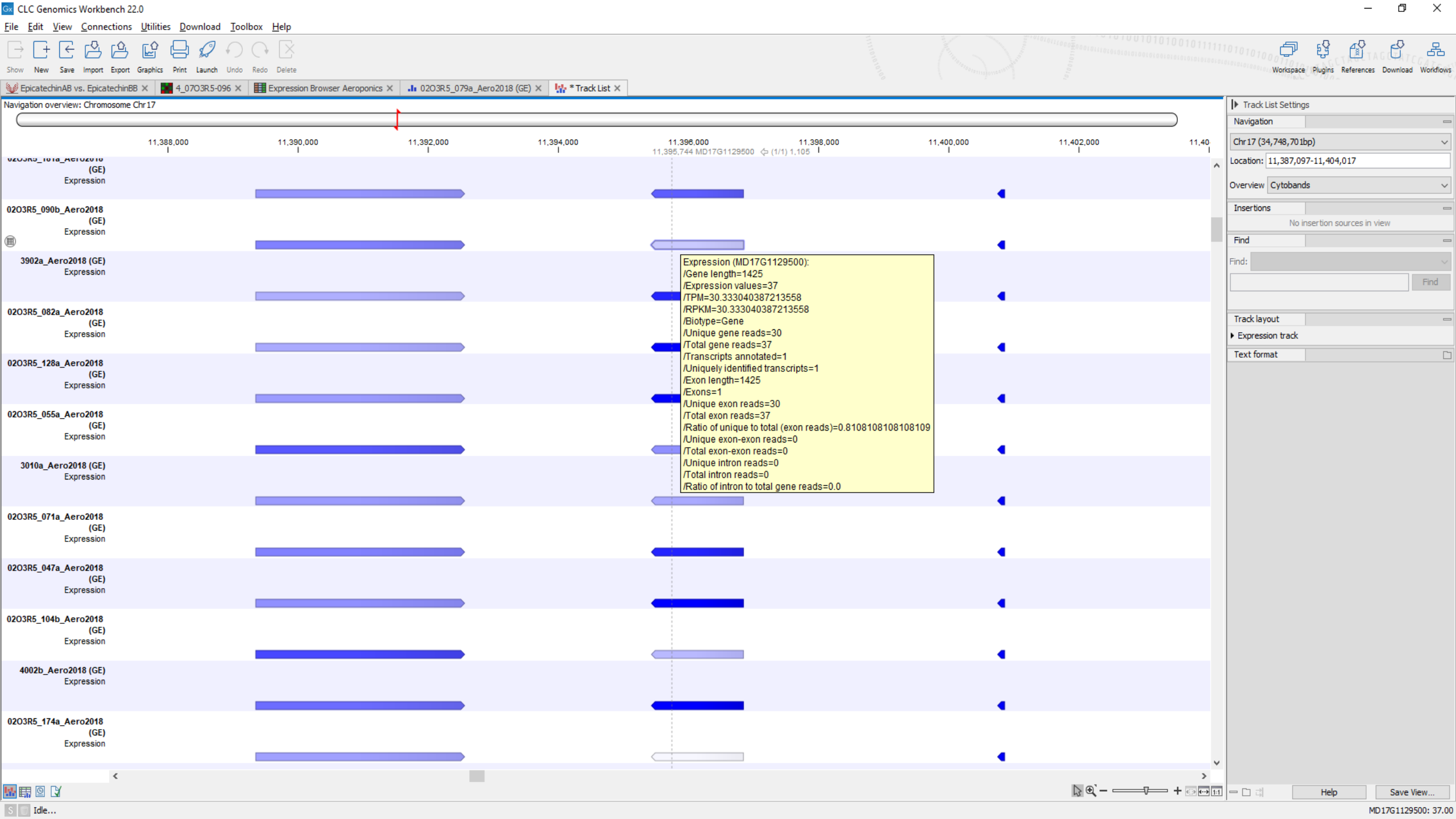


Best RNAseq RPKM Prediction

Predictor Screening

Predictor	Mean(Isoquercitrin)		Rank ^
	Contribution	Portion	
Mean(MD17G1129500)	1.558e+13	0.0734	1
Mean(MD00G1021200)	1.069e+13	0.0503	2
Mean(MD09G1070100)	8.806e+12	0.0415	3
Mean(MD10G1312900)	7.996e+12	0.0376	4
Mean(MD16G1059400)	5.591e+12	0.0263	5
Mean(MD17G1115100)	4.87e+12	0.0229	6
Mean(MD12G1150200)	4.484e+12	0.0211	7
Mean(MD17G1150400)	4.109e+12	0.0193	8
Mean(MD17G1108400)	3.108e+12	0.0146	9
Mean(MD15G1234700)	2.914e+12	0.0137	10
Mean(MD01G1041500)	2.712e+12	0.0128	11
Mean(MD00G1054500)	2.622e+12	0.0123	12
Mean(MD10G1265400)	2.57e+12	0.0121	13
Mean(MD08G1199600)	2.278e+12	0.0107	14





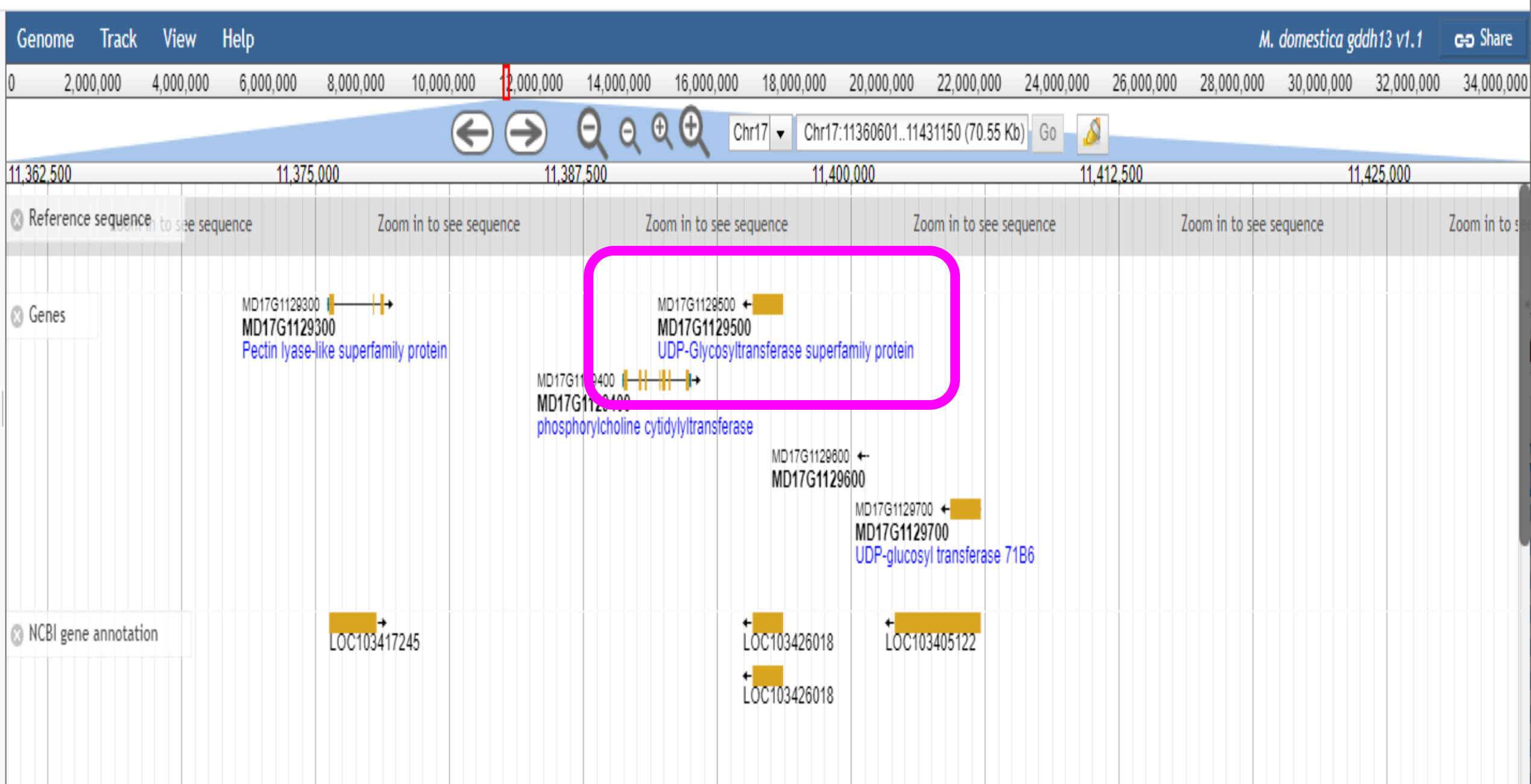
Sand Culture Root Gene Expression QTLs

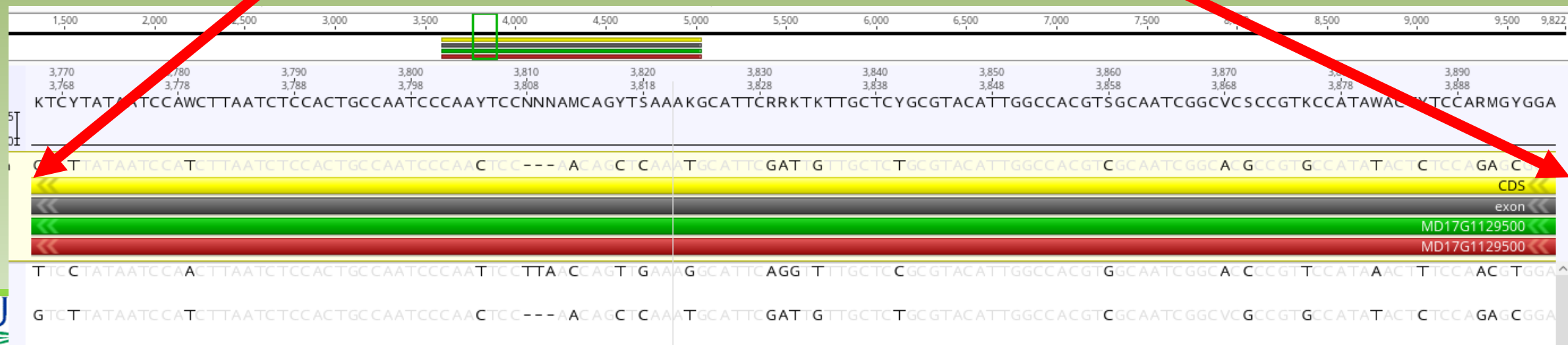
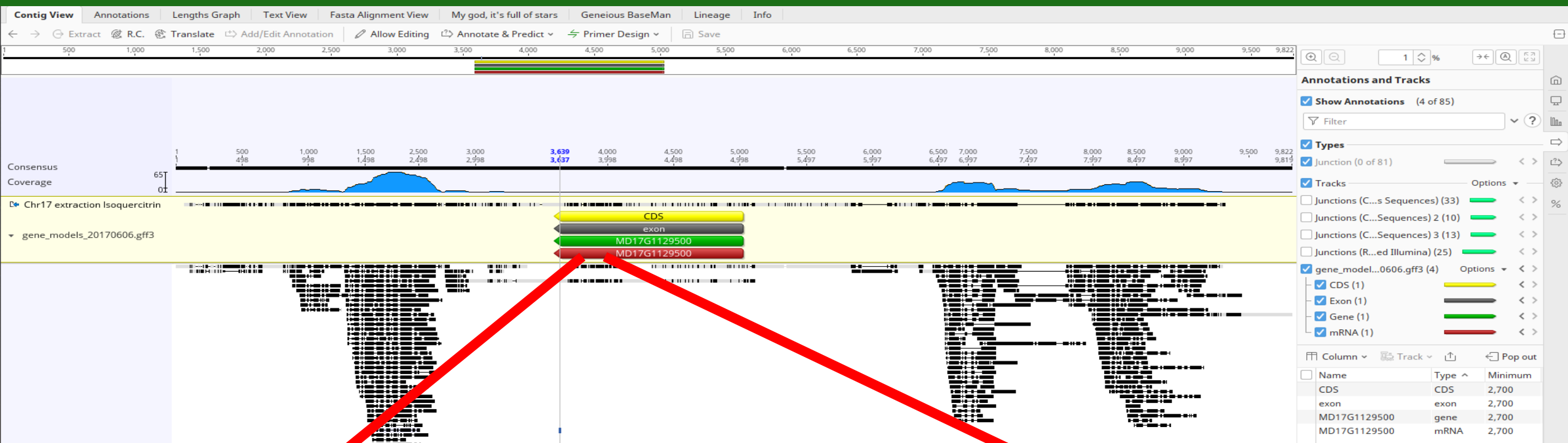


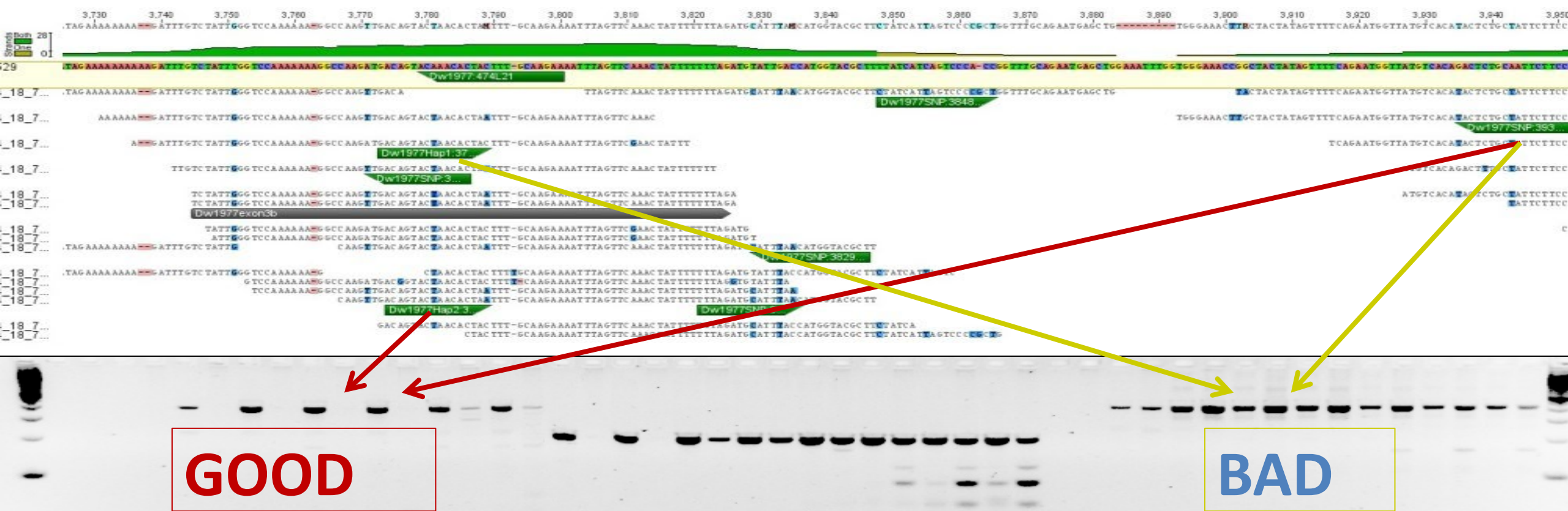
mal location

LOD

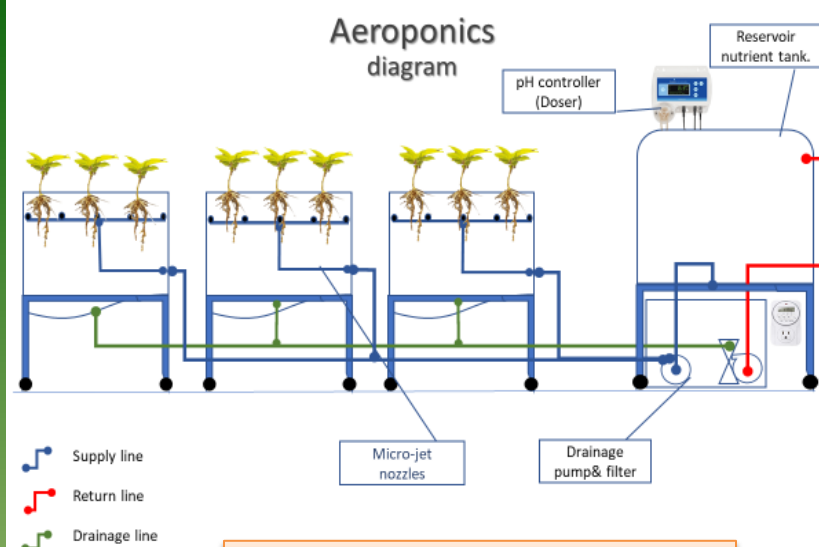








Aeroponics diagram

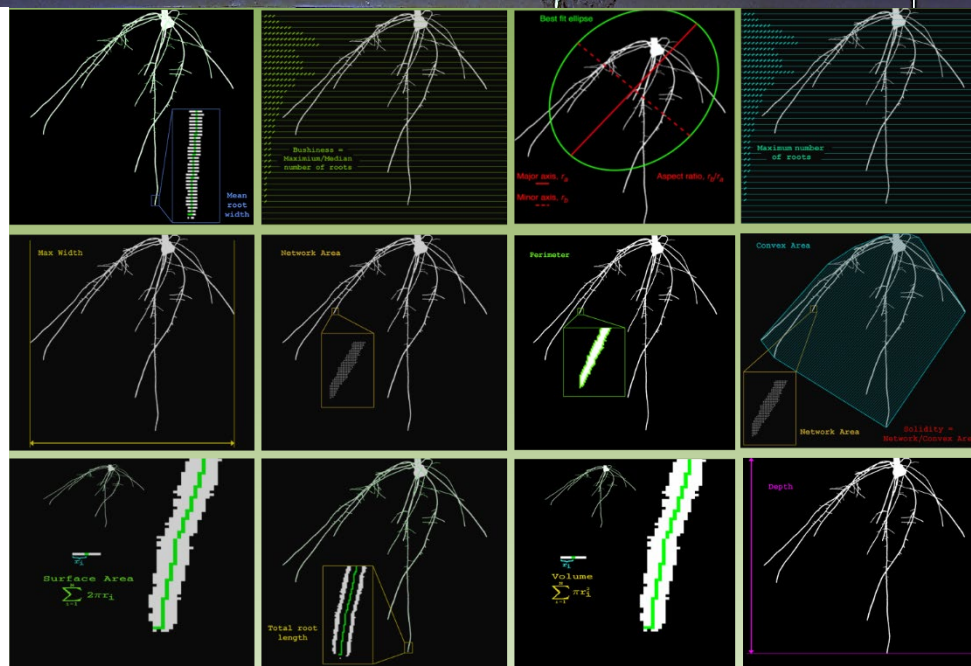


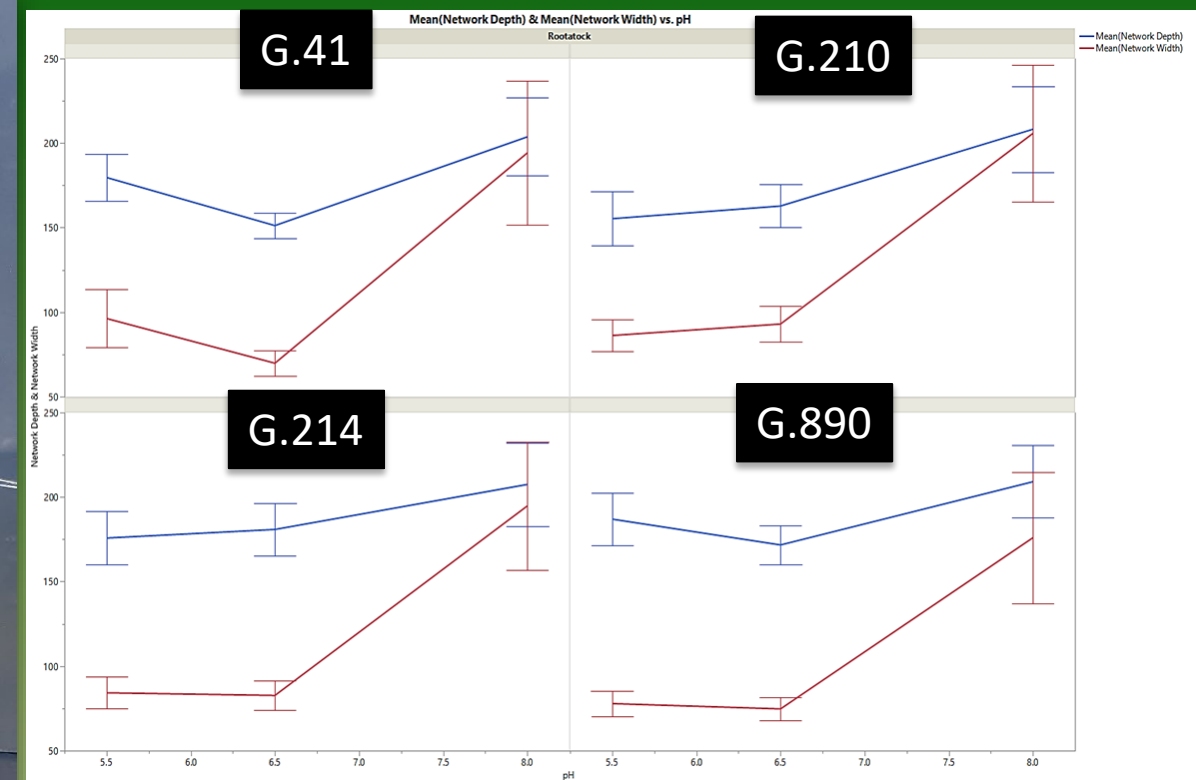
Dr. Ali Farqani PhD work

Root development after 4 weeks in pH 5.5



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.



What is the molecular mechanism that is causing the virus hyper-sensitivity in some Geneva rootstocks?

- Purchased uniform virus tested (clean) micro-propagated G.935, G.890, G.969, G.213 rootstocks from Sierra Gold
- Transferred rootstocks to aeroponic system
- Chip budded 10 trees of each rootstock with “dirty RRHC” and 10 with “clean RRHC”
- Grew trees, collected data and root tissues at different time points for gene expression analysis.





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Plant Genetic Resources Unit, Geneva, NY



G.969

V

C



G.935

V

C



G.890

V

C



G.222

V

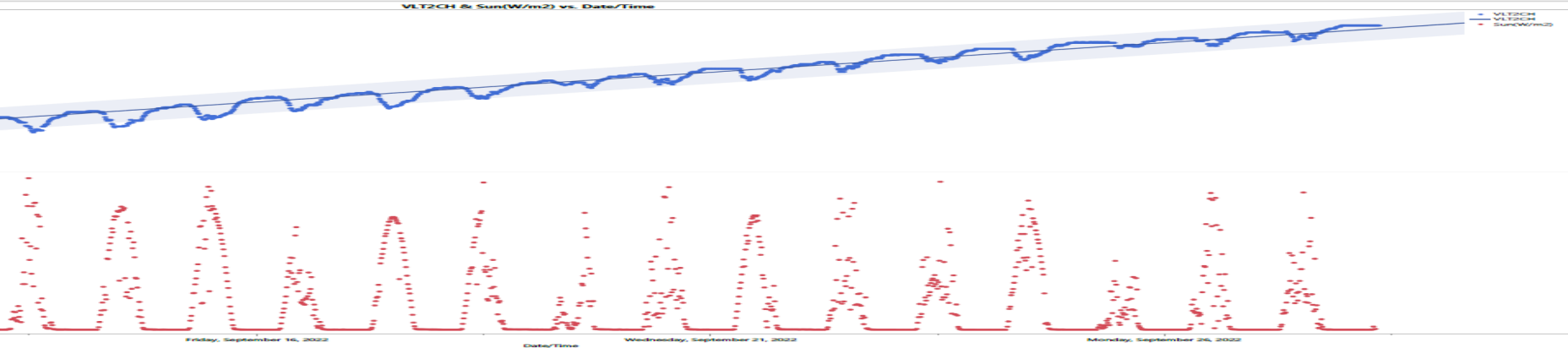
C



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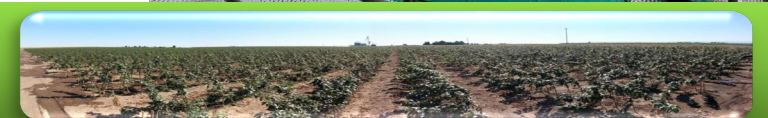
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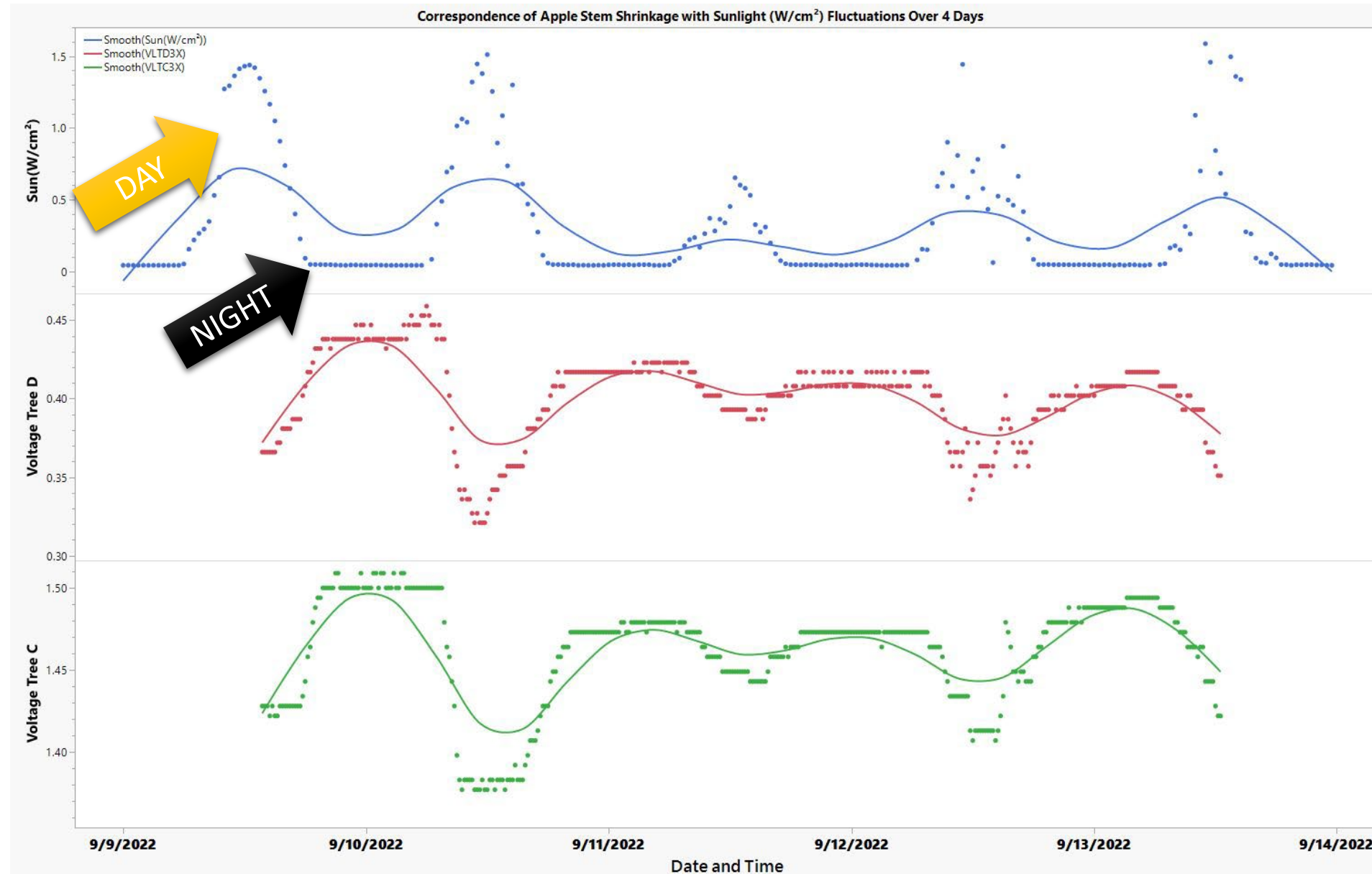
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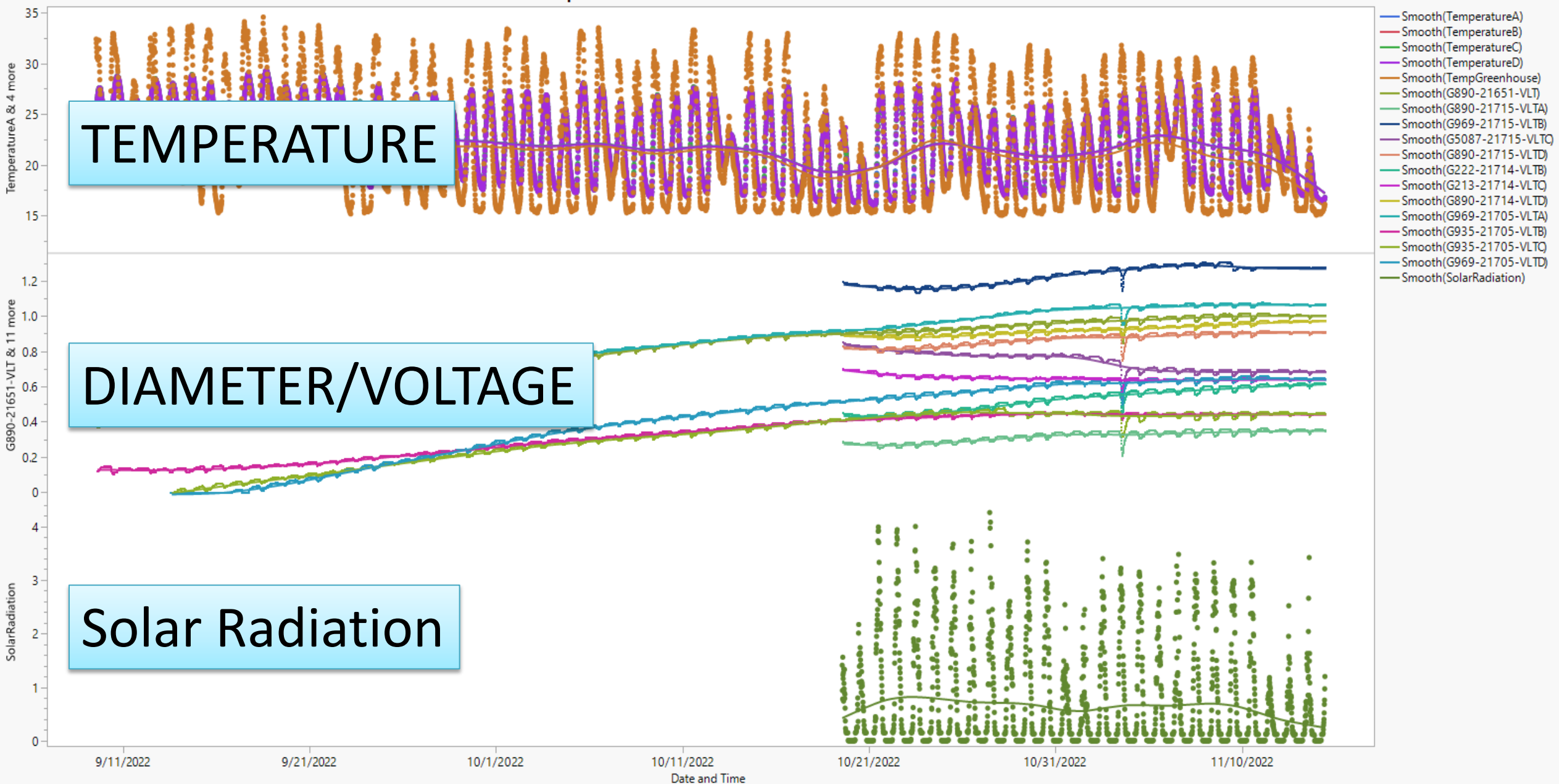
**Apple Rootstock Breeding Program
Plant Genetic Resources Unit, Geneva, NY**



Correspondence Between Fazio Lab Dendrometer Voltage Reading and Daily Fluctuations in Sunlight

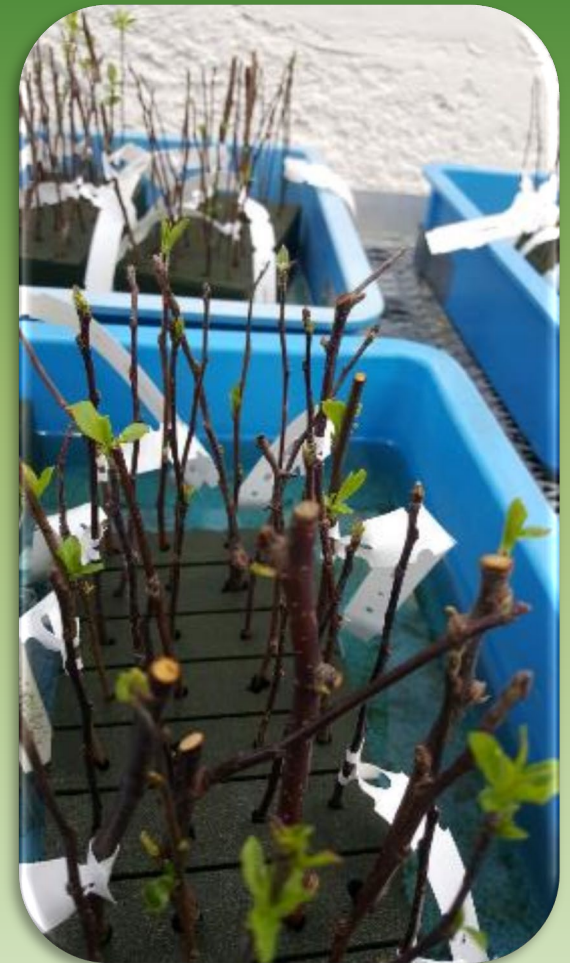
- Dendrometer designed and 3D printed by Fazio
- Dendrometer is a linear potentiometer that detects movements of the piston as changes in voltage.
- Attached to Spectrum Watchdog Data Logger
- Voltage changes in linear potentiometer can detect movement down to 10 microns
- Swelling and shrinking of stems (100 micron) correspond to evapotranspiration correlated with sunlight
- Cloudy, rainy days (September 11 and 12) are clearly sensed by apple trees





Current and Future Directions

- Water availability and climate change.
- Integration with robotics, remote sensing and training systems.
- Interactions between apple rootstocks and apple viruses.
- Designer rootstock: Pairing and Matching.
- Woolly Aphid resistance
- Rhizosphere composition.
- And more....





Left: A struggling G.969 apple tree that had been grafted with a dirty virus laden scion. Below: Collection of fruit data at the WSU Sunrise research orchard In Wenatchee, WA – Dr. Musacchi harvesting apples from a rootstock trial.



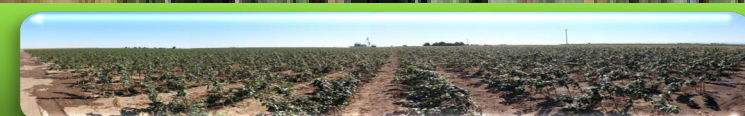


Left: Honeycrisp tree on G.969 rootstock grafted with clean, virus free wood growing well. Above and right: Rootstock field trial at a Stemilt Growers orchard in Quincy, WA featuring Geneva rootstocks. These growers' trials are essential for field performance evaluation.



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



Given the high demand for disease resistant, productive Geneva Rootstocks, nurseries (Brent Smith of TRECO) are using additional propagation methods (softwood cuttings) to make as much material as possible to satisfy orders.





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





Tissue Culture of Geneva rootstocks at North American Plants (Oregon) to generate Virus Free Foundation material for establishment of rootstock beds in conventional nurseries and field trials.



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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.





Thank You!



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