Hop Botany, Cultivation, and Breeding

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The Importance of Hops

Regional Economic Importance

- U.S. Production centered in the PNW.
- 77% in WA.
- 16% in OR.
- 7% in ID.
- 2011 value (US) = $180 million
- Annually Top 12 in crop value for Washington

Humulus spp. Overview

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

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

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

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.

Annual vs. Perennial Growth
- 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 Bines

- 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.
- 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.

Photoperiod Sensitive

- Hops are a short day plant.
- Under a critical number of light hours - 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.
- Results in defined “Production Stages”

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.

**Importance of Photoperiod Sensitivity**

- 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 dependent.
  - 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**

- 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.

**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

**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.
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.

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.

_comments on development_

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

_varietal impact_

- Physiology and development are impacted by variety.
- Crop management is variety dependent.
- 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 and meet the industry needs_

- Breeding objectives based on the needs of all stakeholders.
  - 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.
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.

### Farm Costs
- Cost/Acre
- Yield

### Handler Costs
- Cost
- Storage
- Pellet Recoveries
- Extract
- Recoveries
- Shipping

### Brewery Efficiency
- Quality
- Flavor
- Goal

Developing Objectives

- The hop trade consists of two distinct markets:
  - Alpha/Bitter
    - Processed hops.
    - Yield measured in Kg. per acre.
    - Typically high alpha varieties, increasingly aroma.
  - Aroma
    - Minimal processing.
    - Yield measured in lb. per 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).

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.

From Crosses to seedlings

- Typically stained 75-90% of the starting population.
Hop Breeding Scheme

**Year 1: Parental selection and crossing**
- Based on breeding objectives

**Year 2: Early selection**
- Greenhouse screening
- High density field screening
- 10% selection rate

**Years 3, 4, 5: Intermediate selection**
- Remaining plants transplanted to 18' trellis
- 1% selection rate

**Years 6, 7, 8: Advanced selection**
- Expand selections to multi-plant plots
- 2% selection rate

**Years 9, 10, 11: Elite trials**
- Selections expanded to commercial trials
- Selection rate: 2%

**Year 11+: Commercialization**

Cultivar Release: Year 11

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

Yields of New U. S. Aroma Varieties

Organic Hop Breeding: YCR 4, Palisade® Example

- Conventional
- Organic

Organic Hop Breeding: YCR 4, Palisade® Example

- Hop Yield and Cost per Acre Conventional vs. Organic

- Organic Yield Comparison: Top Ten Breeding Lines vs. Palisade
Future Trends in Hop Breeding

- Molecular research
- Marker assisted selection
- Gene mapping
- Gene functionality
- Non-brewery usage
- Continuing conversion to new varieties
  - Driven by disease pressure, storage issues, basic economic pressures, and continued growth in craft brewing.
  - Increases focus on AROMA

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.

Season Average Price For Hops 1992 - 2011 ($/lb)

(source: NASS)

Thank you for your time.

Questions?