CORNELL UNIVERSITY
New York State Agricultural Experiment Station
USDA ARS

Geneva Breeding Programs

Concepts of Apple Rootstock Breeding and Selection: A Journey Through the Development of New Apple Rootstocks

G. Fazio, H. Aldwinckle, T. Robinson

Introduction

- Breeding work for the Geneva® rootstocks was initiated by Drs. Cummins and Aldwinckle in 1967.
- The USDA/Cornell program is actively breeding and selecting new rootstocks (about 2,500 in the pipeline) – Dr. Aldwinckle and Dr. Robinson represent Cornell University in the program.
- The program, has always focused on developing yield efficient, disease resistant rootstocks (fire blight, etc).
- It is now focusing on characterization of other important traits such as replant disease resistance, drought tolerance, cold tolerance, etc.

Apple Harvest Doud family farm (1916, Miami Co. Indiana)

Auvil Fruit Farm (Vantage, WA 2005 – next to Columbia River)

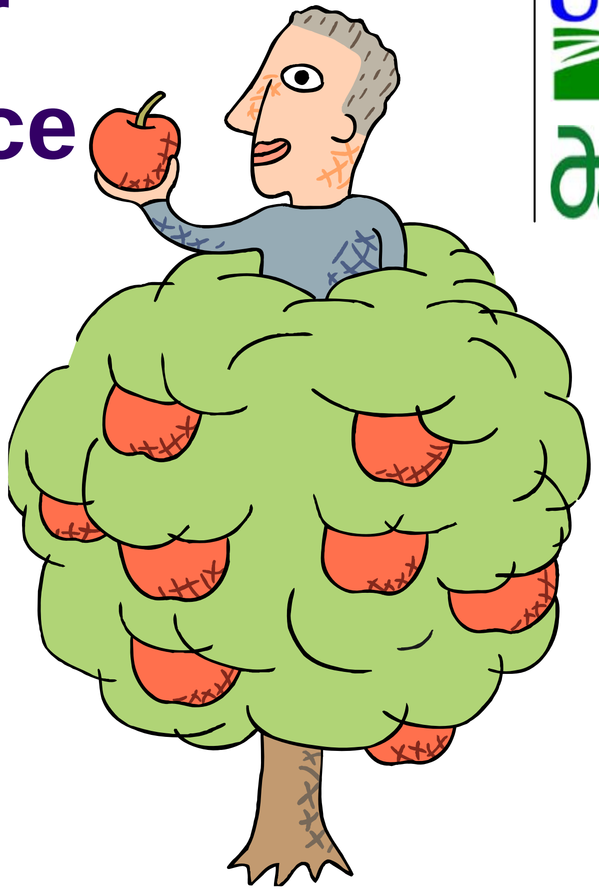
Benefits from the implementation of dwarfing rootstocks

Less sprays

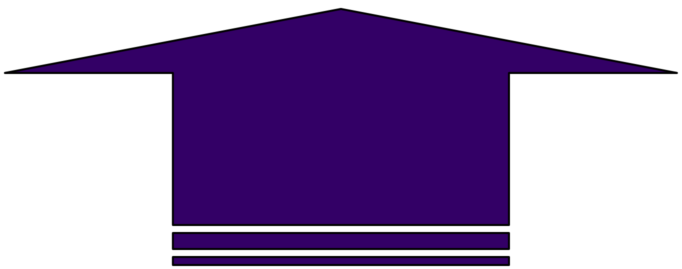
Less ladder accidents

Increased productivity

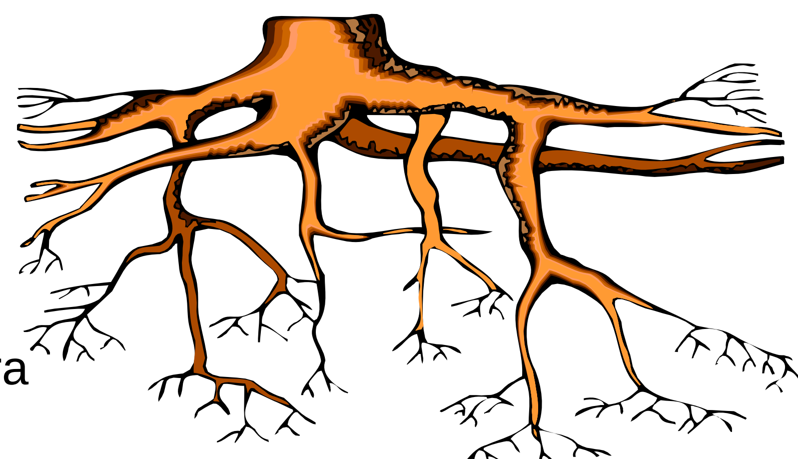
Improving Rootstocks for Superior Tree Performance



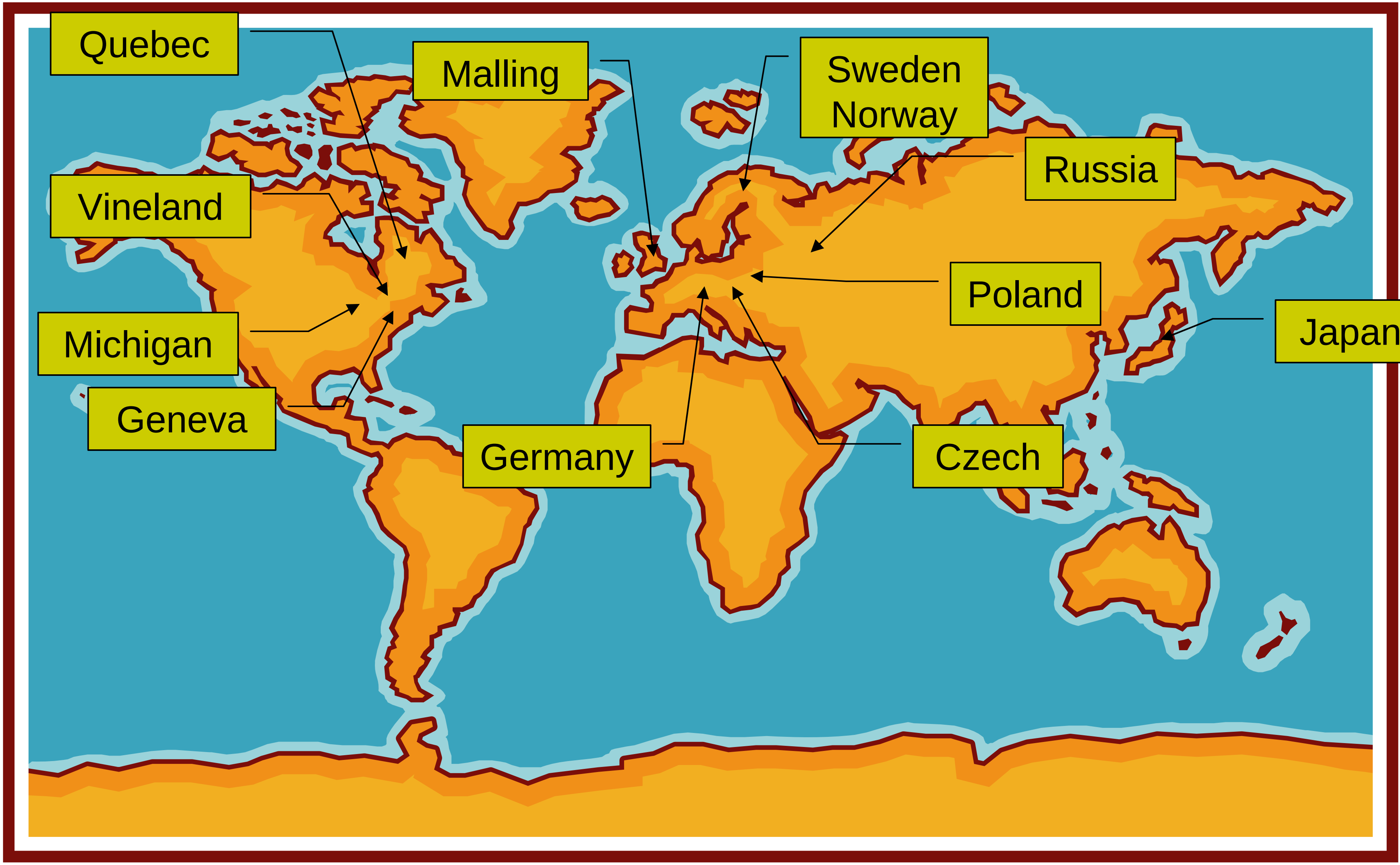
- Fruit Color and Quality
- Fruit Size
- Disease Resistance



- Plant Architecture – Dwarfing
  - Molecular mapping and selection tools
  - Genomics
- Yield and productivity (Nutrition)
- Precocity
- Abiotic Stress Resistance (Cold)
- Disease Resistance
  - Fire blight ($40M 2000 epidemic, MI)
  - Replant disease complex
- TRANSGENIC ROOTSTOCKS for a plethora of traits



Active Apple Rootstock Breeding Programs 1970s and 80s



Active Apple Rootstock Breeding Programs 2005

New and Experimental Apple Rootstocks in the U.S.

Polish	Czhec	Malling	Russia	Vineland	Quebec	Japan	Germany	Geneva
P.14	JTE-B	AR-86-1-20	Bud 57-195	V.1	SJP84-5218	JM1	Supp. 1	G.11
P.22	JTE-C	AR-86-1-25	Bud 60-160	V.2	SJP84-5217	JM2	Supp. 2	G.16
	JTE-D	AR-295-6	Bud 61-31	V.3	SJP84-5198	JM3	Supp. 3	G.41
		AR-931-15	Bud 62-396	V.4	SJP84-5162	JM7	Supp. 4	G.65
		AR-440-1	Bud 64-194	V.7	SJP84-5231	Marubakaido	PiAu 56-83	G.935
		AR-680-2	Bud 65-838		SJP84-5174			G.30
		AR-486-1	Bud 67-5(32)		SJP84-5189			CG.2001
		AR-628-2	Bud 70-8-8		SJP84-5180			CG.2003
		AR-69-7	Bud 70-20-21					CG.2006
		AR-360-19	Bud 71-3-150					CG.2022
		M.20	Bud 71-7-22					CG.2034
								CG.2406
CG.3142	CG.3736	CG.3902	CG.4001	CG.4002	CG.4003	CG.4004	CG.4005	CG.3001
CG.4011	CG.4013	CG.4018	CG.4019	CG.4021	CG.4038	CG.4049	CG.4088	CG.3007
CG.4094	CG.4113	CG.4172	CG.4210	CG.4213	CG.4214	CG.4247	CG.4288	CG.3029

Geneva Rootstock Selection Traits

TRAIT	EVALUATION YEARS	LOCATION
Fire Blight resistance	1 or 7	Greenhouse/Field
Phytopthora resistance	1	Greenhouse
Replant Disease Complex	1 or 7	Greenhouse/field
Wholly apple aphid res.	1	Greenhouse
Juvenility - Spines	3-4	Field/Stoolbed
Stoolbed rooting	3-4	Field/Stoolbed
Growth habit - Brittleness	3-4	Field/Stoolbed
Dwarfing	8-12	Orchard
Precocity	8	Orchard
Suckering	8	Orchard
Yield – Biennial bearing	12	Orchard
Cold hardiness	15	Orchard
Drought tolerance	4	Orchard
Graft union compatibility	5	Orchard

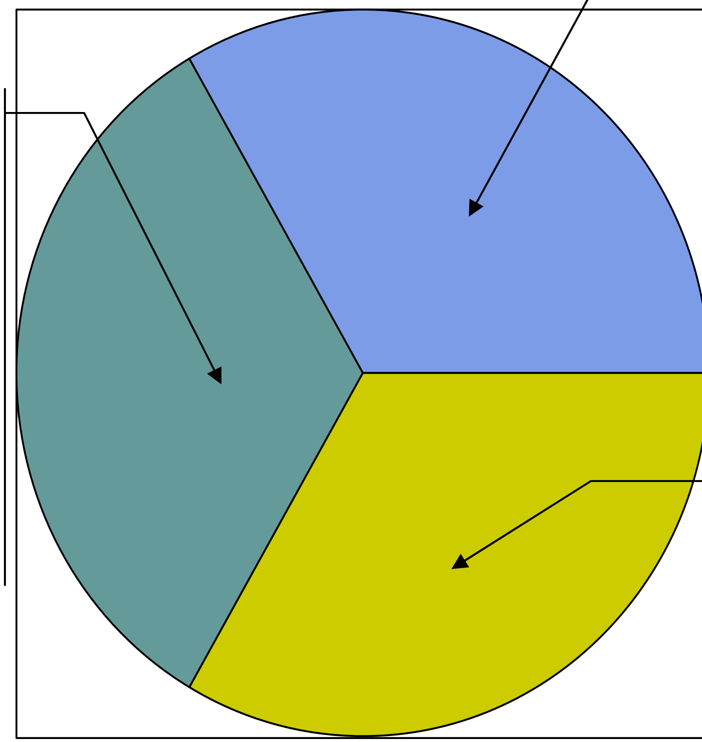
Insects and diseases of apple rootstocks

- Fire blight (*Erwinia amylovora*)
- Crown rot, root rot (*Phytophthora spp.*)
- Woolly Apple Aphid (*Eriosoma lanigerum*)
- Southern Blight (*Sclerotium rolfsii*)
- White root rot (*Rosellinia necatrix*)
- Texas root rot (*Phymatotrichum omnivora*)

Apple Rootstock Breeding: Resources and Activities

Lab & Greenhouse

-Seedling inoculations
-Molecular markers
-Tissue culture
-Plant pathology
-ETC.



Orchard Production

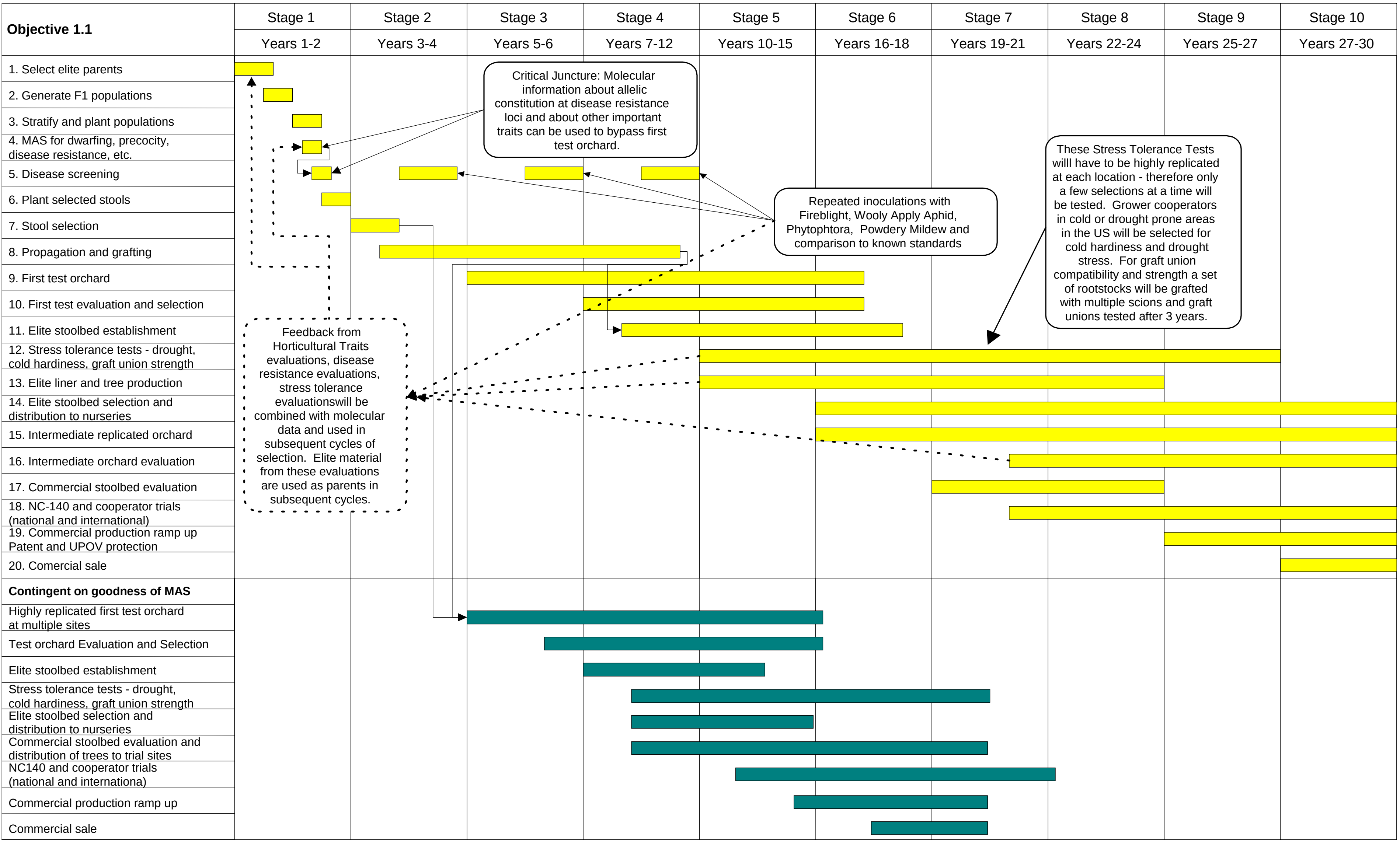
-Individual yield and growth
-Disease incidence
-Scion compatibility
-ETC.

Nursery

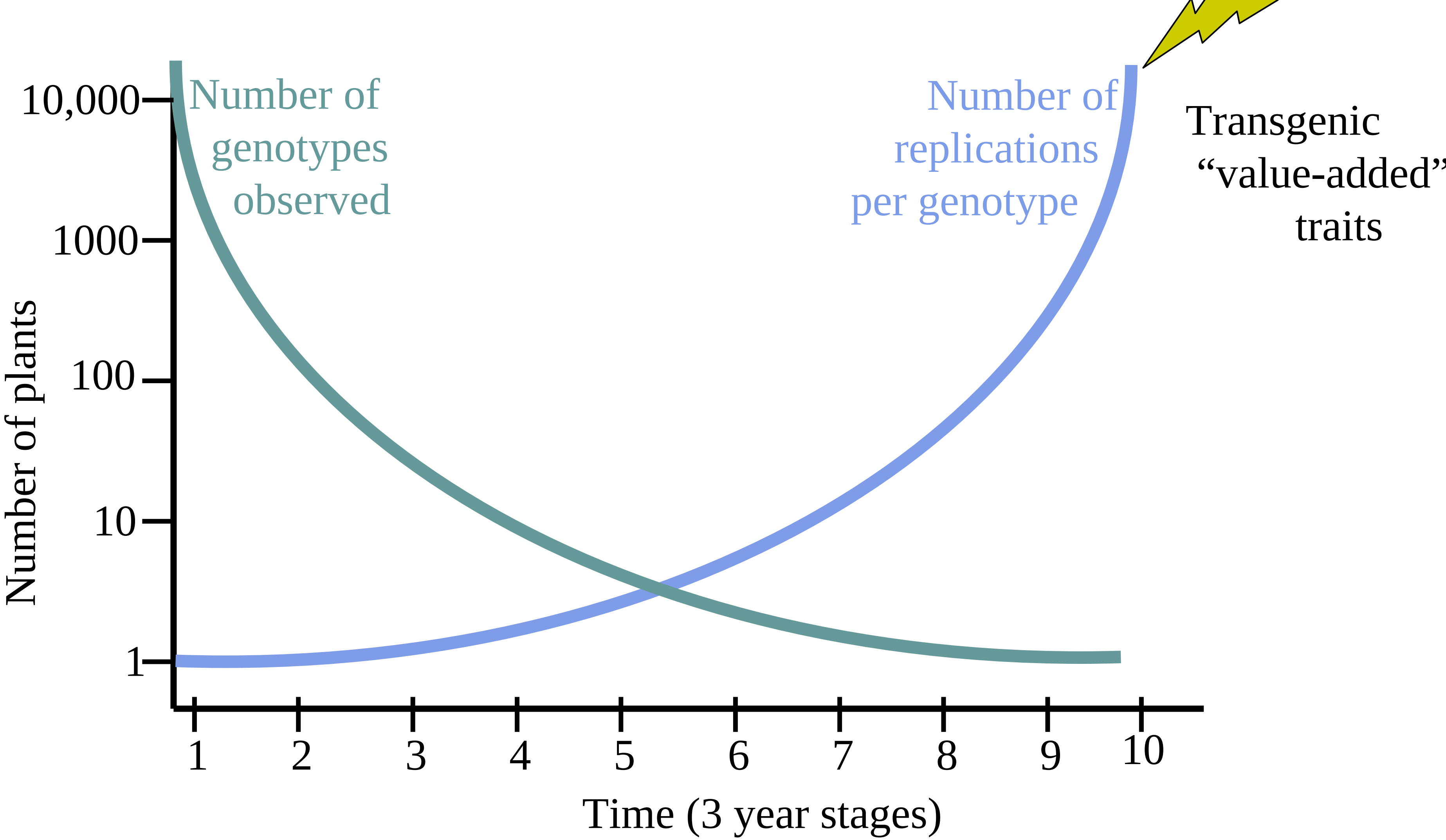
-Liner production
-Tree Production
-Stoolbed evaluation
-Transplant Evaluation
-ETC.

Apple Rootstock Breeding is a very resource intensive endeavor.

Apple Rootstock Breeding and Selection Protocols



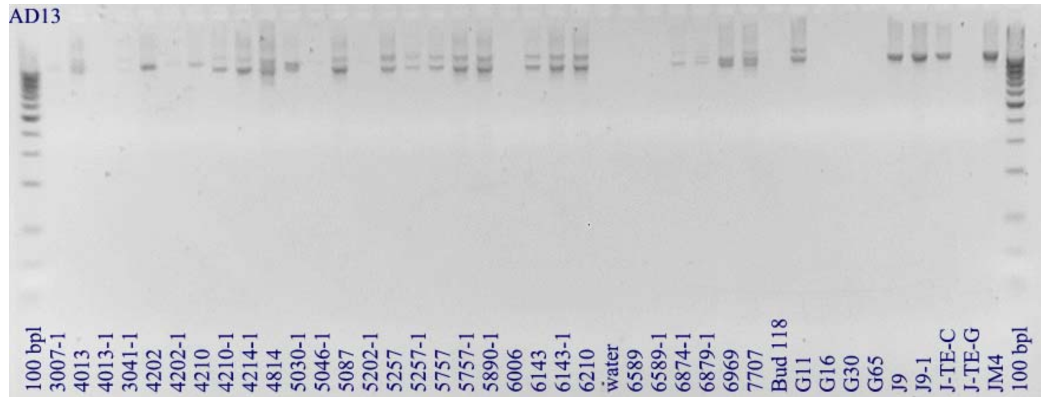
Breeding and Selection of Apple Rootstocks - Simplified



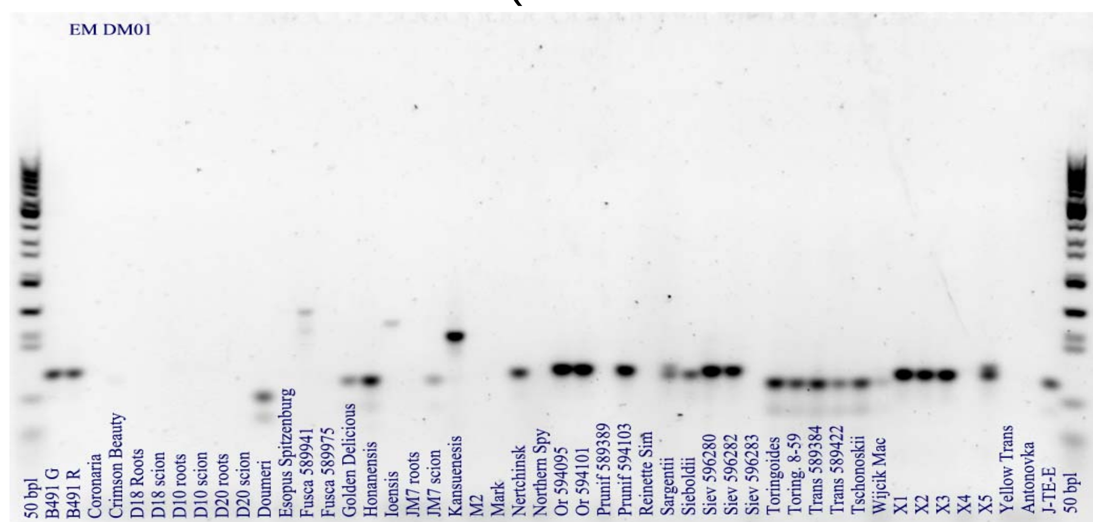
B. Johnson

Criteria for Parent Selection – Phenotype and Molecular Markers

- Dwarfing
- Precocity
- Disease Resistance
  - Fire Blight
  - Phytopthora
  - Powdery Mildew
  - Apple Scab
- Yield and Field Performance
- “New” Gene Pools



AD13 SCAR scab marker (Boudichevskaia et al. 2006)



EM M01 SCAR powdery mildew marker (Evans et al. 2003)

New Gene Pools at the Plant Genetic Resources Unit (PGRU) Geneva, New York

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

2808 wild *Malus* seedlings from 310 populations from Kazakhstan, Russia, China & Turkey

Malus sieversii from Kazakhstan 1989 - 1996

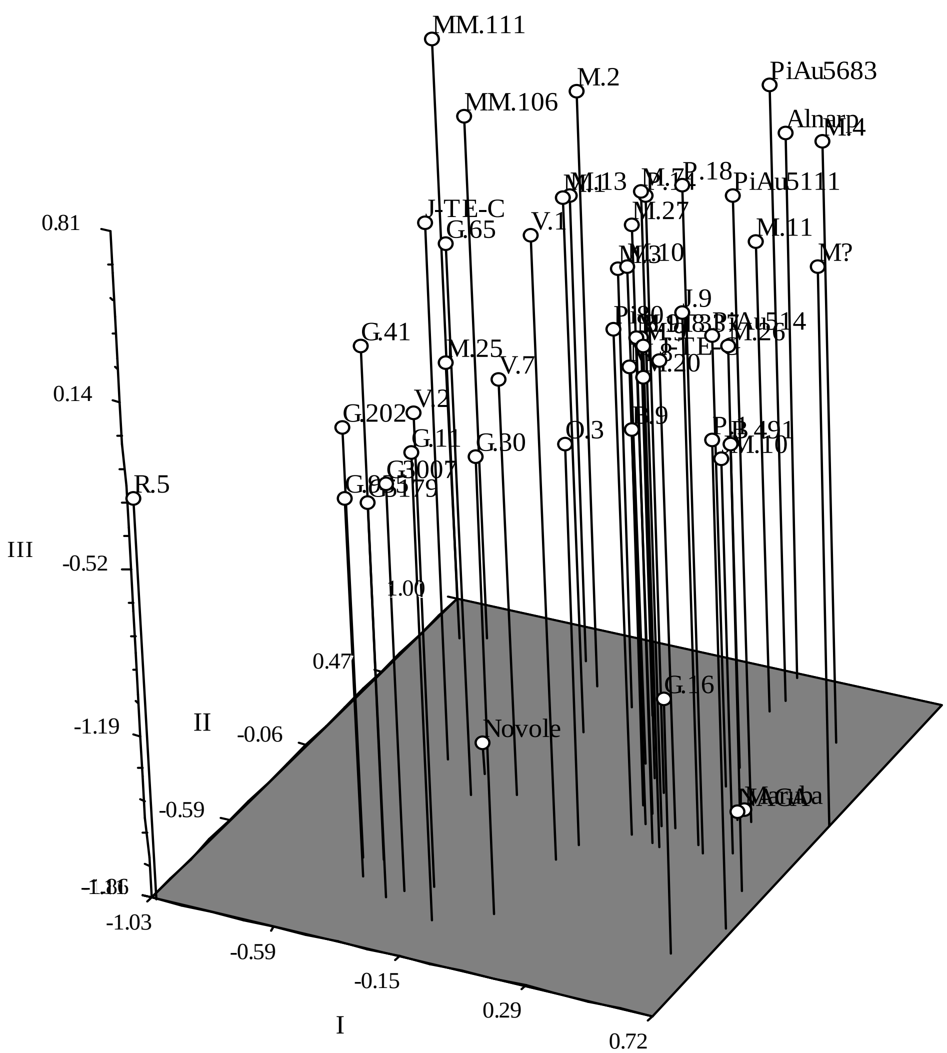
Site 9 w/ depletion by grazing animals

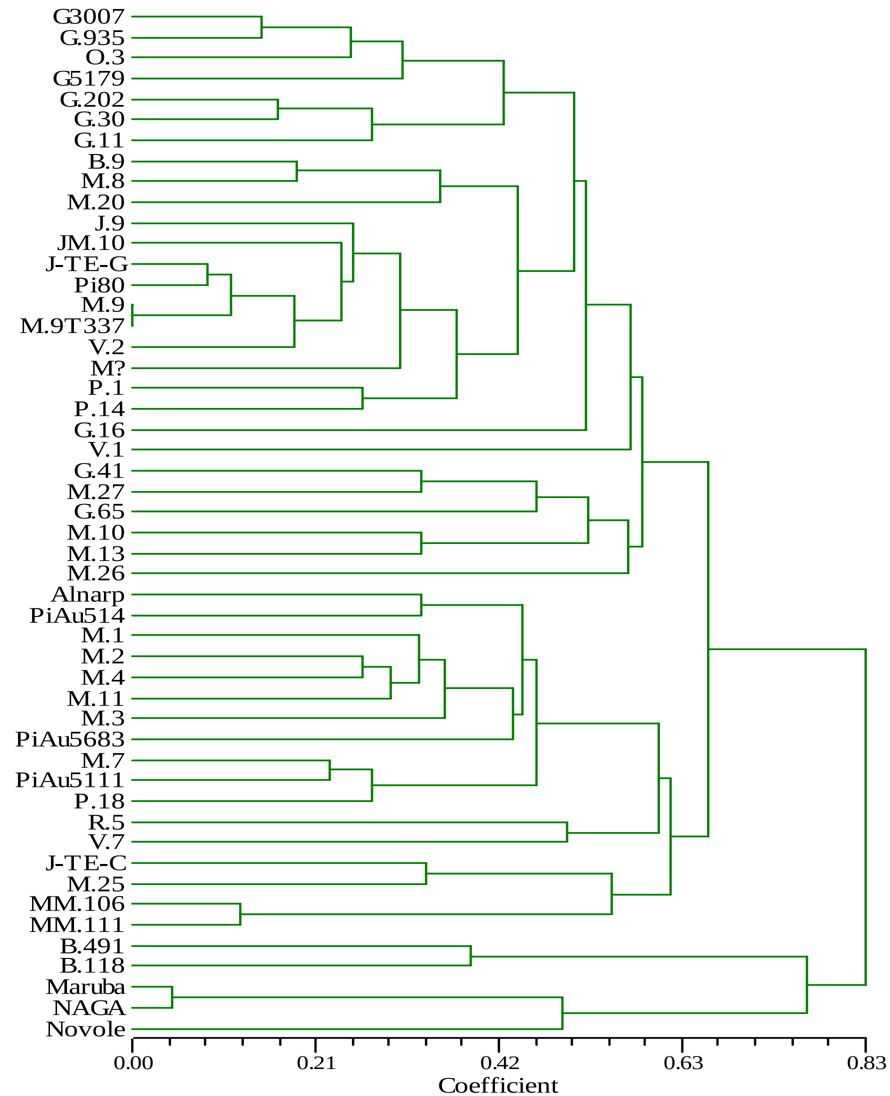
Site 6

Excellent apple-scab resistance from some sites

Site 5

Gene Pool Identification – Combining SSR, SCAR Markers





Crossing Parents – Stage 1

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Seed Harvest – Stage 1 – 2,000-10,000 seeds per cross

Disease Screens – Stage 1 – 3,000 to 10,000 seedlings/year

Disease Screens – Stage 1 – 3,000 to 10,000 seedlings/year

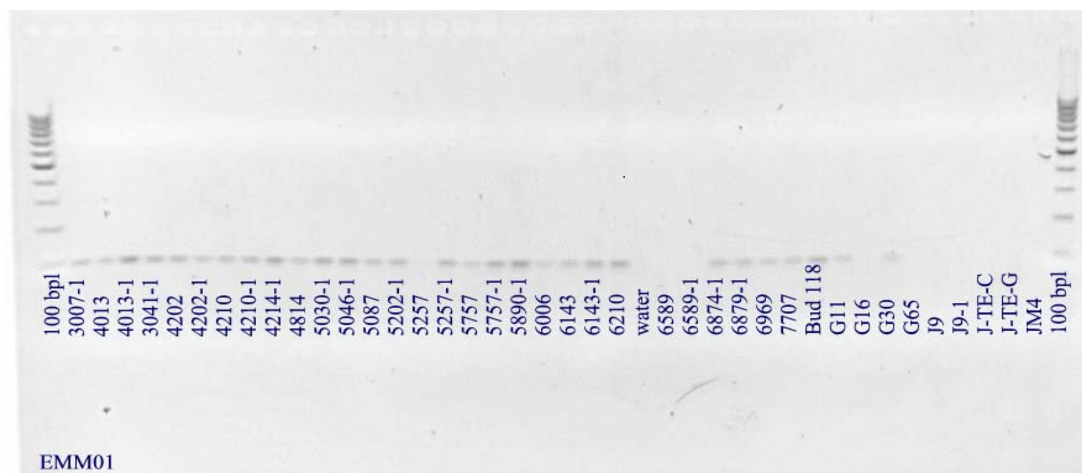
Fire blight - *Erwinia amylovora*

- Major disease for apple rootstocks in North America
- Bacterial disease with strain differentiation
- Resistance sources available
- Rootstock infection routes:
  - suckers
  - injuries
  - systemic movement of bacteria from scion

Fire Blight Screening – Stage 1
500 to 2,000 seedlings

Integration of Marker Assisted Selection – Stage 2

- High throughput PCR markers – SCARs, SSRs
- Target traits:
  - Dwarfing
  - Powdery mildew resistance
  - Scab resistance
  - Wooly apple aphid resistance
- Use published and “in house” markers



Propagation and Evaluation of Layering Stool-Bed Properties

Harvest of Rootstock Liners – Evaluation of Rooting

Rootstock Liners in Tree Nursery for Budding/Grafting

First Test Orchard – Stage 3

- 3-10 replicates per rootstock genotype
- 50-100 different genotype selections every year
- All grafted with same scion
- Evaluated for 8-12 years

Early field selection of precocious genotypes – Stage 4

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Expansion of Layering Beds to Increase Replications – Stage 4

Evaluation of Layering Stool Beds – Stage 5

Rootstock Liner Evaluation – Stage 5

Second Test for Resistance to Biotic Stresses – Stage 5

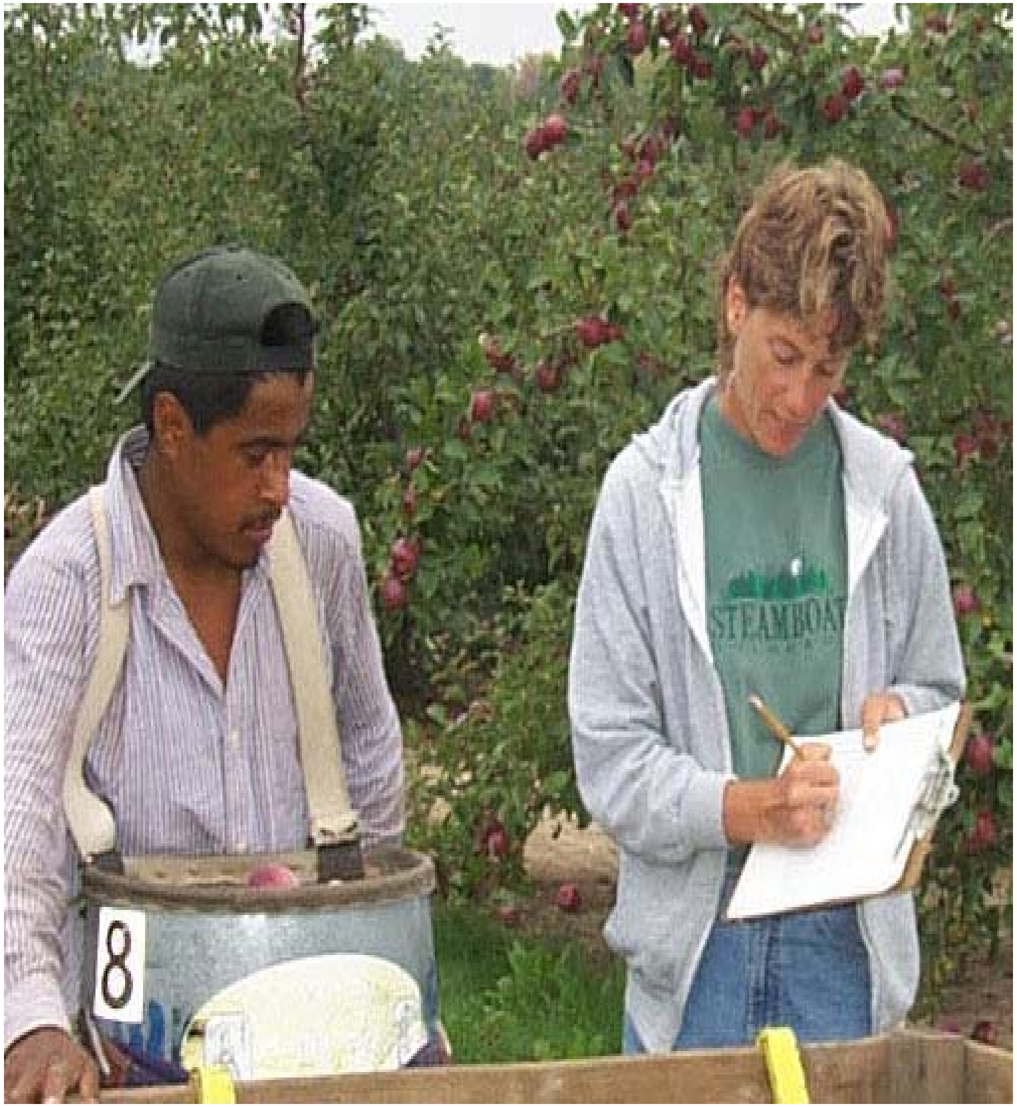
Fire Blight Inoculations with Multiple Strains

Inoculation with Wooly Apple Aphid (*Eriosoma lanigerum*)

Water Logging test with Phytophthora Inoculation

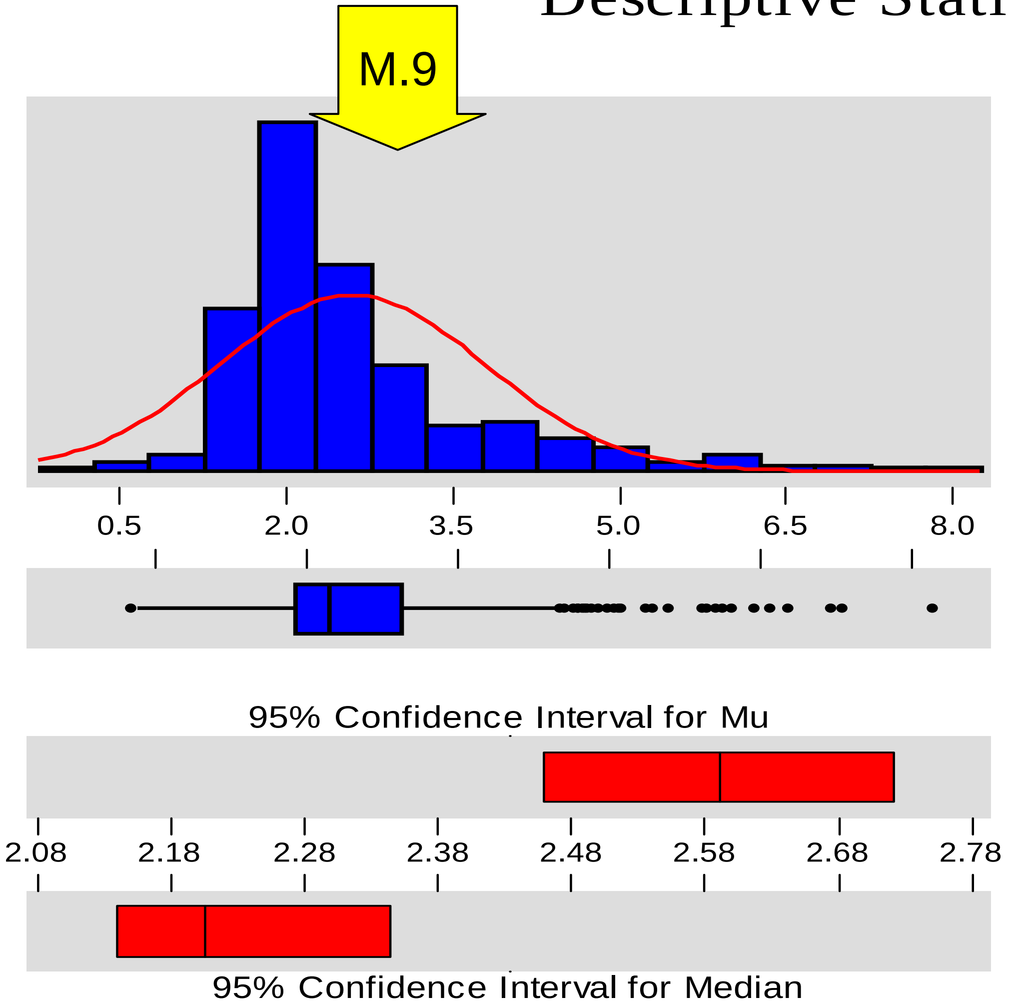
Replicated Orchard Trials in Multiple Locations – Stage 6

- Precocity
- Yield
- Fruit Size
- Dwarfing
- Tree Survival
- Disease Incidence
- Tree Architecture
- Burr Knots



Cumulative Yield Efficiency Measurements

Descriptive Statistics



Variable: CUM-YEFF

Anderson-Darling Normality Test

A-Squared:	17.106
P-Value:	0.000
Mean	2.59040
StDev	1.19212
Variance	1.42114
Skewness	1.75248
Kurtosis	3.70960
N	317
Minimum	0.24800
1st Quartile	1.87200
Median	2.20500
3rd Quartile	2.91550
Maximum	8.18500

95% Confidence Interval for Mu

2.45867	2.72214

95% Confidence Interval for Sigma

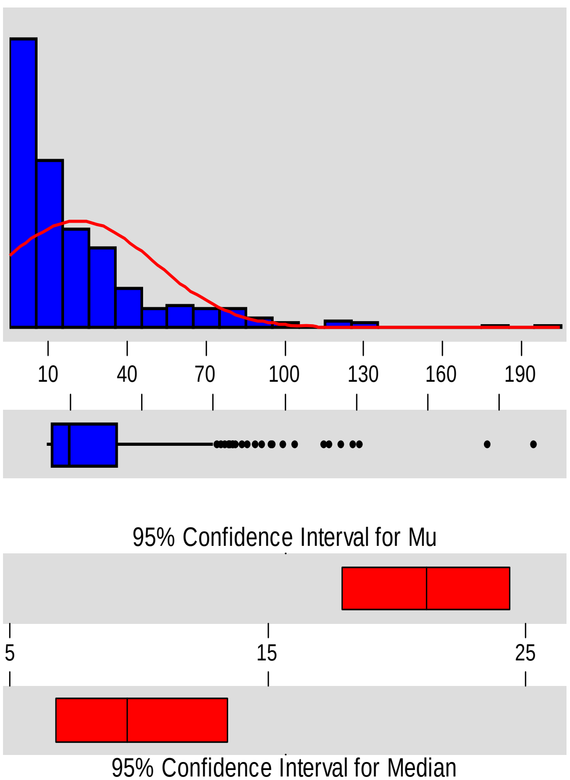
1.10598	1.29292

95% Confidence Interval for Median

2.13806	2.34268

Replicated Orchard Trials in Multiple Locations – Stage 6

Descriptive Statistics



Variable: Suckers

Anderson-Darling Normality Test

A-Squared:	27.087
P-Value:	0.000
Mean	21.1430
StDev	29.4424
Variance	866.858
Skewness	2.55072
Kurtosis	8.75868
N	317
Minimum	0.000
1st Quartile	2.000
Median	9.500
3rd Quartile	29.166
Maximum	204.000

95% Confidence Interval for Mu

17.889 24.397

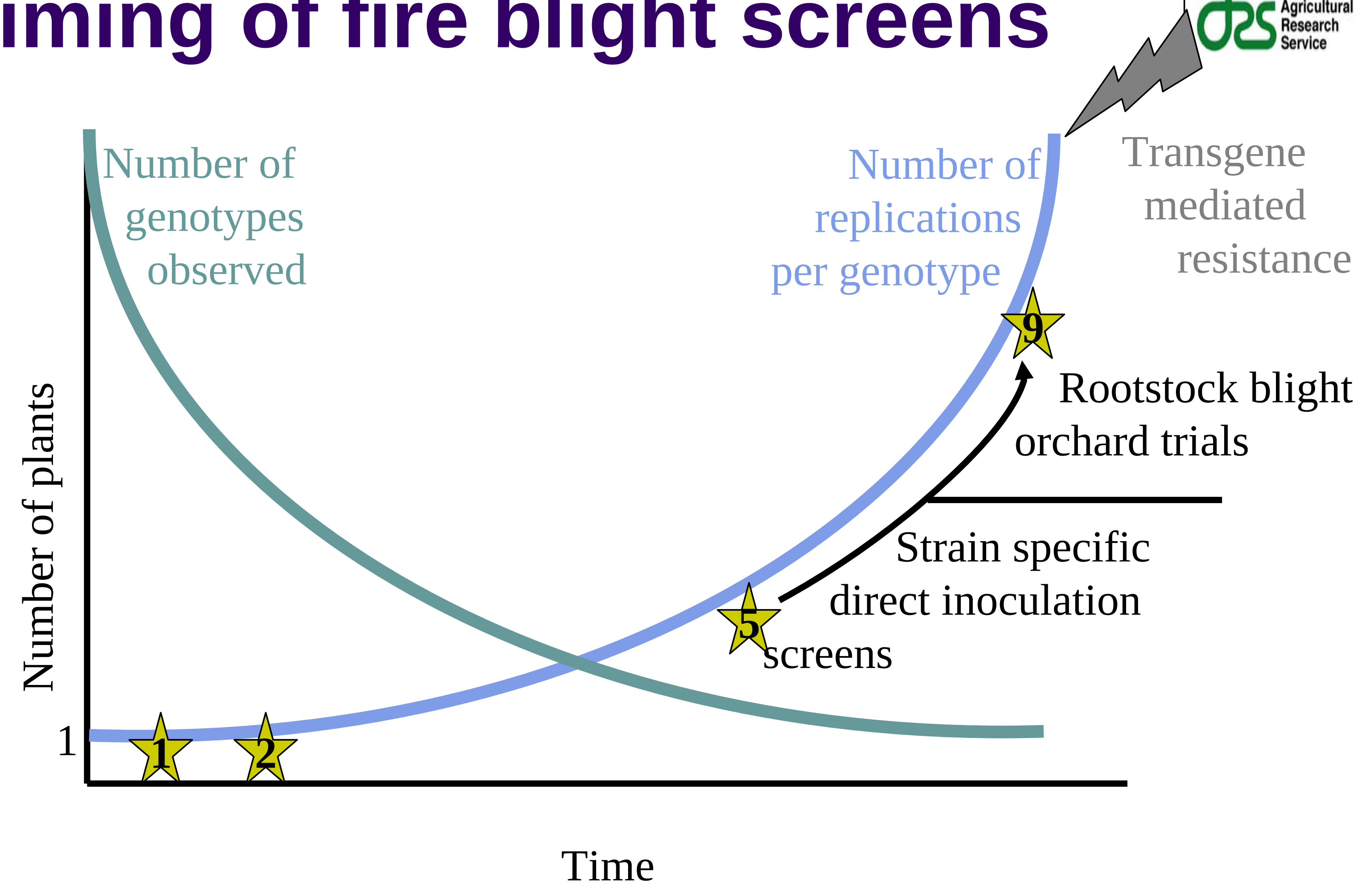
95% Confidence Interval for Sigma

27.315 31.932

95% Confidence Interval for Median

6.719 13.403

Timing of fire blight screens



Screening for Resistance to Fire Blight (*E. amylovora*)

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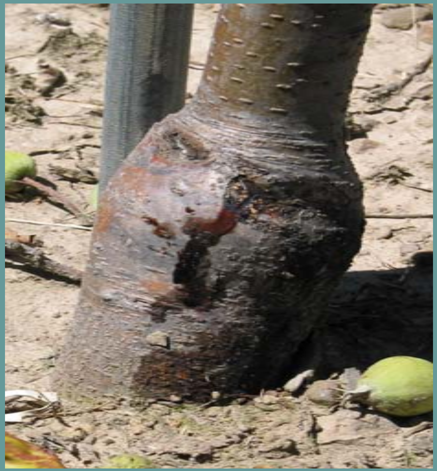
FIELD INOCULATIONS ON FINISHED TREES

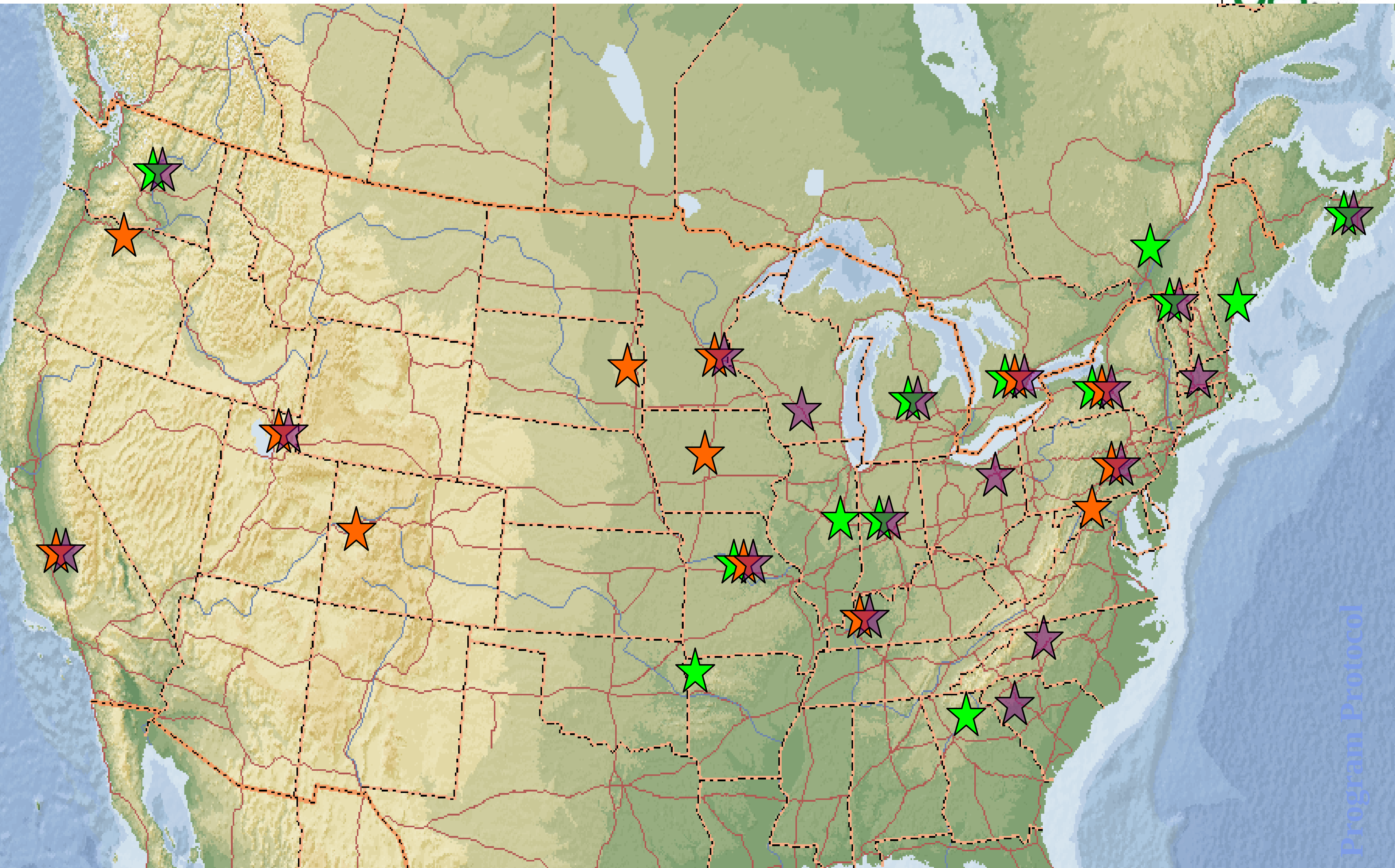
GREENHOUSE INOCULATIONS ON LINERS



Commercial Stool Bed Trials – Stage 7

- On site trials of elite rootstocks at commercial nursery locations
- Evaluate liner productivity and quality under commercial conditions
- Generates nursery stock for major orchard trials (NC-140, large grower trials)

Trials with NC-140 Cooperators – Stage 8



Drought Tolerance Tests

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Work of Dr. PARRA

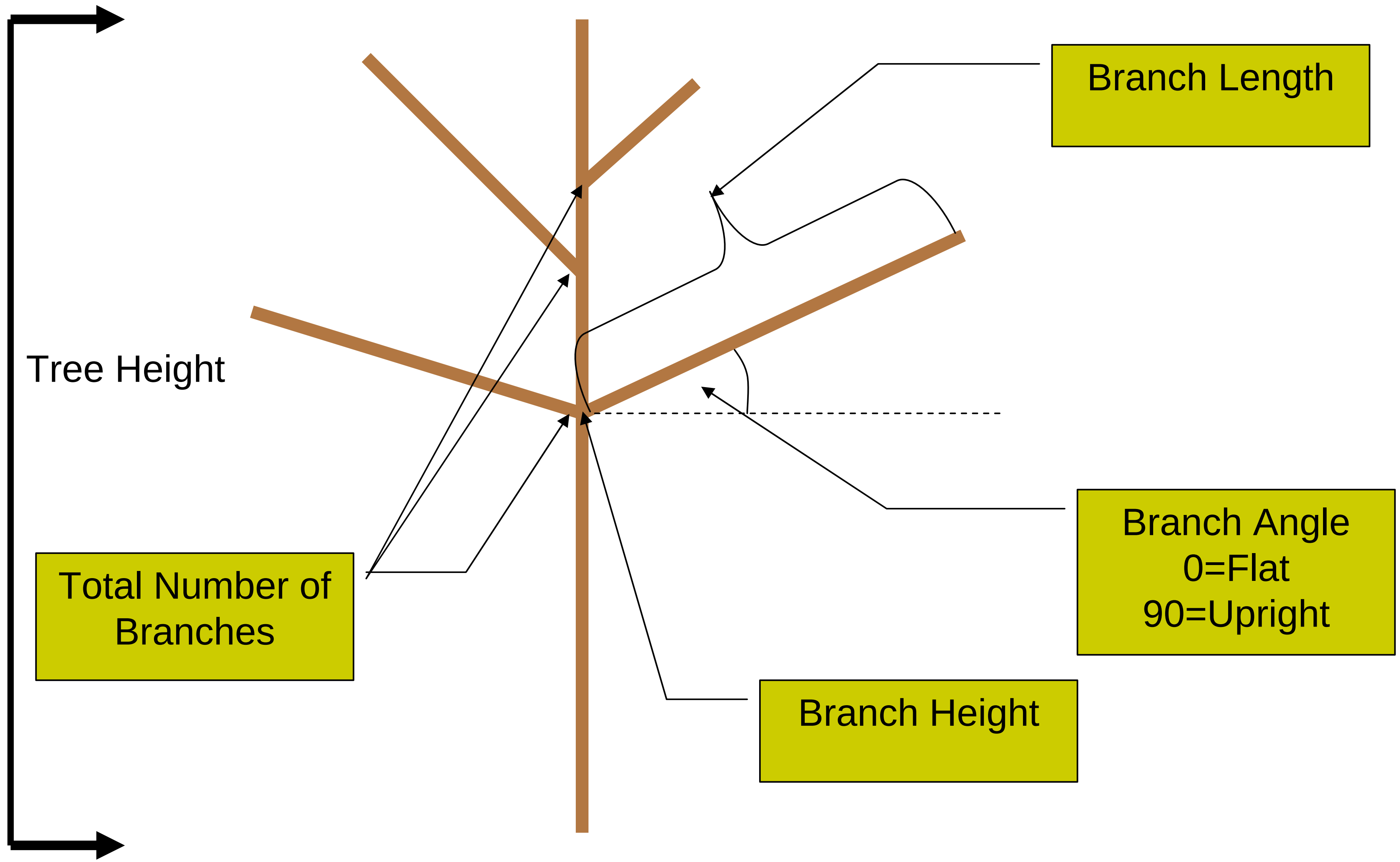
Graft Union Strength Tests

Pictures Courtesy of Mike Parker (NC State University)

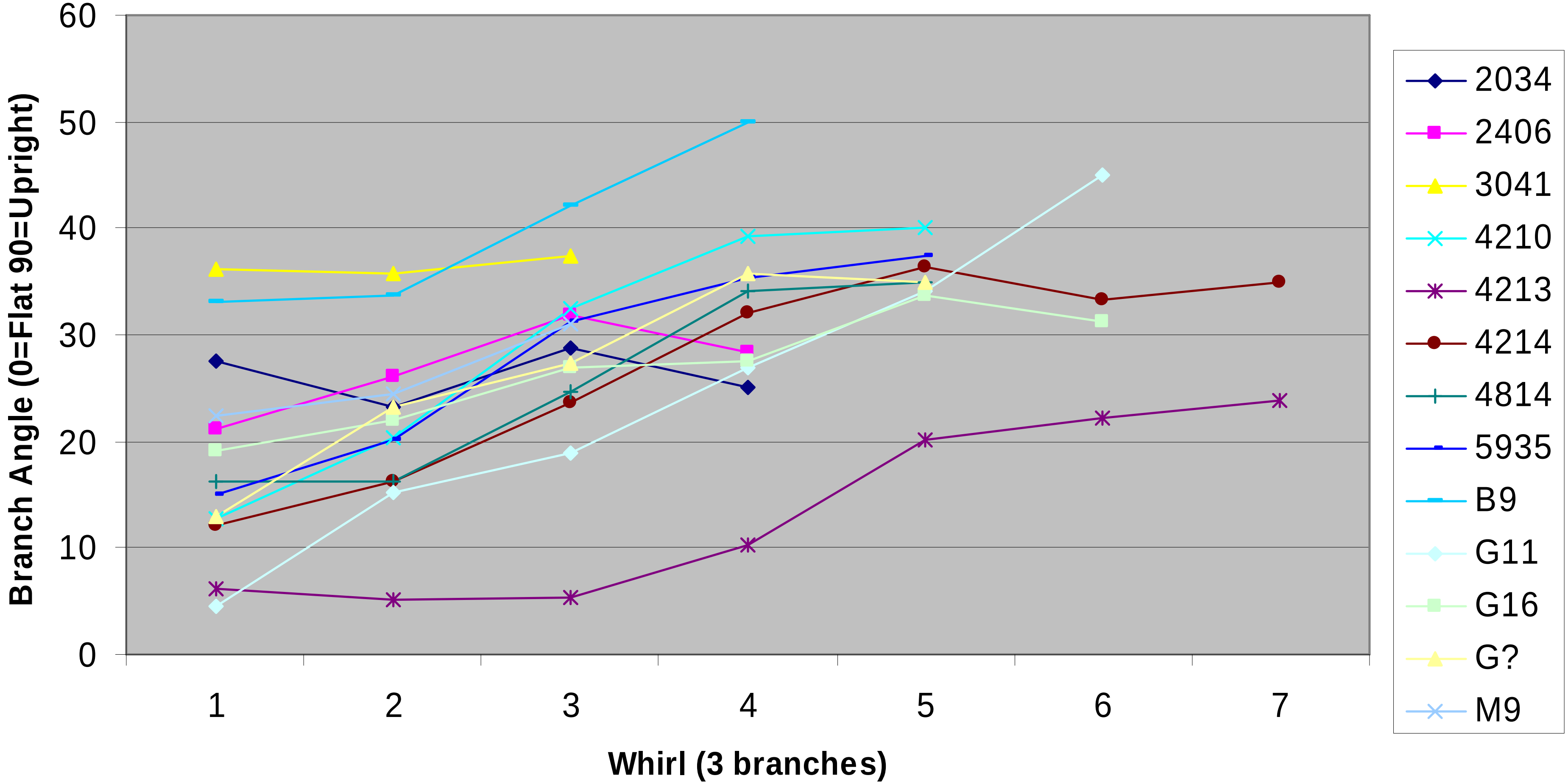
On Farm and Nursery Trials in Several U.S. Locations – Stage 9

- Large scale trials planted in WA, PA, MI, NY
- Trials include 20-45 different genotypes

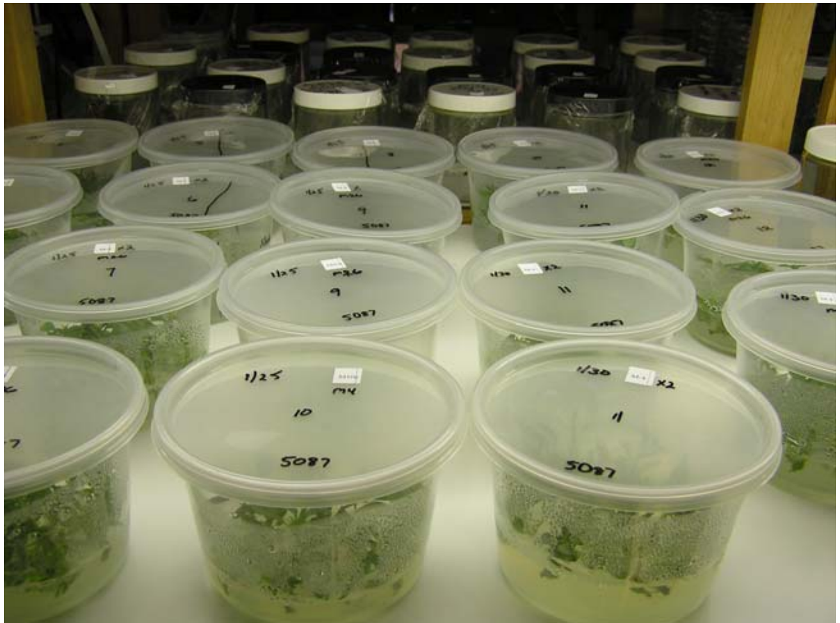
Nursery Tree Measurements on 10-15 Trees per Rootstocks



Branch Angles of Brookfield Gala Trees on Several Dwarfing Rootstocks for 7 Whirls



Stages of Micro-Propagation Prior to Release – Stage 10



Commercial Release and Continued Testing – Stage 10

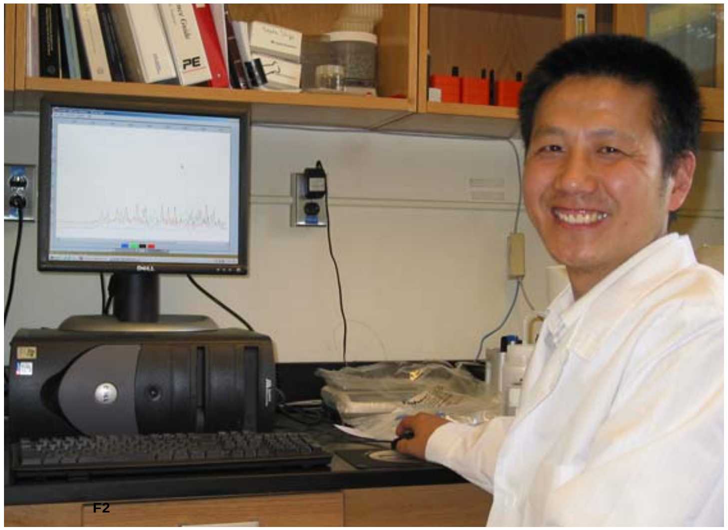
- Program has released 6 new rootstock genotypes to date.
- G.16 and G.30 G.202, G.41, G.935, G.11 are commercially available in U.S.
- Release decision for six more elite rootstock genotypes expected in 2008.

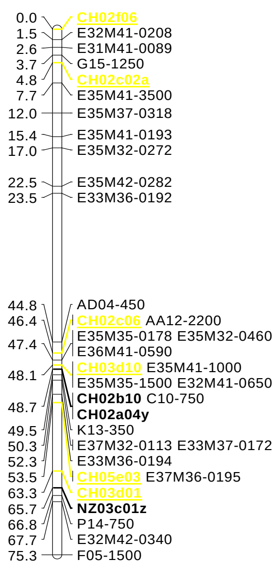
Large Scale Production of Rootstock Liners

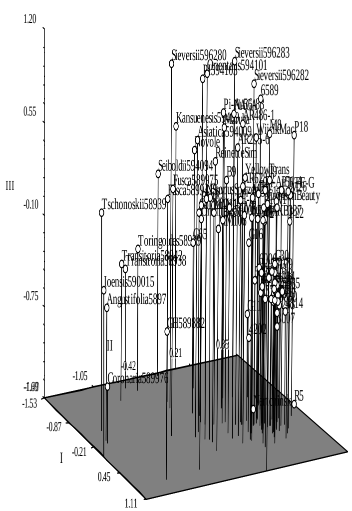
Production of High Quality Nursery Trees and Adoption By Growers

Nursery trees on Geneva 202 rootstocks and planted in high density orchard.

QTL Mapping of Apple Rootstock Yield & Disease Resistance Traits



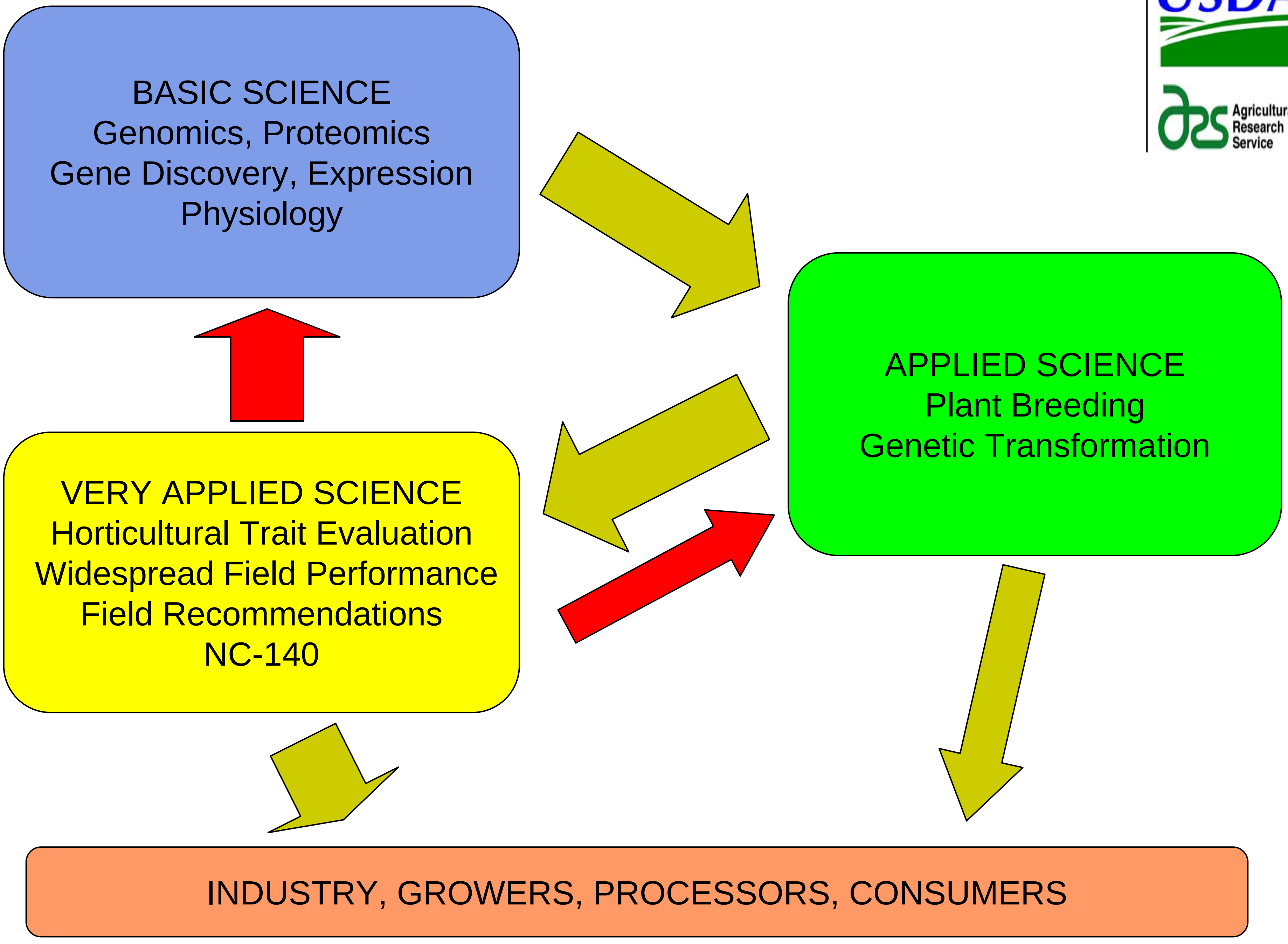




- Dr. Wan Yizhen
- Construct a molecular map of Apple Rootstock using microsatellites, SNP, SCAR.
- Map and develop markers for plant architecture and disease resistance traits.
- Develop basic knowledge on Chinese apomictic species for seed propagated rootstocks.
- Transgenic approaches for improving rootstock performance.

Research Work on Apple Rootstocks Requires Many Collaborators and Institutions

- Cornell University:
  - T. Robinson (Orchard Systems)
  - I. Merwin (Horticulture - Replant)
  - H. Aldwinckle (Plant Pathology)
  - L. Cheng (Physiology)
  - S. Brown (Scion Breeding)
- Michigan State University:
  - R. Perry (Rootstocks)
  - S. VanNocker (Genomics)
- Washington State University:
  - B. Barrit (Scion Breeding)
  - D. Main (BioInformatics)
- USDA ARS PGRU:
  - A. Baldo (BioInformatics)
  - P. Forsline (Apple Collection)
- USDA ARS AFRS Kearneysville:
  - J. Norelli (Transgenics)
  - C. Bassett (Stress Physiology)
- USDA ARS Wenatchee:
  - M. Mazzola (Plant Pathology)
  - Y. Zhu (Genomics)
- PENN State University:
  - T. McNellis (Genomics)
  - J. Schupp (Horticulture)
- Over 40 scientists as NC-140 collaborators
- Washington Tree Fruit Research Commission


BASIC SCIENCE
Genomics, Proteomics
Gene Discovery, Expression
Physiology
APPLIED SCIENCE
Plant Breeding
Genetic Transformation
VERY APPLIED SCIENCE
Horticultural Trait Evaluation
Widespread Field Performance
Field Recommendations
NC-140
INDUSTRY, GROWERS, PROCESSORS, CONSUMERS

Genomic Revolution

- We know that M.7 rootstock is less precocious than M.9. Do we know why?
- We know that M.9 dwarfs more than M.26? Do we know why?
- Through Genomics much is being discovered about how rootstocks do all that they do.
  - NSF funded project that aims to discover what genes are turned on and off in the apple scion by different rootstocks. (Dr. McNellis, Penn State)
- Tree architecture modified by apple rootstocks….
- Wealth of new genetic material

The Geneva® Apple Rootstock Breeding Program

Todd Holleran, Sarah Bauer, Yizhen Wan

Funding from IDFTA, WTFRC, USDA, Cornell

The Road Ahead (2003 NC-140 Mtgs. Door County, Wisconsin)