Hop Botany, Cultivation, and Breeding

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Hop Botany, Cultivation, and Breeding

- Importance of hops.
- Basic botanical information.
- Crop development and cultivation.
- Impact of hop varieties.
- Variety development.

The Importance of Hops

Regional Economic Importance

- U.S. Production centered in the PNW.
  - 77% in WA.
  - 16% in OR.
  - 7% in ID.
- 2008 value (US) = $319.8 million
- Annually Top 12 in crop value for Washington

Humulus spp. Overview

- Family: *Cannabaceae*
  - *Cannabis*
    - *C. sativa*
  - *Humulus*
    - *H. lupulus*
    - *H. japonicus*
    - *H. yunnanensis*

(Neve 1991)

Humulus lupulus

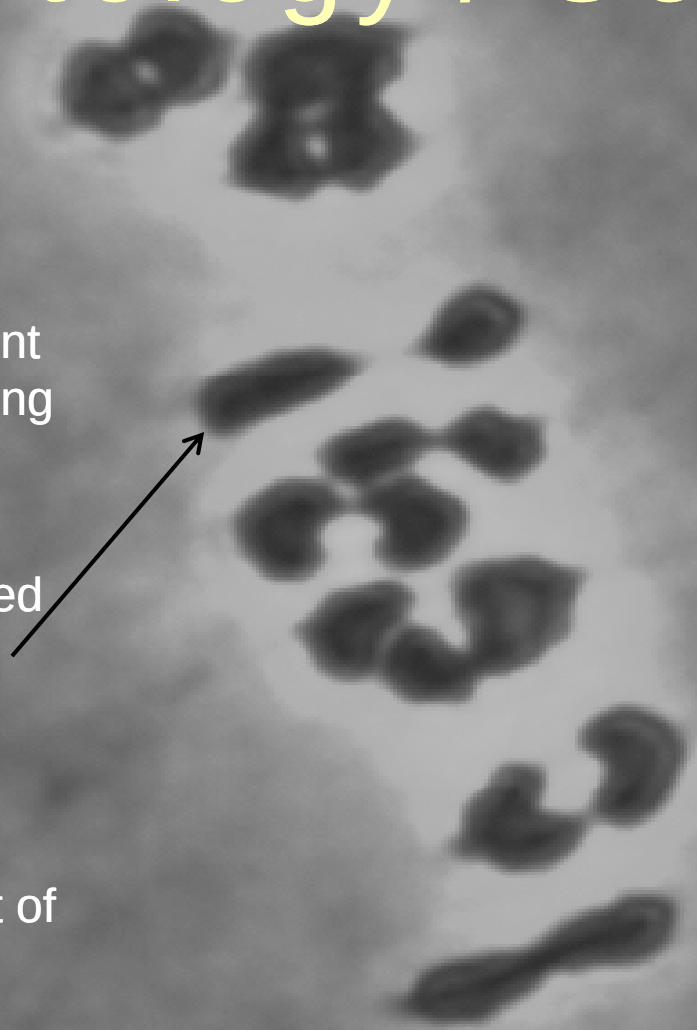
- “Hops”
- Dioecious, perennial, climbing vine
- Indigenous to the Northern Hemisphere
  - Origins in Europe:
    - *H. lupulus* var. *lupulus*
  - Origins in Asia (mainly Japan):
    - *H. lupulus* var. *cordifolius*
  - Origins in North America:
    - *H. lupulus* var. *pubescens*
    - *H. lupulus* var. *neomexicanus*
    - *H. lupulus* var. *lupuloides*

Hop Basics

- Genetically complex.
- Annual above ground.
- Perennial below.
  - Allows for clonal propagation.
- Climbing vine requiring a support system.
- Photoperiod sensitive
- Dioecious (male and female plants).
  - Male-no commercial value
  - Female-Produces the valued strobiles, “cones”

Hop Cytology / Genetics

- 2n = 2x = 20
  - Variation in chromosome morphology
  - Normal bivalent formation during meiosis
- Dioecious
  - Sex determined by X any Y Chromosome interaction
- Out Crossing
  - Large amount of variation



Is it an annual or a perennial?

- The above ground portion of the stem is annual.
  - Dies off at dormancy.
- The root is perennial, can survive low winter temps.
  - Requires a dormant period.
- The plant also produces rhizomes (below ground stems).
  - Buds become new spring growth.
  - Easily propagated from cuttings.

Clonal Propagation

- Propagation of hops purely vegetative
  - Root cuttings
  - Layering
  - Softwood cuttings
- Resulting plants genetically identical to parent material

Climbing Vines

- In the wild-usually found climbing on companion species.
  - In cultivation, trellis is used.
  - Typical Field Setup:
    - Trellis 18’ high
    - Plant spacing at 3.5’ x 14’ or 7’ x 7’.
      - Result is 889 plants per acre
    - Anchored twine is used to support plant growth.
  - Alternative systems: several variations, low trellis
- The vine wraps clockwise around string.
  - Function of phototropism and thigmotropism (Light and Touch).
- Rapid growth: The hop plant will grow a foot or more a day under ideal conditions. 18-25’ in a season.

Dioecious Plants

- Separate male and female plants
- Commercial value derived from the strobiles or “cones” of the female plant
- Male plants utilized only for hybridization
- Pollination results in:
  - Unwanted seeds
  - Increased cone size

Male and Female Inflorescence

The “Cones”

- These are the manufacturing unit of the commercial hop plant.
  - The cones contain lupulin glands (actually modified vine hairs).
  - These glands contain the chemistry we are after:
    - Essential oils: well over 100 compounds, contribution to aroma.
    - Soft resins: beta acids, and the all important alpha acids.
  - Lupulin accounts for 20 – 30 % of cone weight.

Lupulin Glands

Mature Female “Cones”

Male flowers at anthesis

Developmental Physiology of the Hop Plant (or Production Stages)

- The hop plant goes through numerous stages of growth throughout the year.
  - Each stage has its own unique characteristics.
  - Therefore each stage of growth requires its own unique management scheme.
- Main Stages of Growth
  - Dormancy
  - Spring regrowth
  - Vegetative Growth
  - Reproductive Growth
  - Preparation for Dormancy

Dormancy: October through February

- October through February:
  - Late summer the plant allocates photosynthetically derived starches to storage roots
  - The starch is converted into soluble sugars.
  - These sugars are the energy needed to commence spring regrowth.

Dormancy: October through February

- What's going on in the field? Not a whole lot.
  - Compost applications.
  - Working the ground.
  - Prepping new yards.

Spring Regrowth March through May

- The end of dormancy is signaled by increasing day length and increasing temperatures in the spring.
  - The plant utilizes the soluble sugars as energy to emerge from dormancy and commence regrowth.
  - The initial regrowth occurs rapidly producing vines unsuitable for crop production.
  - The plant relies on the energy reserves of the root until the end of May, at which time the starches and soluble sugars reach their lowest points of the year.
  - To maximize plant health, supplemental nutrient management will be needed.

Spring Regrowth March through May

- What's happening in the field?
  - Spring pruning- March-April
    - Effort to maximize consistency for training
  - Weed control
  - Applications of dry fertilizer
  - Twining
  - Training- one of the most important aspects of crop production.
    - Timing is varietal specific and critical.
    - Generally target 3 vines per string.
  - Irrigation begins

Photoperiod Sensitive

- Hops are a short day plant.
  - Under a critical number of light hours (more accurately it is the length of the dark period)-floral initiation.
  - Also node dependant.
  - Over the critical amount, vegetative growth.
  - In shorter day areas, flowering occurs as soon as the node requirement in met-yield not maximized.
  - In longer day areas-vegetative growth is maximized prior to shortening days of mid to late summer.

Vegetative Growth

- The vegetative growth stage, for the purposes of crop production, occurs from the end of May through the end of July.
- It can be separated into two phases:
  - 1. From May to the end of June/early July: Plant growth is mainly found in the main vine and leaves.
  - 2. July: The bulk of the above ground growth occurs in lateral production.

Vegetative Growth

- What is happening to the vine during vegetative growth?
  - At 3’ of growth the apical bud already contains the initial cells for numerous laterals.
  - At 12’ the apical buds of the vine and the laterals have produced cells predetermined for flowering branches.
  - At 16’ The cone branches have been fully determined in the laterals.

Vegetative Growth

- This is a critical period:
  - The plants reserves are used up.
  - The plant, even now, is already determining how much it is going to yield.
    - We need to manage plant health aggressively during this stage of growth.
    - The goal should be to maximize the health of the plant, while managing growth-this is tricky.

Vegetative Growth

- The importance of controlled growth:
- Internode length (the distance between lateral producing nodes on the vine) plays a key role in crop development.
- Too long of internodes results in less laterals and a brushy top crop.
- Shorter internodes results in the maximization of lateral number and more even distribution of the crop.
- How does one control growth:
  - Proper training
  - Proper nutrient management
  - Unfortunately, we cannot control the weather.

Vegetative Growth

- What's Happening in the field?
  - Monitor, monitor, monitor.
  - Pest/Disease/Weed control
  - Irrigation
  - Fertility

Reproductive Growth

- By the end of July floral production has commenced.
  - The plant shifts its growth energy into production of cones.
  - Vegetative production is greatly diminished.
  - Photosynthetic capacity of the plant is maximized.
  - By the time the cone matures, they can equal up to 50% of the above ground dry matter.
  - Cannot increase cone #. Focus should be on maintaining plant health to maximize cone weight and resin/oil production.
    - Water management
    - Nutrient management

Preparation for Dormancy:
End of August to beginning of September:

- While not really a stage of growth, it is important in the development of the crop for next year.
  - Photosynthetic production of carbohydrates exceeds the needs of plant development.
  - The excess is transported to the roots for storage in the form of starch.
  - Both the dry weight of the roots as well as starch content has peaked by October.
  - The shortening days of late summer signal this transition, followed by cold October temperatures- Dormancy starts.

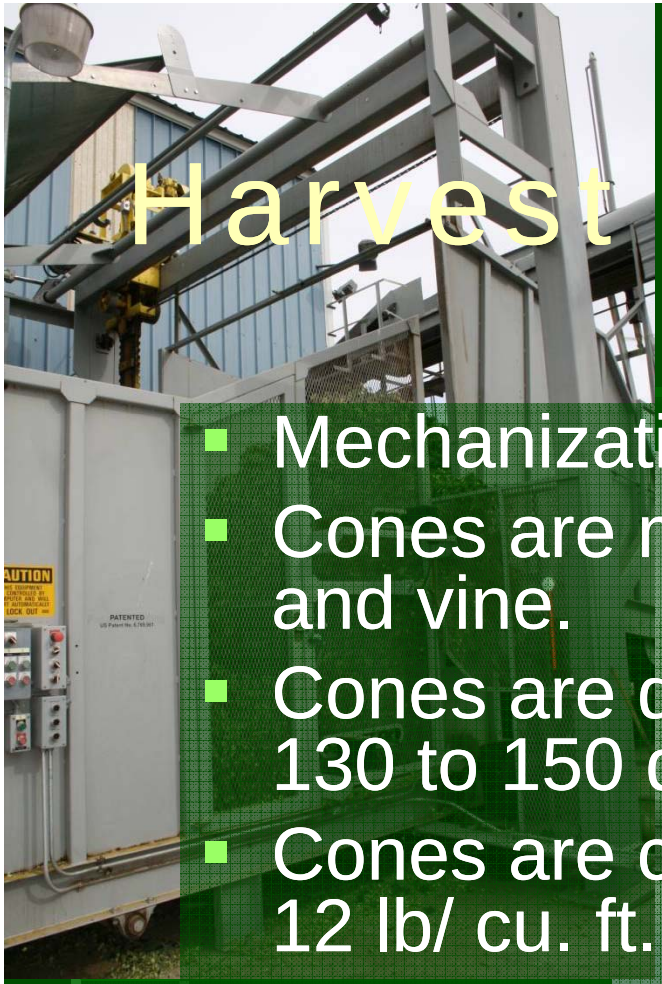
Preparation for Dormancy:
End of August to beginning of September:

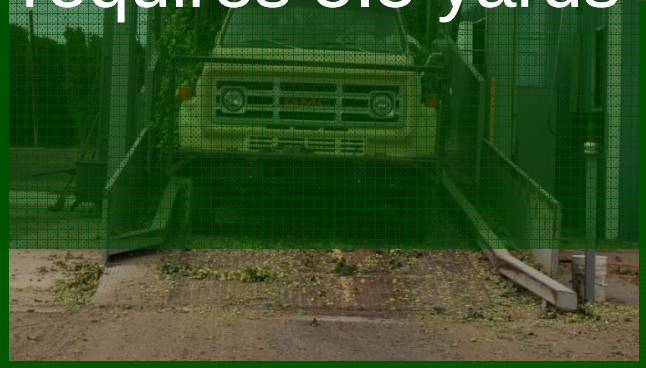
- What's Happening in the field?
- Harvest commences.

Harvest

- Vines are cut and transported to picker.
  - Alternatively, use field strippers
- Material is ran through stationary machine, cones are separated.
- Cones dried for 8-12 hours to 10% moisture.
- Dried cones are cooled (ambient) for 12 to 24 hours.
- Baled and transported immediately to cold storage.

Harvest





- Mechanization is key.
- Cones are mechanically sorted from the leaves and vine.
- Cones are dried in forced air (50 cfm/ft2) at 130 to 150 degrees F.
- Cones are compressed into 200 lb bales at 10-12 lb/ cu. ft.
- Each bale requires 5.5 yards of burlap cloth.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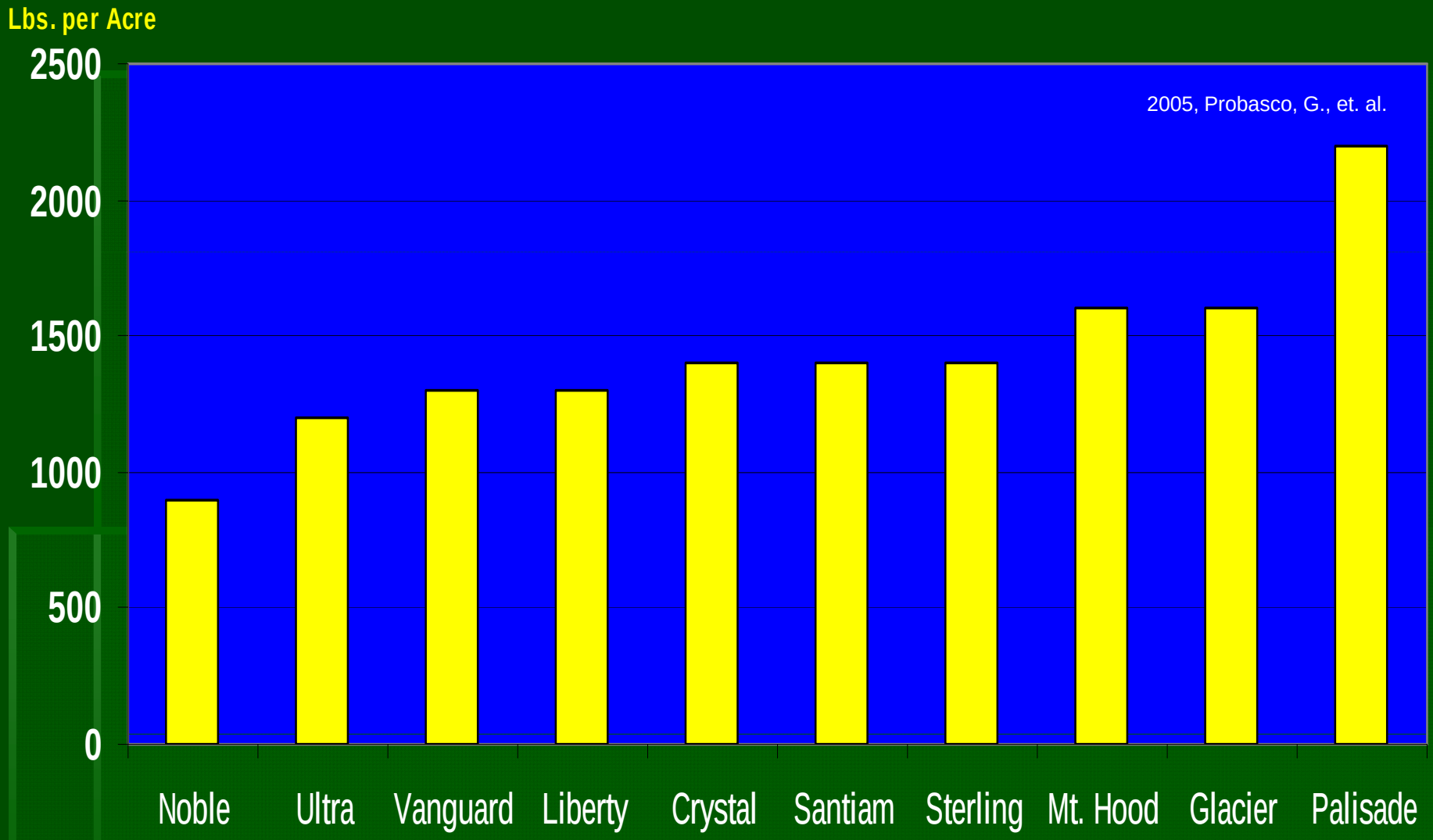
Final Comments on Development

- The stages of hop plant growth need to be understood to properly manage the crop.
- Each stage of growth has its own unique characteristics and therefore unique management requirements.
- Yield is already being determined as early as April and May.
- To complicate things further: Much of this is variety dependant.

Varietal Impact

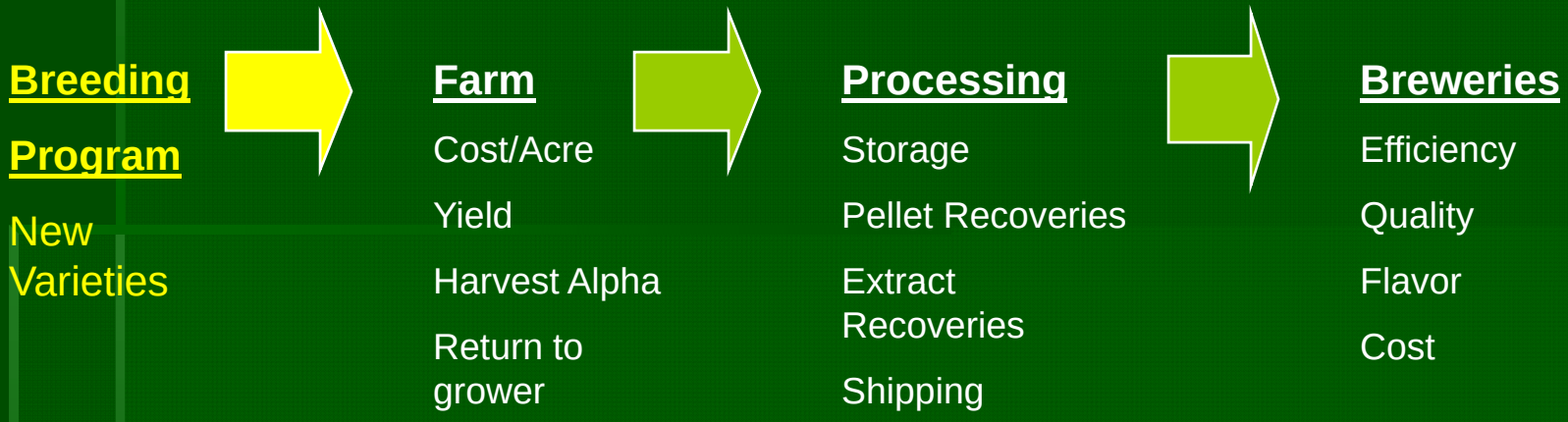
- Physiology and development are impacted by variety.
- Crop management is varietal dependant.
- There is a strong genetic x environmental interaction.
- The goal: Realize the maximum genetic potential.
- The problem: Maximum genetic potential cannot be reached in all environments.
- The solution: Breeding varieties to match the environment.

Yields of New U. S. Aroma Varieties



How important is this?

- Hop Supply Chain: Each link on the supply chain affects subsequent links.
  - The efficiency of a hop has a corresponding impact on the chain.



In other words…

- Breeding objectives based on the needs of the WHOLE industry.
  - Objectives meant to provide brewers with hops/hop products which enhance their brews, while being agronomically efficient.
  - Performance of a variety at every level, from the farm to the brewery, adds to the overall health of the industry.

Developing Objectives

- The hop trade consists of two distinct markets:
  - Alpha/Bitter
    - Processed hops.
    - Yield measured in Kg. Alpha per acre.
    - Typically high alpha varieties, increasingly aroma.
  - Aroma
    - Minimal processing.
    - Yield measured in lb. acre.
    - Typically aroma varieties, some high alphas.
- This is an important consideration when setting objectives.

Specific Objectives

- High yielding high alpha cultivars.
  - Super
  - Varietal
- High yielding aroma cultivars.
  - Improvements on the classics
  - Specialty / dual purpose
  - Organic
- Goal is to combine the above with:
  - Pest and disease resistance.
  - Good storage stability.
  - Desirable brewing characteristics (i.e. low cohumulone, specific oil components).

Hop Breeding Scheme

- Parental selection and crossing
- Early selection
- Intermediate selection
- Advanced selection
- Cultivar release

Parental Selection

- Remember- Hops are dioecious.
  - Distinct male and female plants.
  - Obligate out-crossers, cannot self pollinate.
    - High level of diversity (heterozygosity).
    - Hybrid vigor (Heterosis).
    - Seed propagation not possible.
  - Easily clonally propagated- traits can be “fixed” in single generation.
    - Each new variety results from a single plant.
      - Millions from one.

Crossing

Left: Collection of male flowers for isolation of pollen.
Above: Application of pollen to a bagged receptive female.

The Selection Process

- After crossing, resulting plants are entered into a 10 year selection process.
- Separated into three stages:
  - 1) Early (seedling, single hill)
  - 2) Intermediate (Yield trials)
  - 3) Advanced (Elite plots)

Early Selection: Years 2,3,4

Typical seedling crown

- FAIL FAST: 80 – 90% of original seedling population eliminated in year 1.
- The crowns of the remaining plants are dug and planted in the single hill plots.

Intermediate Selection: Years 5,6,7

- Yield Trials
  - Selections from the single hill are expanded to larger plots (10 – 100 hills).
  - Off-station plots often used to assess adaptability of selections to varying environments.
  - Evaluated for the same agronomic and quality traits (plus oils)
  - Pilot brew trials possible.
  - Analysis: Individual performance, genetic gain, comparison to commercial controls.
    - Use value models as a selection index.

Advanced Selection: Years 8,9,10

- Elite lines:
  - Selected from yield trials.
  - .5 to 1 acre (0.2-0.4 ha) commercial sized plots.
- Purpose:
  - Confirm performance under commercial conditions.
  - Assess stability of the selection.
- Pilot/Medium scale brewer trials.
- Evaluated for agronomic and quality traits including oil composition.

Cultivar Release: Year 11

- After 8 - 10 years of evaluation, release is considered.
- The work is far from over, success is dependant on:
  - Continued agronomic success.
  - Grower acceptance, usually short term.
  - Brewer acceptance, long term.

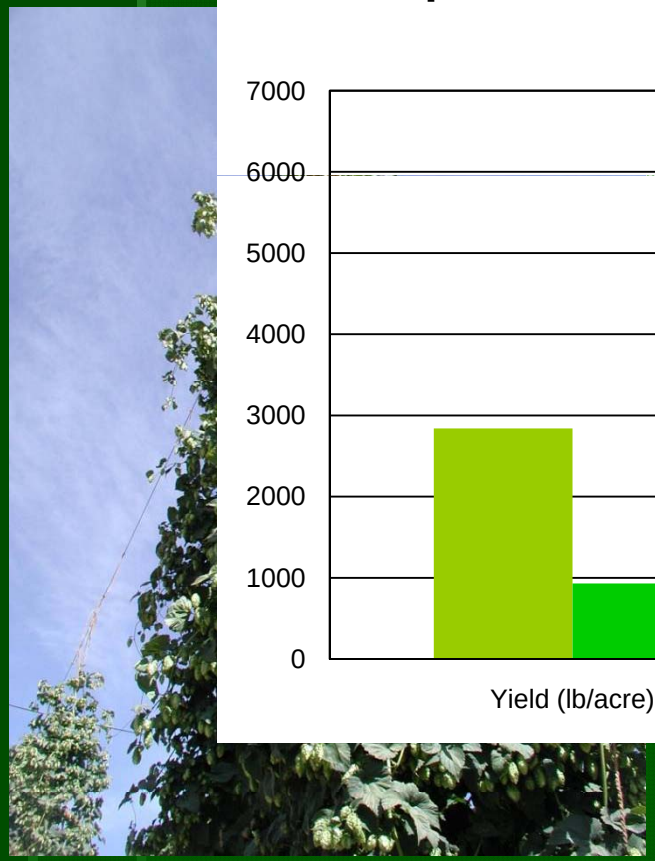
Organic Hop Breeding: Conventional vs Organic, same variety example:

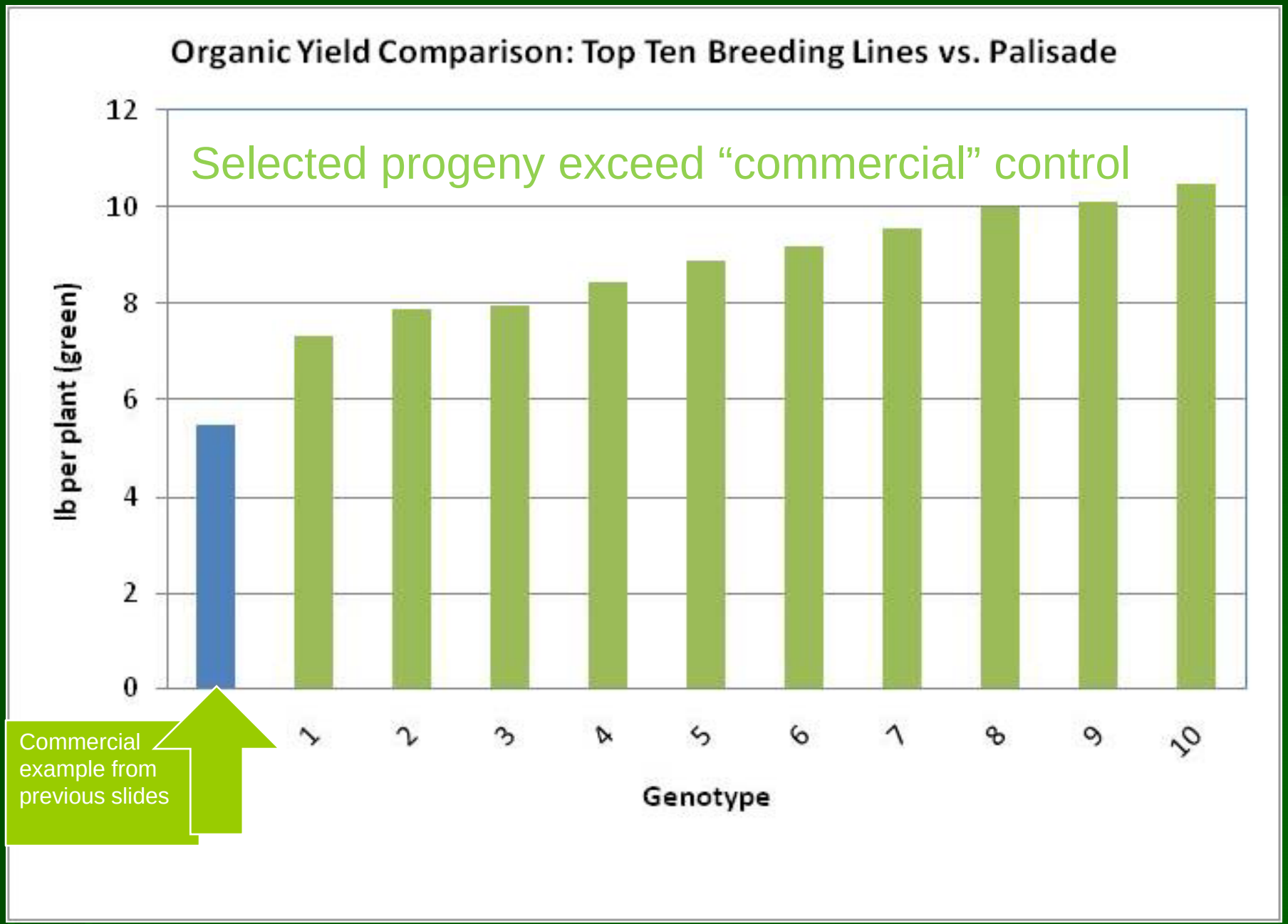
Conventional

Organic

Organic Hop Breeding: Conventional vs Organic, Same Variety

Conve




Organic Yield Comparison: Top Ten Breeding Lines vs. Palisade
Selected progeny exceed “commercial” control
lb per plant (green)
12
10
8
6
4
2
0
1
2
3
4
5
6
7
8
9
10
Genotype
Commercial example from previous slides

Agronomic success is evident, but…

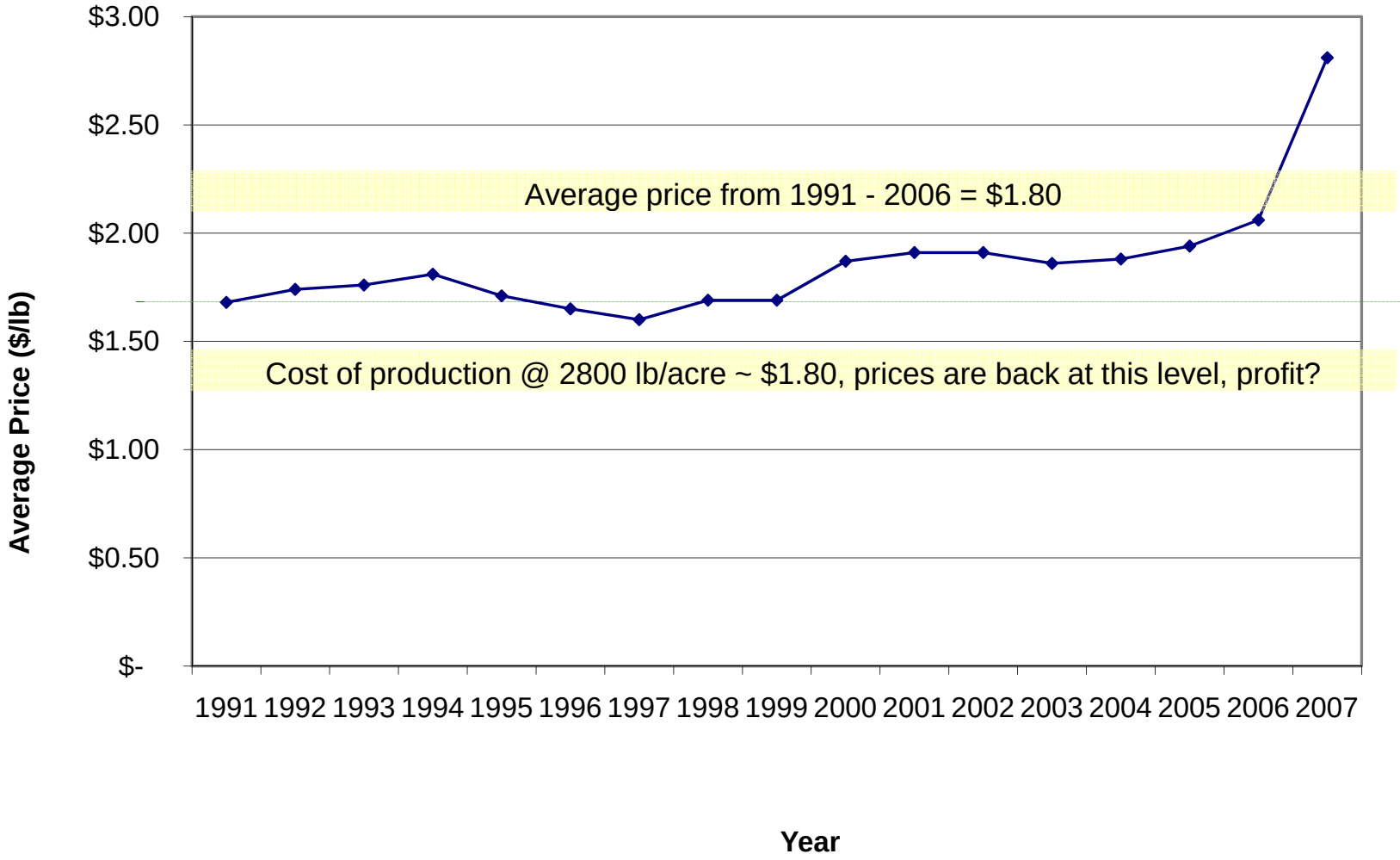
can we market them?

The Final Challenge: Marketing

- Hops are listed in NOP section 205.606, which allows their use in organic products.
  - Non-organic hops can be used to brew “organic” beer.
- Conventional hops are easy to come by in most any variety.
- Above all they are cheaper.
- The result is, most “organic” beers are not made with 100% organic hops.
- Despite availability, organic hops difficult to sell profitably
- This may determine the fate of organic hops in the U.S.

- Question: Is this an indicator of TRUE demand for: “Buy Local” and “Sustainably Produced” campaigns?

CONVENTIONAL Challenges: Season Average Price of Hops (U.S.)



(source: NASS)

Parting Thoughts: Overcoming Challenges

- Do your homework.
  - Know your plant, environment.
  - Know your market.
    - Organic? Local? Sustainability?
    - Hops as a commodity, does not work.
- Developing relationships is key.

Conclusion

- Hops are complex, high cost crop.
  - Not necessarily high value.
  - Knowledge of the growth stages is critical.
- Hop breeding is a necessary, functional step in the hop supply chain.
  - Supplies the varieties which decrease costs in subsequent steps.
  - It is a long complex process which demands commitment.
- Marketing is critical.

THANK YOU!