Plant and Site Selection
Genetics and the Environment
Plant and Site Selection
Genetics & Environment

• Matching crop or cultivar to the best site or the site to the crop or cultivar
• Determines degree of success or failure of a planting or farm enterprise
• With perennial crops, “fixed” factors have long-term effects
Types of Factors

• **Fixed factors:**
  – Regional and local climate
  – Soil characteristics
  – Plant characteristics
  – Planting design

• **Non-fixed (recurring) factors:**
  – Cultural practices
  – Chemical applications
  – Environmental modifications
  – Management skills
Site Modifications

- Inventory site characteristics
- Overlay spatial & temporal characteristics
- Determine limiting factors
- Prioritize limiting factors
- Modify or adapt to limiting factors
Center of Origin

• Apple (*Malus x domestica*)
  – *M. sieversii* from Tien Shan mountain range on border between China, Kazakhstan, Kyrgyzstan, and Tajikistan to Caspian Sea – ancestor of dessert apples
  – *M. silvestris* from region near Lake Constance, Switzerland – ancestor of cider apples
Malus sieversii
Kazakhstan

Latitude 48°N with continental climate
(semi-arid to arid with cold winters & hot summers)
Lake Constance
Latitude 48°N with Mediterranean climate
(dry with moderate summers & winters)

Ancient apple-growing history

Glacial & volcanic soils

Modern apple orchards
Marker-Assisted Selection

Apple Traits

• Dwarfing rootstocks
  – Hydraulic conductivity
  – Hormone translocation
  – Graft union anatomy

• Precocious scions
  – Weakly associated with dwarfing

• Diseases
  – Apple scab (*Venturia inaequalis*)
  – Fire blight (*Erwinia amylovora*)
  – Replant (*Cylindrocarpon destructans, Phytophthora cactorum, Rhizoctonia solani, Pythium spp.*)
Genomics

- Apple EST Project
- International Grape Genomics Program
- Genome Database for Rosaceae
  [http://www.mainlab.clemson.edu/gdr/](http://www.mainlab.clemson.edu/gdr/)
Climatic Requirements

Temperate-zone fruit crops

- Winter temperatures must not be so cold that plants or crop are killed
- Winters must not be so warm that buds get inadequate chilling to break winter rest (endodormancy)
- Growing season must be long enough to mature the crop
- Climatic conditions during the growing season must be adequate for the crop to develop good quality fruit

Westwood, 1993
Winter Freeze Injury

- Average annual minimum temperatures (USDA Hardiness Zones)
- Average daily minimum temperature of coldest month
- Coldest recorded temperature
- Days with average daily minimum $\geq 0^\circ C$
- Days with average daily minimum $\geq 0^\circ C$ in Jan. & Feb.
USDA Plant Hardiness Zones

http://www.usna.usda.gov/Hardzone/hzm-nw1.html
Climate Diagrams

Precip curve

OLYMPIA (21m) 10.5 1301

Mean daily min temp of coldest month

Min temp < 0°C

Coldest temp

>100 mm/month precip

Temp curve

YAKIMA (326m) 10.3 208

(35–36) Wash.

Arid

Avg min temp < 0°C

Hamilton, 1986
Chilling Requirements

‘Stella’ sweet cherry
CU=0.87+0.079T-0.012T^2

Growing Season

- Days from last spring frost to first fall frost (frost-free days)
- Days after full bloom
- Growing degree hours for spring bud development ($\text{GDH}^{\circ}\text{C} = 1 \text{ hr per } 1^{\circ}\text{C} > 4.5^{\circ}\text{C}$)
- Accumulated heat units for harvest maturity
Figure 12-4. The relationship of the number of accumulated heat units during 36 days after full bloom to the days required from full bloom to mature Bartlett pear fruit. The warmer the postbloom period, the shorter the time to maturity. [After Lombard et al. 1971.]
Terrôir

- Vineyard’s specific combination of geography, climate & soil characteristics
- Differences in wines made from same variety, region, production practices, harvest maturity, or winemaking process
- “Fingerprinting” of chemical elements
Site Characteristics
Washington Viticulture Appellations

- GDD (≥50°F) >2000°
- Long day length during growing season
- Sites with good air and water drainage
- Soil moisture deficit during growing season
- Soils from Quaternary-age sediments
Soils

- Mollisols
- Aridisols & Entisols
- Inceptisols & others
- Ultisols
- Spodosols & Andisols
- Mollisols
- Aridisols & Entisols
Climate Factors
Wine Grape Quality

- Air & soil temperatures
- Continentality & temperature variability
- Amount & quality of sunlight
- Rainfall & distribution
- Relative humidity & vapor pressure deficit
- Windiness
- Weather during ripening period

Gladstones, 1992
Mean Annual Precipitation
## Wine Grape Maturity Groups

<table>
<thead>
<tr>
<th>Group</th>
<th>GDD</th>
<th>Red wine</th>
<th>White wine</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>1150</td>
<td>Pinot Noir</td>
<td>Chardonnay</td>
</tr>
<tr>
<td>4</td>
<td>1200</td>
<td>Zinfandel</td>
<td>Riesling</td>
</tr>
<tr>
<td>5</td>
<td>1250</td>
<td>Merlot</td>
<td>Chenin Blanc</td>
</tr>
<tr>
<td>6</td>
<td>1300</td>
<td>Cabernet Sauvignon</td>
<td>Grenache</td>
</tr>
</tbody>
</table>

GDD: growing-degree days

Gladstones (Table 5), 1992
Growing Degree Days
Washington State


- Yakima Valley (Prosser)
- Walla Walla (Benton City)
- Red Mountain (Patterson)
- Horse Heaven Hills (Matawa)
- Wahluke Slope (Wenatchee)
Temperature & Sunlight
Growing Season

Gladstones (Figure 2), 1992
## Ideal Ripening Weather

Table wine types during final month

<table>
<thead>
<tr>
<th>Climate factor</th>
<th>Light</th>
<th>Medium</th>
<th>Full</th>
<th>Walla Walla (Sept.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean temp (°C)</td>
<td>15-18</td>
<td>18-21</td>
<td>21-24</td>
<td>18</td>
</tr>
<tr>
<td>Sunshine (hrs)</td>
<td>&gt;210</td>
<td>&gt;240</td>
<td>&gt;240</td>
<td>267</td>
</tr>
<tr>
<td>Rain (mm)</td>
<td>&lt;75</td>
<td>&lt;75</td>
<td>&lt;75</td>
<td>23</td>
</tr>
<tr>
<td>Early eve %RH</td>
<td>55-60</td>
<td>50-55</td>
<td>50-55</td>
<td>41</td>
</tr>
<tr>
<td>TVI</td>
<td>&lt;34</td>
<td>&lt;38</td>
<td>&lt;38</td>
<td>41</td>
</tr>
<tr>
<td>Highest max temp (°C)</td>
<td>&lt;30</td>
<td>&lt;33</td>
<td>&lt;36</td>
<td>33</td>
</tr>
</tbody>
</table>

RH: relative humidity; TVI: temperature variability index

Gladstones (Table 3), 1992
Washington AVAs, 2005
Marketing Terrôir

- Horse Heaven Hills (proposed)
- Lake Chelan (in discussion)
- Columbia Cascade (in discussion)
- Columbia Gorge
- Rattlesnake Hills (proposed)
- Wahluke
- Horse Heaven Hills (proposed)
Economic Realities

The apple variety life cycle.

Apple Variety Price Cycle

The apple variety price cycle showing the position of four varieties in the late 1990s.

Barritt, 1999
## Commercialization of Apple Cultivars

<table>
<thead>
<tr>
<th>Cultivar</th>
<th>Commercial (yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delicious</td>
<td>&gt;50</td>
</tr>
<tr>
<td>Golden Delicious</td>
<td>&gt;50</td>
</tr>
<tr>
<td>Granny Smith</td>
<td>&gt;50</td>
</tr>
<tr>
<td>Braeburn (1952)</td>
<td>30 (New Zealand)</td>
</tr>
<tr>
<td>Gala (1960)</td>
<td>20 (New Zealand)</td>
</tr>
<tr>
<td>Fuji (1962)</td>
<td>20 (Japan)</td>
</tr>
<tr>
<td>Jonagold (1968)</td>
<td>20 (Europe)</td>
</tr>
<tr>
<td>Pink Lady (1985)</td>
<td>10 (Australia)</td>
</tr>
</tbody>
</table>
Genotype

- All genes possessed by an individual organism within its chromosomes
- Relatively stable, except for occasional gene mutations
- Some genes are not expressed until organism reaches a certain stage of development
Phenotype

- Any measurable or observable characteristic possessed by an organism
- Specific expression of a gene (trait)
- Collective sum of all traits of an organism
Genetics x Environment Interaction

- Phenotype is a function of an interaction between genotype and environment \((G \times E)\)
- No single genotype will be optimal in all environments, which vary in both space and time
- Natural selection is the process by which the environment culls out sub-optimal genotypes
Phenotypic Variation

• Ability of an organism to reversibly modify its phenotype is called phenotypic plasticity and is measured as phenotypic variation.

• Complete analysis requires “mapping” genotypes into phenotypes expressed in different environments.
No Phenotypic Plasticity

Environment (depth of soil water)

Rooting depth

Optimum adaptability

G1

G2
Optimum Adaptive Plasticity

Environment (depth of soil water)

Rooting depth

Optimum adaptability

G1

G2
Experimental Approaches

• **Gradient:**
  Vary a few environmental variables under controlled conditions

• **Reciprocal transplant:**
  Plant all genotypes in a range of environments that vary in many aspects
Analyzing Phenotypic Variation

• Variation among genotypes (G)
• Variation among environments (E)
• Variation among both genotypes & environments (G x E)
Genotype X Environment Interaction

Environment (depth of soil water)

Rooting depth

Optimum adaptability

G1

G2
Analyzing G x E Interactions

• Used to select genotypes:
  – Better adapted to a specific location
  – More stable in a range of locations

• Stability:
  – Low variation of a particular trait when measured over numerous locations and/or years

• Statistical methods are used to calculate stability indices
Calculating Stability Index

• Regression analysis of reciprocal transplant experiment

• Two variables are plotted:
  – Measure of the environment at each location is called environmental or site index (= average performance of all genotypes at each site)
  – Phenotypic response of each genotype at each site

• Phenotypic response of each genotype at each site is “regressed” against its respective site index
Stability Index

- Slope of linear regression line (regression coefficient) is the stability index
- The point where the average site index crosses each genotype’s linear regression line is the average performance of that genotype for that trait
Apple Rootstock Trial

- Three rootstocks - M.7 EMLA, M.9 EMLA, M.9 (EMLA = East Malling-Long Ashton, M = Malling)
- ‘Starkspur Supreme Delicious’ trees planted in 1980-81 in replicated plots in 27 sites across N. America
- Performance evaluated for 10 years
- Stability indices calculated by linear regression
<table>
<thead>
<tr>
<th>Site (state)</th>
<th>Mean YE</th>
<th>M.9</th>
<th>M.9 EMLA</th>
</tr>
</thead>
<tbody>
<tr>
<td>CA</td>
<td>5.5</td>
<td>7.2</td>
<td>3.8</td>
</tr>
<tr>
<td>MA</td>
<td>5.2</td>
<td>5.5</td>
<td>6.8</td>
</tr>
<tr>
<td>OR</td>
<td>3.8</td>
<td>4.1</td>
<td>3.9</td>
</tr>
<tr>
<td>OH</td>
<td>3.5</td>
<td>14.3</td>
<td>4.2</td>
</tr>
<tr>
<td>MI</td>
<td>2.1</td>
<td>2.9</td>
<td>2.8</td>
</tr>
<tr>
<td>WA</td>
<td>1.9</td>
<td>1.9</td>
<td>2.3</td>
</tr>
<tr>
<td>PA</td>
<td>1.8</td>
<td>1.6</td>
<td>3.8</td>
</tr>
</tbody>
</table>

YE = Yield efficiency (kg fruit per cm² trunk cross-sectional area)
Cumulative Yield Efficiency (kg/cm² TCSA)

Genotype response vs. (kg/cm² TCSA) Environmental Index

Grand site mean

M.9
M.9 EMLA
M.7 EMLA
Summary

• Cumulative yield
  – M.9 EMLA and M.9 trees had higher cumulative yields than M.7 EMLA, but only in the very poorest environments

• Tree size
  – M.9 trees were larger than M.9 EMLA trees, but only in the poorest environments

• Yield efficiency
  – M.7 EMLA trees had the lowest yield efficiency across all environments
  – M.7 EMLA and M.9 EMLA trees had more stable yield efficiencies than M.9 trees
  – M.9 EMLA trees had the highest yield efficiency in poor environments, but M.9 trees had the highest yield efficiency in better environments
Conclusions

• Some genotypes are less “stable” - they may perform better in good environments and worse in poor environments, or vice versa
• Some genotypes are more “stable” - they may perform poorly in all environments or good in all environments
Questions

• What aspects of the environment account for differences in the performance of genotypes?
• How might those aspects of the environment be identified?
• How might those identifiable environmental factors affect genotype performance?
Cultivar Growth Evaluation

International Apple Growth Study

- Multi-national cooperative study evaluating apple growth responses to climate and environment (Italy, New Zealand, UK & 6 US sites) representing:
  - 18° latitude
  - 50+ days difference in growing season
  - Differences in sunlight, temperatures, rainfall, and relative humidity
  - Standard cultivar (‘Jonagold’), rootstock (M.9 EMLA), tree density, and pollinizer placement

International Apple Growth Study

Jonagold/M.9 planted 1991/92

TCSA (cm²)

Years from planting

Italy
New Zealand
New York
Washington

Tustin et al., 1997
Rootstock Evaluation

NC-140 Apple Cultivar/Rootstock Project

• Compare growth & productivity of up to 10 cultivars growing on up to 7 rootstocks across 6 sites (IA, IN, KY, ME, PA, VA) planted in 1990

• Consistently, Mark was the most efficient rootstock across sites, with M.9 EMLA intermediate and M.26 EMLA least efficient

NC-140 Apple Cultivar/Rootstock Study

Yield efficiency* (kg/cm² TCSA)

- Iowa
- Kentucky
- Maine
- Pennsylvania
- Virginia

Up to 10 cultivars planted in 1990

M.9 EMLA
M.26 EMLA
Mark

*Cumulative YE, 1992-1999

Hirst et al., 2001
Wine Grape Cultivar Evaluation
British Columbia

Aroma
- Riesling
- Fontanara

Flavor
- Floral
- Spicy
- Diesel
- Citrus
- Apple
- Vegetal
- Peach

Reynolds et al., 2004