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Cultivating Hops for Cone Production in Nebraska

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The hop cone is the primary product of agronomic value when growing *Humulus lupulus* L. (common hop). Cones are modified stem and leaf structures that protect the female flower cluster. Lupulinic resins accumulate on the cone bracts during maturation and contain the chemical compounds used in flavoring beer. Chemical compounds vary by varietal character and influenced by the environmental and geographical conditions in which they are grown.

In 2019, total hops production in the United States was 59,739 acres with 69% being grown in the state of Washington and only 4% being grown outside of the states of Washington, Oregon, and Idaho (*USA Hops*,Yakima, WA). Hops can be grown in very diverse climates, but it is the climatic consistency of the Pacific NW that provides product consistency and reasoning most are grown in the region. Hops is a niche crop outside of the Pacific NW, however, it is an opportunity for specialty crop growers to supply hops of unique character to local craft brewers. This publication provides a general understanding of hop growth and Nebraska specific cultivation practices used to maximize cone development and associated characteristic qualities.

Figure 1. Hop cone formation in early July near Lincoln, NE showing collections of female flower structures protected by expanding bract leaves.

Cone Description

Cones are the inflorescence structures produced only on female plants of this dioecious plant. A cone consists of between 20 and 60 flowers found on a central axis, or shortened stem, each being covered by a modified leaflet, known as a bract (Figure 1). In agronomic hop production, female plants are cultured, not to form seed but, to direct energy into cone expansion and development of chemical compounds. The presence of male flowers (Figure 2) is an indication of a male plant that should be removed to prevent seed develop-

Figure 2. Hops are dioecious. Staminate flowers form only on male plants, as shown in this image, whereas cone-forming pistillate flowers develop only on female plants.

ment, or may be a spontaneous hermaphroditic response to excessive climatic temperatures on female plants of temperature sensitive varieties. Without flower pollination, the cone bracts continue through the maturation process, forming resins and essential oils on multi-cellular lupulinic glands located within the epidermal cell layer. These compounds are easily recognizable on the bract leaves as the golden yellow-colored "dust" particles found on the surface, or 'lupulin'. Seedless cones produce not only more lupulin, but lupulin of higher quality compared to cone structures allowed to be fertilized and produce seeds.

Chemical Compounds

Brewing properties include bittering compounds found within the resins, essential oils, and polyphenol substances or tannins. These qualities are influenced by hop varietal character, ecological and environmental conditions, and cultivation practices (Mahaffee et al, 2009, Rodolfi et al, 2019). Hop growers select varieties based upon those that can be marketed to their clientele. A specific challenge to most Nebraska growers is the inconsistency of the annual climatic temperatures and seasonal variation. A Nebraska hops cultivar trial conducted from 2016—2019 (author unpublished data) evaluated eight hops varieties in four different locations across the state. Three-year harvest data suggests greatest productivity, season to season product consistency, and trueness to varietal character can be accomplished in the Scottsbluff area.

There are multiple acids found within resin compounds. Cohumulone is the principle compound associated with alpha (α) acids, whereas colupulone is associated with beta (β) acids. Hop cone lab analytical testing will generally measure total α-acids and β-acids, but additionally provide measurements specific to cohumulone being a percentage of total α- acids and colupulone as a percentage of total β-acids. This information is important to brewers. Alpha acids contribute to the bittering of beer, with higher levels creating a harsher profile. Some hop varieties are naturally high in alpha acid content and less are needed in the brewing process. Beta acids are less important for the brewing process but affect bitterness of product by oxidation over time, affecting beer quality during storage. The α- and β-acid ratio is important in attempts to maintain qualitative aspects until consumed.

During cone maturation (Figure 3), the β-acids are first produced. These acids gradually transform to α-acids through exposure to solar radiation. Resins within the cone initially are high in β-acid and low in α-acid content, but balance shifts during the ripening process. Cones that are exposed to bright light and become overripe will have very high α-acid content in relation to β-acids. For this reason, it is important that sunlight infiltrates the hop canopy to expose cones as uniformly as possible to improve acid balance and consistency. For Nebraska growers, hopyards should be planted in a north-south orientation to maximize light penetration into the mature hop canopy.

Figure 3. Cones develop rapidly after flower initiation, and lupulin glands (glandular trichomes or hairs) accumulate resins and essential oils that are used commercially.

Essential oils in hop cones contain more than 200 different volatile compounds that create the individualized aromatic qualities noted in hop varieties (Mahaffee et al, 2009). The essential oil compounds are grouped either as hydrocarbon fractions (*terpenes*) or oxygen fractions (*oxidated*). These volatile substances are similarly formed from acetic acids found within the oils, and influence α- and β-acid oxidization during cone maturation, post-harvest processing, and storage. Post-harvest cone degradation results from exposure to warm temperatures, atmospheric oxygen and light. Cone harvest should begin when lab test results indicate alpha acid is nearing varietal target, however, is often estimated as being when cone dry weight is between 20–23%.

Harvesting involves machine stripping of cones from the annual top growth (bine) and then immediately into the air-drying process to avoid cone degradation. Commercial processors hammer-mill dried cones, cold press them to form pellets, and seal in light excluding foil packages. Nebraska growers generally harvest cones using small portable cone strippers but find the additional processing equipment to be cost prohibitive. With less investment, cones are dried on stackable drying screens with ambient air blown upward through the cone to prevent compaction. Once dried to 8—10% moisture, they are compressed as whole cones into light excluding packages. Whole cones are not preferrable in brewing, but small craft or home brewers can adapt to create something different for the local market.

Polyphenols, or tannins, are of natural importance to plants as deterrents against pests, are used for growth regulation, and provide for coloring. For brewers, these phytochemicals contribute to bittering, aroma, and formation of foam, and they inhibit growth of microorganisms in beer. There is emerging interest in the wide spectrum of polyphenols found within hops, as studies show that they may human health benefits, such as; preventing inflammation during cancer treatment (Baniyash et al., 2014, Chai et al., 2015), helping to treat arthritis (Stacke et at., 2011), regulating glucose and blood pressure (Pang et al., 2007) , and treating hormone imbalances during menopause (Bowe et al., 2006, Keiler et al., 2013). Nebraska growers have an opportunity to direct market hops to consumers for teas, tinctures, pillows, and sachets used for holistic health for treating mild cases of anxiety, stress, mood swings, and as a sleep aid (Franco et al., 2014, Kyrou et al., 2017, Ulbricht et al., 2012).

The understanding of development of these chemical compounds and progression through maturation provides insight to the hop grower on the importance of intentional cultivation and post-harvest handling of this unique crop.

Plant Characteristics

Commercially cultivated hop plants that have economic value were developed from European-type hop crossed with North American genetic material (Mahaffee 2009). Plants consist of a perennial underground rhizome (stem) and root structure that annually produces an extensive above-ground shoot system that can grow as much as 20 feet in a single season. Two types of roots are evident: a spreading fibrous root system that is important for nutrient and quick water uptake, and a swollen vertical root system (6 to 12 feet deep), used for deep access of water and nutrients and to provide a storage site for starch and nutrients (Rybacek, 1991).

Perennial woody underground stems (rhizomes) have shortened internodes, and are of thicker diameter than those found on the seasonal extensive above-ground growth. Vegetative buds are located on the underground stem in which the soil provides protection from winter cold injury (Figure 4). These buds give rise to the annual above-ground vegetative growth that progresses to the reproductive stage of flower and cone development. Buds on the underground rhizome include both active buds that grow as soon as conditions permit and dormant buds that are hormonally activated when necessary or when matured for vegetative growth in later seasons.

The annual above-ground growth consists of a vegetative and a regenerative system (Rybacek, 1991). The vegetative system is composed of the main stem (bine), vegetative buds, lateral branches, and leaves that are highly efficient at photosynthesis. The regenerative system of importance for cone development is found only on female plants. Flowers are induced on this plant in response to shortened duration of daylight following summer solstice in places where day lengths of more than 15 hours occur. The female flower structure originates as a small burr composed of a compressed stem having 20 to 60 individual flowers, each with a pair of modified leaves called bracts. As the female flower matures, the bracts expand and form the appearance of the resulting cone. No seeds are formed when grown in the absence of pollen from male plants, but the cone will continue to develop. Lupulin glands on the bract leaves produce the α- and β- acids used in the brewing process and aromatic qualities produced in the essential oils that provide varietal character. The lupulin and essential oil qualities continue to change through maturation of the cone and it's the visual formation and α-acid level that is monitored to determine harvest timing.

Figure 4. Buds form on the perennial woody vertical rhizome to produce the next season's climbing bine of the reproductive stage that produces hop cones.

Perennial Plant Structure

The underground perennial woody stem has buds that may grow vertically to form new wood, form the annual above-ground vegetative and flowering top growth, or grow

Figure 5. In addition to a vertical rhizome, hop plants form outward-reaching stolons that form vegetative buds to establish a new growth away from the parent plant. Unmanaged, the growth formed from the stolon can lead to the aggressive spread of this plant.

horizontally as suckers and stolons (Rybacek,1991). There is an extensive root system consisting of shallow, annual fibrous rootlets that account for rapid nutrient and water uptake and skeletal roots that stores energy resources and expands the reach to draw additional resources (Rybacek,1991). The woody stem consists of both old wood and new wood, with its primary purpose is to maintain regenerative tissue for development of new vegetative buds needed for the annual above ground growth. Buds can remain dormant for up to four years on old wood, but viability deteriorates rapidly thereafter, necessitating the continual regeneration of new wood to maintain the health of the plant (Rybacek,1991). Growth of the underground stem structure from old wood may appear as a vertical rhizome with multiple buds on short internodes, or also as a broadly reaching horizontal stolon (Figure 5) having multiple buds with longer internodes and being strong in apical dominance. A healthy underground stem structure includes both new wood and old wood, having as much as one third of it being new wood at any given year. The stem should be in well-drained, high gas exchange soil environments or reduced vigor or disease may occur. Nebraska soil conditions vary widely, with heavy soils found in much of the eastern part of the state and silty or sandy soils through the broad river valleys, sand hills and the western region. Cultivation practices in heavy soils should include banking up the soil bed (curbing) mid- to late-season to protect buds on the newly formed wood and this will additionally improve drainage and gas exchange around the old wood.

Cultivation Practice

Hop yards are planned and developed for multiple-year productivity given that 3-year-old hop plants are considered mature and generally remain productive for more than 10 years before needing rejuvenated or replaced. The rejuvenation process is due to the ultimate decline of old wood in the perennial underground plant structure and irregularities associated with "self-rejuvenation" by the plant. There are two different aspects of cultivating hops, the nurturing of the underground plant (perennial wood) and culture for the above-ground vegetative and flowering (regenerative) annual growth.

Perennial Wood

Hops can be grown in a wide array of soil types; however, for commercial hop production, the soils should optimally be deep, well-drained, and remain friable under frequent equipment operations during the growing season (Mahaffee, 2009). Cultivation practices implemented for enhancing hop cone development must consider both the benefits and risks to the perennial plant. Soil type will direct the need for and timing of cultivation activities (including the movement of equipment), the timing and amount of irrigation, and fertilization rates and frequencies. For example, there is less concern when growing hop in sandy soils on soil compaction from farm activities or too wet of conditions for the perennial wood; however, irrigation and fertilization must be provided more frequently at lower rates to support growth and prevent loss of nutrients from the root zone.

Hop plant starts are available from various sources, however, there are risks that varieties are not true to type or potentially carry virus and disease from less experienced propagators. There presently is no national certification program and there are no guarantees for plant quality. It is recommended that materials are sourced from commercial propagators that use regenerative material from the National Clean Plant Network and buyers should investigate how the propagators maintain cleanliness of the propagation stock. Farmers can use rhizome pieces for spring planting; however, greatest plant success comes from container-grown plants.

Figure 6. When the soil warms in spring, the strongest buds on the underground wood produces "bull" shoots that will be removed during the timed cut-back process. Secondary buds emerge to create bines that will be trained on the trellis system.

These are available in varying pot sizes dependent upon plant age, with the largest being those propagated during the previous season and over-wintered before being planted in spring.

First-year plant propagates have a short underground stem with a few active buds, no dormant buds, and a complete but small root structure. The first-year vegetative growth from the active buds should not be trellised, but allowed to remain as a stem-leaf cluster directly on the ground. The energy manufactured through photosynthesis will translocate to the newly forming perennial wood, and new buds will be formed for the following growth period.

In the second- and third-year growth cycles, the underground wood expands, forming a new growth ring each year and developing buds for the annual above-ground growth (Rybacek,1991). New wood is developed upon the old wood through lateral growth of the rhizome and the outward elongation of stolons (Rybacek,1991). Maintenance of plant spacing is controlled through employment of the annual spring cut-back, and removal or shortening of the outward growth from elongation of the stolon. Seasonal growth emerges from the buds on the new wood, and dormant buds will form on up to 4-year-old wood (Rybacek,1991).

The annual growth of hop lasts from spring emergence of the vegetative spikes until the shortened daylength and cooling temperatures ends the annual growth cycle and initiates dormancy of the perennial underground wood. Once the underground wood falls into full dormancy, the resting period lasts approximately six to eight weeks. Buds will swell in preparation for seasonal growth and are quickly activated when environmental conditions warm. Seasonal emergence is regulated by plant health, soil depth and density, changes in ambient temperature, water availability, and nutrition.

Annual Growth

Above-ground vegetative growth emerges initially from the strongest buds formed on the previous season's wood (Figure 6). These shoots are called "bull" shoots, as there is a significant amount of energy provided to this growth from the perennial underground wood. These shoots are brittle and easily broken due to their high water content. The first three visible nodes above the ground are capable of producing new terminal growth in the event the apex is damaged (Rybacek,1991).

Seasonal growth of the hop plant for cone production is managed through the implementation of a "timed cut back" following initial spring sprouting of the bull-shoot stems. Cut back of the first shoots provides a few benefits. It:

- Unifies the growth stage of plants within the hop yard,
- Narrows the cone harvest period for individual varieties,
- Reduces extraneous growth,
- Maintains individual productive plants,
- Lightly suppresses vigor to narrow internodes and increase flowering/cone productivity, and
- Suppresses upward movement of the perennial wood

The date of the spring cut-back is variable, depending on such factors as weather conditions and stage of plant development. This should occur early in the season before new growth has drawn too much energy from the perennial wood. The period for cut back in Nebraska typically falls between the first and third weeks of April. It should not be done after the first of May if plant development is delayed due to a late-season warm up. New growth that emerges following the cut back is trained when shoots are 18 to 24 inches in length and the tip begins to show twisting or spiraling, typically in mid- to late-May.

Cultivated hops are grown under a trellis system that supports the natural climbing habits (bining) of plants. In this system, cables are suspended on poles from 18 to 20 feet above the plants, and biodegradable ropes (e.g. coir, hemp, or paper) hang directly from the cable to the base of the plant. Hop stems that are greater than 18 inches of length will indicate the ability to climb through a sweeping or spiraling of the upper 4 to 6 inches of the shoot tip (Rybacek,1991). Once the tip intercepts the suspended rope, it will wrap clockwise around the rope and begin its upward climb.

Hops are able to self-train and climb the trellis system, but crop uniformity is achieved through implementation of a planned training date window. Plants should be prevented from climbing until this period in which similar length bines are lifted and gently wrapped onto the training ropes. This

Figure 7. A small hop yard in Scottsbluff, NE with plants trained on coir rope suspended on a cable trellis system. The annual reproductive bine is shown reaching the top cable at about summer solstice, at which time flower initiation begins.

date typically falls three to four weeks following the timed cut back, however, is directly influenced by ambient temperatures. Trellis ropes should be suspended just previous to the training period to reduce the number of plants that self-train. Two shoots that are 18 to 24 inches in length are selected and individually lifted and gently wrapped clockwise 1 to 2 times around the rope. Depending upon the trellis system, either two or four bines are allowed to grow from a single plant, and no more should be trained that can cause excessive weakening of the perennial wood (Figure 7). Vegetative shoot growth can be quite rapid during warm periods—as much as 1 foot per day.

The period in which training occurs greatly influences cone productivity and quality. Research indicates that early training can slightly lower yields, but a late training can cut yields in half (Darby & Calderwood, 2015., Jezek, 2010., Rybacek, 1991) There are no specific guidelines on training dates, but are developed through individual farmer experience and data collection. Seasonal variation will affect speed of regrowth following the cut back, but a farmer can consider that early maturing varieties need to be trained when first ready and the later maturing varieties can safely have training delayed.

For Nebraska hop growers, the growth rate can be predicted through consideration of variety vigor, projected harvest date, and historical temperature trends for the first three weeks of June. Take for example the variety Cascade, harvest is projected to be during mid- to late-August and has a projected yield of 1.5 pounds of dry hops per plant (*Hopsteiner*, New York). This moderately vigorous plant is projected to grow about 6 to 10 inches per day, with the goal to reach the top trellis cable by summer solstice (June 21). In Nebraska, training date can be approximated by back dating from June 21 an average of eight inches per day. Using this method, it is approximated that it will take 27 days (May 25) from successful training to reach the top of the 18-foot trellis. There are many influencing factors that affect varietal growth rate, but this method can successfully approximate training date until personal experience and seasonal records are developed as a cultivation tool.

Maximizing Cone Development

Cone productivity is an intrinsic varietal character, but greatly influenced by cultivation technique and environmental conditions (Jezek, 2010). When developing a hop yard, choose varieties that align with site environmental conditions through information gathered from plant propagators and networking of regional growers. The following key cultivation strategies provide approaches to maximize hop productivity.

Pre-season Preparation

Production activity plans can be developed through information gathered from plant propagators/suppliers, extension publications, conferences and from reviewing self-maintained farm records. It is important to create a strategic plan for cultivation activity timing and management practices that maximizes variety growth. All supplies should be purchased early in the season to verify availability and have ready for use when needed. The hop field is prepared by removing all previous season plant stems, ropes, and debris to reduce incidence of disease and tightening the cable trellis system and irrigation system repair as required.

Soil Health

Production systems vary by soil type and condition. It is optimal to use cover crops as a way to improve soil fertility and organic matter if possible. In heavier clay soils, preseason edging/curbing of hop rows are used to lift plant beds to improve drainage and aeration for health of the perennial wood. Sandy and silty soils, such as that in western Nebraska, should not be curbed as it will encourage wind erosion. Soil tests should be performed as soon as possible in the spring to evaluate general soil character and nutrient availability; however, early initial annual growth is directly related to health of the plant from previous seasons care. Any corrective action required from a spring soil test would need to be implemented prior to, and during, the rapid growth period following the timed cut back.

Fertility

Initial growth observed in hops draws upon nutrients stored from the previous season growth in the underground perennial wood. During the spring, the plant requires many macro and micronutrients to maximize growth. The nutritional requirements change over the course of vegetative development through flowering and cone development. During the rapid growth response from timed cut back to reaching the top of the trellis wire, nitrogen (N), potassium (K), and calcium (Ca) are taken up in large quantities. Potassium and Ca deficiencies should be corrected early in the season, and N should be readily available for the period of rapid growth (Rybacek, 1991).

General recommendations for hops indicate that approximately 150 pounds of N per acre should be made available to the plant annually (Mahaffee 2009, Neve 1991). The question of how much actual N fertilizer to apply is not that easy of an answer. The following demonstrates how one should potentially determine what the true N application rate should be (Gingrich et at, 2000);

Example: Grower with 1,000 hop plants per acre

- Total decapitated per plant dry weight (DW) at harvest: ~3 pounds
- Projected cone dry weight from plant harvested (~33% total DW): ~1 lb
- Amount of N removed in decapitated hop plant (~2.1% of plant): ~1 ounce
- Number of plants removed on an acre: 1,000
- Amount of N removed per acre: 1,000 plants × 1 oz N = 63 lb N removed

As expected yield/annual vegetative growth changes, so does the N requirement. Using the same 1,000 plant per acre example, consider a highly performing variety that might have an expected 2.2 lb cone harvest:

- Total decapitated per plant dry weight (DW) at harvest: ~6.7 lb
- Projected cone dry weight from plant harvested (~33% total DW): ~2.2 lb
- Amount of N removed in decapitated hop plant (~2.1% of plant): ~2.2 oz
- Number of plants removed on an acre (variable by grower): 1,000 typical
- Amount of N removed per acre: 1,000 plants × 2.2 oz N N= ~140 lb(#) N removed

To optimize productivity, it is critical to consider the potential harvest of the crop to approximate the amount of N needed for the plant. If for example, a soil test from the hop yard indicates 36 lb N per acre, the grower would need to provide at the very minimum the difference between that required for the expected harvest and that available in the field. It should be noted that though lab tests provide nutrient level information, not all is available for plant uptake due to aspects of soil chemistry. For the example, the grower would want to provide at least 27 lb N for plants having an expected harvest of 1 lb cones, and 104 lb N for plants having 2.2 lb of cones at harvest.

In a 2017 University of Nebraska-Lincoln (UNL) statewide hop cultivar trial, soil tests illustrate the variation one might find across the state and the importance of having a soil test done specific to the growers hopyard (author unpublished data). Test results from a hop planting near Norfolk in Hobs silt-loam had 142 # nitrogen per acre (N/A), a plot near Lincoln in Wymore-Aksarben silty-clay-loam had 73# N/A, a plot near Sutton in Hasting silty-clay-loam had 51# N/A, and a plot near Scottsbluff in Trip very fine sandy-loam had 36# N/A. Each of these soil types vary in the ability to hold nutrients and consideration must be given to the approach additional nutrients are added in relation to nutrient holding capability. The higher the clay composition in soils, the greater the ability for it to hold nutrients, so a single seasonal nutrient application may be satisfactory. Soils containing more silt and sand would better be managed by several small, timely applications of fertilizer to meet plant need.

No matter the fertilizer rate or the timing of application that is decided by the grower, it is important to apply the nutrients to the plant root zone. Calibrate the application rate to provide the desired amount on a per-plant basis with less of an emphasis on the per-acre rate as demonstrated in the example provided.

Irrigation

Between 27 to 32 inches of water is required to support the annual growth cycle of hop (Mahaffe, 2009). Rainfall supplemented with irrigation must be readily available during the active vegetative growth, flowering and cone development stages, and to meet the transpiration losses associated with high temperatures and winds. Though hops are deep rooting, a majority of water uptake is in the expansive fibrous root structure near the soil surface. Natural rainfall in Nebraska varies greatly by location and season so hop growers will find it beneficial, if not absolutely necessary, to irrigate their hopyard. Annual precipitation averages 27–31” for areas in eastern Nebraska, 19–28” throughout the central region, and 15–18” in the Nebraska panhandle. Initiation of irrigation is dependent upon season, but typically begins mid-May and lasts until nearing harvest. It is best to provide irrigation through drip emitter application to direct water placement and reduce plant canopy moisture that encourages development of disease. Care must be given to provide enough water to meet the plants needs, but to not cause excessive leaching that carries nutrients out of the root zone.

Weed Management

Weeds directly compete with hops for available nutrients and water required for the rapid vegetative development phase and filling of cones. Weed competition is greatest during the first two years of establishment and often the result of newly exposed soil turned in preparation of the hop planting bed. In Nebraska, large weeds such as marestail (*Conyza canadensis*), Palmer amaranth (*Amaranthus palmeri*), and velvetleaf (*Abutilon theophrasti*) compete for available water and shade-out newly planted hops plants. Additionally, weeds such as bindweed (*Convolvulus arvensis* L.), smartweed (*Polygonum pensylvanicum*), sweet clover (*Melilotus officinalis*) and wild carrot (*Daucus carota*) can become persistent and invasively choke out hops if not controlled. In mature hop, weeds are less problematic given the aggressive plant growth habit of hop and cultivation practices utilized that discourages weed growth. There are many weed management approaches to consider, including hand removal, cultivators and "finger-weeders", flaming, mulches, and chemical herbicides. It is important to note that if a chemical approach is used, products selected must be labeled for hop and the intended use. It is important to follow labeled instructions and adhere to preharvest interval requirements (PHI), which is the wait time between a pesticide application and crop harvest.

Insect Management

There are several insects that can cause injury to hop, and pressures can vary by seasonal conditions and adjacent land uses. Most hop insect pests are opportunist feeders, and not specifically a pest of hops. Hop is not the most enticing plant for insects, but under the right conditions, a pest may proliferate the hop yard and cause enough damage to affect economic value. For Nebraska growers, the most common insect to cause damage is the potato leafhopper *(Empoasca fabae)*, a light green, wedge-shaped insect shifting across the underside of leaves (Figure 8). These insects overwinter in southern pine and move northward in prevailing winds during the spring (O'Neal et al, 2015). Leafhopper injury is noted as V-shaped chlorosis on the leaf blade, progressing towards margin that become necrotic. Though economic thresholds have not been determined, heavy feeding and resulting chlorosis can kill first-year plants and greatly reduce plant vigor and yield of productive plants (O'Neal et al, 2015).

Additional pests of concern to Nebraska growers are two-spotted spider mite *(Tetranchus urticae)* and the general grouping of caterpillars (*Lepidopteran* larvae) and grasshoppers (*Caelifera*). Hop is fully grown by mid-July with all cultivars having various stages of cone development through July and August. Heat and typically dry conditions during this time is conducive to the rapid increase in pest populations so intensive crop scouting (3-day intervals) is necessary to determine the appropriate pest management strategy.

Figure 8. Leafhopper is an example of a common hop pest that additionally causes leaf margins to yellow and desiccate, called "hopper burn".

Crop scouting should include the identification of hop pests and the change in population in time, as well as type and population change of beneficial insects that might naturally suppress pests. Predatory mites *(Galendromus occidentalis)* and black lady beetle *(Stethorus picipes)* populations often increase at the same rate as hop feeding mite, greatly reducing the need for chemical controls. Insect biodiversity should be encouraged as a healthy hopyard will have many species of beneficial insects that can keep pest insects suppressed. Commonly observed predatory insects found in UNL hop evaluation plots include; lacewing *(Chrysopa, Chrysoperla*, and *Hemerobius)*, long-legged flies *(Dolichopodidae sp.)*, parasitic wasps *(Ichneumon sp. and others)*, lady beetle larvae *(Hippodamia sp., Coccinella sp.)*, and mantids *(Mantidae sp.)*. Growers will find the *Field Guide for Integrated Pest Management in Hops* 3rd Ed. (O'Neal et al, 2015) a valuable resource in visual identification of common pests and diseases of hops for the Midwest.

Nebraska growers will find insect pest problems to vary greatly by year and variable seasonality. It is recommended to monitor pests through scouting and only use chemical treatments when populations necessitate control. Chemical treatments bring imbalance to insect biodiversity and may result in causing another pest to become a problem. An integrated approach to pest management includes; appropriate hop plant nutrition, removing weeds within and around the hop plot, planting cover crops between hop rows to encourage biodiversity, and avoid the use of broad-spectrum chemicals for pest control. As with all pesticide treatment plans, apply only chemicals approved for the crop, in the appropriate manner, and in accordance with the pre-harvest interval (PHI) requirement.

Disease Management

Hop variety, yard layout, trellis system, and cultivation method each are contributors to the incidence of disease and the severity of an infection if it does occur. There are few chemical products presently cleared for use in Nebraska for hops, so having an integrated pest management plan is vital. Downy Mildew *(Pseudoperonospora humuli)* is the most challenging disease of growers in the eastern and southcentral regions of Nebraska that is expressed during long rainy and cloudy periods in spring and early summer. Disease symptoms include short/compressed growth spikes, pale green to bright yellow foliage, and characteristic black sporulation on the underside of leaves (O'Neal et al, 2015). In UNL cultivar trials (author unpublished data), Chinook, Centennial, Columbia, and Willamette illustrated tolerance to disease infections and remained productive even when symptoms were presented. Cluster, Crystal, Perle and Zeus were highly susceptible to DM that resulted in death of mature plants. Chemical fungicides must be applied prior to conditions that encourage disease expression as post-application methods have limited success for disease control. Fungicides with an active ingredient of dimethomorph, metalaxyl, fluopicolide, cyazofamid or mandipropamid have shown excellent efficacy in preventing DM. Fungicides should be applied as a protectant prior to any indication of disease, typically just after emergence with additional treatments as indicated by the label, typically every 7–10 days until the PHI. Read and follow all chemical label instructions, and apply chemicals approved for the crop, in the appropriate manner, and in accordance with pre-harvest interval (PHI) requirements. The *Compendium of Hop Diseases and Pests* (Mahaffee et al., 2009) is a tremendous resource for learning about hop cultivar susceptibility and identification of diseases and pests.

Nebraska high winds increase the susceptibility for growers to encounter Fusarium Canker (*(Fusarium sambucinum)*. It is important that growers maintain tight hop climbing ropes as winds create excessive movement on the underground connection of annual top growth to the underground wood. This connection becomes weakened and stress cracks allow for penetration of the fungus. Symptomology includes yellowing of older leaves on the bine, general bine wilting, and swelling at the stem base that easily snaps off when moved (O'Neal et al, 2015). There are no fungicides available for control of this disease. Infections can be prevented by having a tight trellis, hilling soil at the base of bines, reducing free soil moisture, and maintaining soil pH near neutral.

Prevention is the key for managing diseases. Most diseases are directly attributed to free moisture remaining on the leaves and cones of the plant for more than two hours. Irrigation should be directly applied to the soil surface through drip irrigation and avoid the use of overhead spray irrigation systems. Nebraska growers typically position trellis systems in a north-south orientation to maximize light exposure to the plant. This additionally aligns with prevailing winds to assist in air movement within the plant canopy, aiding in drying foliage to prevent disease development. Integrated management includes removal of the lower 36 inches of the vegetation to encourage air movement and is typically accomplished by chemical removal, when hop plants are nearing the top wire in June.

Harvest

Flower initiation in hop is a plant response to the shortening of the light period following summer solstice (Neve, 1991). Cone formation and development is varietal dependent, and timing of harvest is determined by the amount of cohumulone (α-acids) and colupulone (β-acids) formed within the essential oils. Cone harvest for early maturing cultivars in Nebraska begins in early-August and given the warm temperatures, all varieties likely will be harvested by the first week of September. Harvest dates depend upon variety flower initiation, plant maturity and health, seasonal temperatures, wind, soil moisture, and amount of insect and disease pressure (Mahaffee, 2009). Harvest date is determined through analytical testing of cone quality; however, it can be approximated through determination of cone dry weight and visual darkening of the yellow lupulin to a dark golden color. Harvesting too early results in low essential oil composition, weak aroma and poor flavor qualities, whereas harvesting late oxidizes the compounds desired for brewing, reducing product quality and creating off-flavors and aroma.

Harvest involves cutting and removing the complete bine (annual stem) from the trellis system and plucking off the cones separate from the leaves. Hand plucking of cones is possible for small growers but extremely time consuming, taking an individual as much as an hour to remove all the cones on a single bine. Nebraska growers should consider purchasing their own cone harvester if growing more than 400 plants (1/2 acre). Bines are removed from the field by cutting approximately 3 feet above the soil surface, near the bine transition point from vegetative to the reproductive growth and cut at the top wire. Plants should not be allowed to drop to the ground but dropped either on a tarpaulin or directly onto a hayrack so that the cones remain clean and free from debris. Harvested bines are taken to a protected area for processing to slow evapotranspiration and maintain

Figure 9. Hop bines are pulled through a small portable harvester that strips the bine and separates the cones from plant debris.

cone quality. The bottom end of the hop bine is attached to a hook that pulls the bine through the picking machine, removing all vegetation and separating leaf litter from the cones through a series of incline belts or screens and blowers (Figure 9).

The cones should immediately be transferred to the drying process where the 80% moisture level is lowered to approximately 8–12%. Large hop growers use convection heated drying Oasts that can dry cones in as little as 10 hours. Nebraska growers initially will not have enough resources for such equipment but can simply dry cones in stackable screen bottom trays that has a box fan blowing upward through the bottom using ambient air (Campbell & Pearson, 2019). Cones should be no deeper than 3" and need to be turned about every 12 hours to uniform drying. Once desired moisture content has been reached, the cones are vacuum packed as whole cones or large quantities are compressed and baled. Craft brewers prefer using hops that have been pelleted, which involves specialized processing equipment to mill the cones, press the cones into pellets, and then packaged in vacuum sealed foil packaging. Hops do not store well in ambient air temperatures so should be stored in the freezer (24–28°F) to maintain quality.

Post-Harvest Plant Care

The hop bine vegetation that remains in the field following harvest is maintained as carbohydrates within the vegetation are repositioned to the overwintering perennial wood of the plant, providing the stored energy necessary for commencing the next season's growth. Irrigation should continue into the fall but no additional fertilization should be given so vegetative growth is not encouraged. By late October, the plants have transition into dormancy and the remaining top growth can be removed from the hop yard. Removal of leaf and stem litter during the late fall and winter will aid in reducing fungal pathogens that may affect the next season's plant growth.

Summary

Nebraska hop production will likely remain as a niche crop for growers to offer unique and locally grown products to craft and hobby brewers. The inconsistency of Nebraska's climate presents many challenges to the grower, that includes temperature variation that affects growth and maturation rate, to the volatility of weather, such as severe winds and hail that strips foliage or cones ready for harvest. Without a network of hop growers regionally, Nebraska growers must procure much of their own equipment, process their own product, and develop their own market. Through Nebraska cultivar trials (author unpublished data), hops productivity is best in the western part of the state, likely due to the dryer climate, well drained soils and cool night temperatures, however, severe weather presents the greatest challenge to bringing seasonal harvest uniformity. Growers intent on producing hops need to choose cultivars that will do well in Nebraska's warm summer temperatures and resistant to DM when possible. Hopyard placement should be in areas with well drained soils and trellising that is positioned in a north-south orientation to improve light incidence within the mature hop during cone development. Cultivation timing will vary by year and is best aligned with stage of plant growth. Hops can be productive in Nebraska with adequate irrigation, proper nutrition, and holistic approach to insect and disease management.

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