



Proceedings from the March 26, 2010 UVM Extension Hops Conference: *Hopping to It!*

Jason Perrault

Jason Perrault is a fourth generation hop grower in Yakima Valley. He is also a hop breeder with technical training in genetics. The following transcript was taken from a presentation he gave at the UVM Extension Hops Conference: *Hopping to It!* at the Trapp Family Lodge in Stowe, VT. This information is for educational purposes only. It should not be presumed to be prescriptive in any way. Speak with your UVM Extension professional if you have any questions or require additional information.

Hop Botany, Cultivation and Breeding. The basic botanical information of hops, crop development and cultivation, the impact of different varieties on the hops market, and the development of new varieties.

Basic and technical information. First, the importance of hops. There is talk about hops being used for medicinal purposes and personal hygiene, but 99% of the hops are used for beer. Hops were initially put into the beer as a preservative and continue to have that purpose, but now it has evolved to where our tastes are looking for that special unique hop, and what we can get from that hop. Hops are used to set a beer apart, and we have really seen that in the North American craft brews, and even in Europe. Traditionally, American beers were disrespected around the world, and for good reason. But now with the evolution of the craft beer industry, we are actually setting the benchmark worldwide, in terms of the breweries and the quality of the brews themselves. Now, maybe that isn't important for a Vermont audience, but for an audience in the Washington region, it is very important economically. It is a fact that most of the US hops production is in the Pacific Northwestern US. The US produces just under a third of the world's supply of hops, 77% of that is in the Yakima Valley in Washington, 16% in Oregon and 7% in Idaho. In 2008 the value was \$320,000,000. It went up some in 2009, and in 2010 it will drop off some. Annually, hops are one of the top 12 highest value crops in our region. It is generally around 30% of the world's crop, with Germany being the top producer.

A little bit of botanical information: Hops are in the *Cannabaceae* family. Its nearest relative outside of its genus is *Cannabis sativa*. There are three species within the *Humulus* genus: *Humulus lupulus*, which is what we are concerned with, *Humulus japonicus* which is actually an annual, and *Humulus yunnanensis*, which grows in China, and is believed to be a perennial. Very little is known about the latter. In fact, they don't even know how many chromosomes it has, or the mythology surrounding it, or anything like that. The hops that we are interested in, as I mentioned, are *Humulus lupulus*. These are dioecious, perennial climbing bines. They are indigenous to the Northern Hemisphere. In Europe there are several varieties of *H. lupulus*. In Asia we have *H. cordifolius*. Species that have origins in North America are *H. pubescens*, *H. neomexicanus*, and *H. lupuloides*. Most modern cultivars are a variation of the European *H. lupulus*.

Hop Basics: Hops are genetically complex. They are dioecious, meaning that you have separate male and female plants, which makes them obligate outcrossers, which causes a lot of genetic diversity. They are an annual above ground, and a perennial below. Hops are a climbing bine requiring a support system. They are photoperiod sensitive.

Hops have twenty diploid chromosomes. The chromosomes are fairly consistent in size; this here is pairing and meiosis. They have two paired chromosomes that are completely different sizes. These are the X and Y chromosomes. This causes some complexity. The primary female and male determining genes are on the X and Y chromosomes, but there are other genes that contribute to that as well. So sometimes you will see plants that are monoecious, they will have male flowers and female flowers. Most of the time those male flowers on the monoecious plants are not viable. They do not produce viable pollen so the plant can't self-pollinate. The end result is that hops are outcrossers. You get a huge amount of variation when you make a cross, and all the progeny are very different. It would be like a family: If I make an outcross, and I get a thousand offspring, every kid is going to be to be different. They may share the same color eyes, or the same color hair, but there is going to be differences in size and shape and any number of different things.

Regarding annual versus perennial: the above-ground portion of the stem is annual. It dies off each year. The root is perennial, and can survive pretty low winter temperatures. Somewhere like Vermont, I would think, for the most part you would be okay without protection. If you have snow cover you're great. If you know you are going to get really cold, and by that I mean consistent temperatures below zero for a period of time, then you would want some cover over the roots. Maybe some straw or something to protect that root crown. They are pretty hardy though. I really don't foresee many problems. The portion of the root that we are interested in is the rhizomes. Technically they are not a root; they are a below-ground stem. At each node on that underground stem are buds that become your new spring growth. Rhizomes are also what you can use to make propagations of the plant, which is one of the nice things about the hops plant. It is easily cloned and propagated. That is important in breeding and commercial production as well, because we can make a cross, identify a plant of interest, and fix those traits in the first generation, and then make cuttings from there. This is in comparison to, let's say, a grain crop you have wait for several generations, selecting along the way, until you get that genetically fixed plant for the traits that you are interested in. So, we do have a lot of complexity that we have to filter through as breeders. But also we have the benefit of being able to fix those traits in that one generation. The result is that in any given hop field, theatrically, every hop plant is genetically identical because it was a cutting taken off of what was originally one plant. So, if I develop a new variety and it ends up on ten thousand acres, you have a million plants that came from that one single plant. Theoretically they are genetically identical. The reality is that you do get off-types out in hopyards, either from the source material, or there is a male around who is pollinating those female cones and you could drop a seed into the crown and end up with a new plant coming up from that crown, or there is also genetic mutation that occurs. I don't know at what rate, but it does happen. So, for the most part, the vast majority of the field is genetically identical, which causes its own problems.

Generally, when we are looking to propagate a plant we are figuring about 10 to 1. You have to cut pretty hard from a plant to get 10 rhizomes from 1 parent plant. But it can be done. The other option is softwood cuttings. You let the mother plant grow and you take the green growth from that plant and cut them at a node, dip that in a rooting hormone, stick it into potting soil, and then into a misting chamber.

This is a very effective way to make cuttings. Actually, when you are starting with only one plant and you want to do a fast, rapid, expansion that is the best way to get it quickly. You don't get as strong a plant the first year, but you do get more plants.

As I mentioned, hops are climbing vines, so in the wild they are usually found growing with companion species. To replicate that under cultivation, in the field we have created our trellises. A typical field set up in the Yakima Valley would be an 18 foot trellis. This is a system of poles and wire worked and our plants are spaced at 3.5 feet by 14 feet, or 7 feet by 7 feet. The math is the same regardless, and you end up with 889 plants per acre. That is a typical set up, and the vast majority of the fields are in that spacing. There are other variations, but this has been the most successful. Some of the other variations include 6 feet by 3 feet, trying to get a lot more plants per acre, but there you would run into shading issues. So, balancing out the shade and the need for the number of plants per acre is where we came up with this 889. Just seems to work. Another variation would be using a low trellis. There has been a lot of interest in low trellis over the years. I have worked with a major farm on a big study on looking at existing varieties on low trellis. We found it can be done, but you do take a big hit in yield. On that same token, you are able to decrease costs by as much as fifty percent. So, there again, you run into the situation, when the price of hops is decent, low trellis doesn't look so attractive because your yield per acre is so much lower. But, when the price of hops is way down and you are looking for all cost cutting measures, that is when low trellis really looks good. Some other advantages: there is some question whether or not it is a more sustainable approach of production because it is easier to cover crop, your rows are closer together, and maybe you can farm that whole floor of that field better. Also, the application sprays are more efficient. There are some tradeoffs. There are positive and negatives to the system. What this system really needs, and what we are also working on, is the breeding of actual dwarf varieties. We found that for the existing varieties, you can make them work, but they aren't ideal. We need varieties designed specifically to grow on a 10 foot trellis. In my opinion, the ideal variety would grow 10 ft, stop, and then just have flowers on nodes that are only 3-4 inches apart all the way down to the ground. We are still a ways out from that, but that is what we are working on. Right now the main limiting fact is economics. It is going to take specialized equipment to harvest that field setup. You are going to need a field stripper to go out there. The least amount you are going to spend on that field stripper is probably about \$50,000, when it's all said and done. That is for one picker, and if you are the size of the average farm in the Yakima Valley, you are going to need multiple pickers. That doesn't include the repair bills and all the customization you have to do because these are being shipped from Europe. Until there is one developed here in the US, if there ever is one, then you have to deal with that. When you are trying to grow a variety that is meant to grow on an 18 foot trellis, what you are ending up with is a plant that grows up, and it just goes right over the top and you end up with this big brushy top so all your cones are in maybe the top foot and a half. What you really need for that to be successful is for the cones to be the full 10 feet of that trellis, all the way down. So right now, by putting a non-dwarf variety on a 10 foot trellis, you are only cropping the foot and a half to two feet at the top, and you really need to crop the entire thing.

The way the vine wraps around the string is a function of phototropism and thigmotropism, primarily thigmotropism. Phototropism is the following of the sun. It is responding to the light of the sun. It kind of gives it the initial direction of where to go. But then as that vine touches something there is a signal that is sent to the cells on the opposite side of that vine to elongate and it pushes it around. So what you get is this wrapping. Now, the interesting thing about the hop plant is the rapid growth. It will grow a foot or more on an ideal day. In fact Charles Darwin was once sick and he had a hops plant growing outside his

window and he clocked how many times he watched it as he lay in bed. So, that's the amazing thing you can just about watch these plants grow, that's how rapid they are.

As I mentioned, they are dioecious. You have male and female plants. The commercial value comes in the female in what are called the strobiles. We just call them cones, but the technical term is strobiles. The male plants are utilized only for hybridization and in fact they are frowned upon, and we try to keep them separate from commercial production. Any seed is a bad thing in a commercial plant. Having males around does increase the size of the cone, which is interesting from an aroma standpoint where you are selling on a per pound of hops basis... you can actually boost the size of the cones and get more weight. The problem is you can get the seed and you can get your per pound price docked for that. We have actually looked at using triploid males to reduce that seed content, and it kind of works, but you still get seed. The other problem with seeds is one that is more indirect. If you start dropping seeds into your field you start getting off types out in your field. You might think that one off-type isn't a big deal, until you get a guy out there digging rhizomes, and he decides to dig fifteen roots from that one hill. That goes into your next yard that you propagate off of, and all of a sudden there are fifteen more off-types. You can imagine if you propagate off that field, and each hill produces ten to fifteen rhizomes...well you get the picture.

These are some pictures of the males right at anthesis, so this male is ready to shed pollen and these are the females right when they are receptive to the pollen. This little gal is designed to pick up pollen. Unfortunately she also picks up powdery mildew spores and other things. These are mature cones. The cone itself is made up of that central strig. At each node you have two bracteoles, and a bract covering those. The bracteoles hold the ovaries, where the seed would occur. These are actually what we consider the manufacturing unit of the plant. The plant contains the lupulin glands; the lupulin glands contain everything we need to brew good beer. There is some flavor profile which can come from the vegetative material on the hops plant as well. But, obviously they are not as important as the essential oils and soft resins that we get from the cones. There are well over 100 compounds in the essential oils, probably hundreds more that we haven't identified. We don't know what they do. The soft resins contain the alpha acids and the beta acids. The lupulin itself counts for about 20 to 30 percent of the overall cone weight. In the female you can see the lupulin at the base of these bracts and bracteoles. Interestingly enough, the male also has lupulin, but it is in such a small amount that it would never be commercially viable. But as breeders, we have developed methods to extract these lupulin glands off those anthers, and then analyze that for its chemical composition. So it kind of gives us an idea of how that male compares to other males. We don't have a clue how it compares to the females because obviously we are comparing two different things. But it does allow us to compare male to male and help us with the selection of male plants for parents in terms of developmental physiology of the hop plant throughout the year.

When we are talking about hop growing, if you don't understand the developmental process that the plant goes through, you won't be successful in growing the plant. Anyone can grow a hop plant, but if you really want to maximize yield and quality you have to understand every developmental stage of the plant. Each stage does have its unique characteristics. Therefore, you have to change your management scheme to match up with those characteristics. So those main stages of growth are dormancy, spring regrowth, vegetative growth, reproductive growth, formation of cones, and preparation for dormancy. So, in dormancy, here late summer and fall, the plant has allocated all of its photosynthetically derived energy down to the roots, that starch is converted into soluble sugars, and that is what it really uses to explode

into growth the next year. At this time let's go out into the field. We may not be doing much out in the field. Maybe putting on some compost, kind of working that into the ground. We may be preparing new yards if we are going to be planting anything. So there isn't a whole lot. The yards are pretty quiet at this time. At the end of dormancy, the days start getting longer, they are getting warmer. The plant then starts using those sugars and it just takes off. In this initial regrowth, for anyone who is growing hops, it just takes off in a really rapid fashion with really long internodes, really gamey growth. These are not what we want for crop production. The plant is really just pushing that first flush of growth out, using a ton of energy. What we do as commercial growers is we go and cut all of that stuff off. We start with the next flush of growth, which is a little more controlled growth. Once we get through this period, probably the end of May or beginning of June, the plants have used up most of those soluble sugars, and now it is using what is in the soil. So here, if it is needed, this is where you would be applying nutrients. In the field, as I mentioned we are pruning and we do this about three weeks to a month before we are planning on training. You time this pruning around your desired training date. So we go through and mow the tops off. We'll do it mechanically with what we call a pruner, which is just some blades that go across the top, taking out those aerial buds. It does two things, one, it gets the desired pruning effect that we want, where we are getting rid of those first vines, but also we're getting rid of those aerial buds. Those are the buds that contain the overwintered powdery mildew spores, the overwintered downy mildew spores, and some other key issues. So, we are getting rid of those. About a month later we are able to train. At this time we are also interested in weed control. If you get a handle on control early on, you are obviously better off later in the season. If you are running a dry fertilizer program this is also the time to put it on. If you are going to do any type of fertilizer program, I prefer to do it as an as-needed program, or at least a split application program. It is personal preference. I think you are going to get a better effect out of the split applications or the as-needed program. It's a little more management but I think it is worth it.

We will start out with pruning. We will go directly behind that with twining. This is where we are actually putting the strings out. Rick gave a good example of that. We are using the same system. We are tying at the top. We have our guys going through, wrapping, or tying up their half hitches up on top and clipping down at the bottom. And then we go into the training. Training is critical. It is all variety dependent, so each variety needs to be trained at a different time. If you train at the wrong time you will impact your crop. If you train too early you could end with too much growth. If you train too late you could end up with not enough. You have to really time it around the type of plant you are trying to grow. I'll talk a little more about this but the key to good hop production is controlling growth. It's not just putting it on the string and saying, "I'm done for the season and we are going to watch it grow now." To really be successful you have to really know how to control that growth. At this time we'll begin irrigating.

Question: When is the time to start training?

Answer: Good question. A lot of it is anecdotal. We just know for a given variety that this is the time period that we need to train. So for example, if we know a variety is late, we know that the later varieties need to be trained later. If the variety is early then we know that it needs to be trained earlier. The problem is, certain varieties fall completely out of that classification all together. Take Cascade for example. That's kind of a medium maturing variety and we would expect, oh, this should be trained the first week of May, the second week of May and it would be fine. But that is not the case. Over the years we find that if we train Cascade at the end of April, like April 25th, we get our best yield. So, a lot of it is

really just learning the variety. There's nothing you can use that will tell you, "Oh, today is the day we train." There are no numbers, no models. I've tried to tie it to Growing Degree Days. I've tried a number of different things. The problem is you can make all the models of prediction based on what you have experienced thus far. The weather, the Growing Degree Days up to that point, but you have no clue what Mother Nature's going to do to you the next day. As soon as we think we can predict when the best time to train is, Mother Nature throws a monkey wrench in the whole thing.

Question: You recommend cutting off the first buds of the spring, and working with the next level. If you were transplanting plugs, as opposed to rhizomes, should you use the first ones or the second ones?

Answer: Are you talking a first year plant? If you have a baby plant, even a second year plant... if you have a mature plant, and by mature I'm talking 3 or more years old, that's when you want to be pruning. It doesn't matter if it comes from softwoods or from rhizome cuttings. At that point all plants are created equal.

Question: If I'm cutting a piece from there to start a new plant, sometimes you use the rhizome and sometimes you use the soft bud. If I'm using that soft bud, should I use that first one?

Answer: You can, sometimes we use that first flush of growth that comes out, and we'll get whatever we can off that hill. They may not root as easily as some of the other more succulent second growth. But you could still get a portion of them to root.

Regarding the pruning and training in Vermont. I'm not going to make any recommendations there because I've never grown hops here. It may be that with the shorter season, you can't afford to prune. But, given our Yakima season, we know that is how we maximize yield. Don't train that first flush of growth.

Question: When do you first start getting growth there?

Answer: We started getting growth a couple of weeks ago this year. Well actually, more than that. Certain varieties you could see the stuff popping up. We had an early spring this year. We have been unseasonably warm.

Question: For the first year, when you are planting it and it starts growing, should you thin some of them off or should you let them all grow?

Answer: The babies, we just let grow because there you don't have as strong of a plant. You don't have as many buds coming up. So the babies we tend to let lie.

Question: And it will help the root system?

Answer: Yes, you want to balance out the energy coming from the root system with the added energy coming from photosynthesis.

Question: What about a two year old?

Answer: Generally speaking, we won't prune a two year old either. But we have been known to go through and do some actual root pruning. We dig off of those beds. It's pretty rare, there again we are still

trying to maximize that root growth. In Yakima we have the benefit of warm weather and irrigation systems. We are able to get a pretty decent crop in the first year. Most areas where they grow hops can't do that. As a matter of fact, we've seen some varieties have their best crop the first year and then it drops off afterwards. This is kind of strange. But in most regions, in the second year, you will get an okay crop. Third year you are at full production, fourth year you are generally at full production. In Yakima we have the benefit of getting a good crop that first year.

Hop photosensitivity has to do with where the training date comes in. You are really trying to time it so, basically, it is a short day plant. Under a critical number of light hours floral initiation occurs. So if your days are real short you are going to get flower initiation. Now, that is not all that goes into that though, it is also node dependent. So, a plant, and it depends on the variety, will need a certain number of nodes before it will flower. So, once it hits that node number, and the days are short enough, it will flower. We time our plants in Yakima so that they are growing, they don't have enough nodes to flower, and then the days generally get longer and then all of a sudden the days are too long to flower, so they just keep growing. Then along about July 1st, well about the 4th of July, my grandfather always said that at the 4th of July you wanted to be at the wire. That's when we were growing all Cluster. That has changed now. Let's just use that as an example. By July 4th, you're over the wire, the days are getting shorter. Then it's okay for it to flower, you've got the growth you need. It's time to flower. You want to kind of time the training around that. This is also why most of the hop plants or most of the hop growing regions are around that 45th parallel. If you get too much further north, you don't get long enough days to get maximum growth. Too far south, your days are almost too short. I've had a lot of guys who say "Hey, you know, all my plants, they get up there around eight feet and they just flower. I can't get them to grow any more." Well, that's why. It's just too short a day.

Here, are some pictures. Tying strings at the top. Back here, this guy has the clip gun. He will grab this string and put those down and clip the string in the ground. It's called a "W" clip. The clip is actually shaped like a "W". So when it goes in the "W"s act like a barb and it holds that string down. Here is where, just after the water is getting turned on. It is actually a baby potted plant. Here's not too long after training and then, plants at maturity.

So, vegetative growth stage: this is where we have used up all our resources, we've trained, everything is on the string and then the plant just takes off. This is where all the growth occurs. At the beginning, May to end of June, early July, the plant growth is found in the main vine and leaves, and at the very beginning of July we are really pushing out side arms, and that's a pretty rapid occurrence. It's funny how much the vines change. They will go from being pretty spindly, until all of a sudden they will be nice and full. What's interesting here is how important this stage is ultimately to your crop. At 3 feet of growth, that little apical bud already contains the initial cells for numerous laterals. The laterals are really what are determining your yield. At twelve feet the apical buds of the vine and the laterals have produced cell that are predetermined for flowering branches. At 16 feet the cone branches have already been fully determined. Before that plant hits the top it has already deciding how much it's going to yield. At 3 feet it's already deciding how much it's going to yield. So, as tempting as it is to say, "Oh, look at my plants, they are on the string, we're getting great growth," the job's not over. In fact, it has become more critical at that point to make sure that plant has everything it needs. And that's why, I think, an on demand nutrient program is more important than just a shotgun approach. Because you need to give those plants the nutrients they need, when they need it. At this point the plant reserves are used up, it's already

determining its yield, and you need to manage plant health aggressively. Your goal is to maximize the health of the plant while managing the growth of the plant. You're managing health versus growth. It kind of sounds counterintuitive, you would think, the more growth you have, the better the plant. But you really want to control that growth because the inner node length also plays a major role in yield. You have so many nodes on that hop plant and you want all those yielding nodes to be below the wire, because once it goes up and over the wire, the signal in that apical bud changes. It's no longer growing up, but it is still pushing out growth to grow upward. It is not necessarily pushing out yielding growth. Ideally, you want all of your inner nodes underneath that wire. Well, it's nearly impossible with most varieties but you are trying to really control that growth. So you want shorter inner nodes. If you are just pushing nitrogen because you want your plants to look great, you are really hurting yourself in the long run. You want to hold back a little bit on the nitrogen, but you still need to give it what it needs. There is no magic bullet, it just takes time; you just have to learn how that plant responds. Every variety is different. Every environment is different. It is just where you should focus your efforts: learning that plant. You really have to watch your fertilizer at this point. My grandfather said, "The best type of fertilizer a farmer can have is his foot prints." I think that is the truth. I don't care what crop it is, you need to be out there learning the plants and learning what they need.

During this time in the field we are monitoring, monitoring, monitoring. We are out in the field; we have guys out there looking for pests and disease. We are responding to what we see in the monitoring. We are going through our spray program. We are going through our weed control program. We are irrigating extensively, at least in the Yakima Valley, obviously here it is going to be different. Then we are managing our fertility program. In terms of monitoring, just to show some examples of types of problems you can run into. The top pictures are of powdery mildew. So you can see the damage you can get there. If that powdery mildew gets in there early, when the developing cone is just set up for collecting pollen, and those spores get in there, it can completely decimate your yield.

The bottom slides are actually downy mildew. Downy mildew in an environment like you have here is going to be a bigger problem than powdery mildew. Powdery mildew causes a mess. It can cause major yield losses but you will have a plant the next year. You can try again. With downy mildew, you will be lucky if this is all you get, some reduced quality. If you get downy mildew down in the crown of your plant it kills the plant. So on a susceptible variety, what I have seen in past years is; you go into the fall, you have most of your plants out in the field, everything is looking good. Come spring 20% of your plants didn't survive. So you are not getting the re-growth. So you are doing that year after year. I've seen old yards that just are devastated. Fifty percent of the plants are dying. This is a serious disease if it is allowed to run rampant.

After our vegetative stage is over, we're entering the reproductive stage. By reproductive, I mean it is just developing its cones. The plant has shifted all of its energy from that vegetative growth. It is shifting now into the production of cones. The photosynthetic capacity of the plant at this point is maximized so it is using all that energy basically to produce the cones. At this point, once those cones are mature it can equal up to fifty percent of the above ground dry matter of that plant. At this point it's futile to increase the number of cones. Your yield is pretty much set in terms of cone number. But what you can do is make sure you are managing the plant properly to get the maximum cone size. That is something you can change. An unhealthy plant produces a smaller cone versus a healthy plant that produces a bigger cone. This can be done through water management and nutrient management right at this period, they kind of

overlap. There is a preparation for dormancy. It's not really a growth stage. I kind of made that up. But your plant is preparing for dormancy. In August, it starts to push those starches down. It is creating the starches needed to convert to soluble sugar for energy in the next year. Okay, like I said, that photosynthetic capacity of the plant is maximized in mid- to late-July. That is what it is really using to create next year's energy. This is where Rick had mentioned the hand harvesting and leaving the vines hanging. This is where that is really important because some varieties, their cones mature early. If you are out there cutting the whole plant out of the field too early, you are not giving that plant the optimum chance. Problem we have is that we have to mechanically harvest. We don't have a choice. We're not going to go out and pick eight hundred eighty nine plants per acre by hand. We tend to leave some material down at the bottom of the plant still green so it is there through the month of September to try to push as much carb reserves as we can. You will never maximize the yield of a plant on an early harvested plant.

Question: When you say you leave some green material down below, you're doing your shoot pruning and stuff, and you have your 4-6 vines that you train and take care of through the summer, in my experience, I'll still get a lot of green growth around the base throughout the summer. My tendency is to leave some of those. Is that the stuff that you are talking about?

Answer: Yeah, I call it "sucker growth." Leave some of that growth at the bottom. Let it crawl on the ground. That's where we tend to get our carb allocation back down to the roots. Some varieties, you never can get it matched perfectly.

Question: Do you test for nutrients?

Answer: We do a little bit of both. The main type of tissue testing we have done in the past is partial testing for nitrogen. That kind of tells us where we need it in production. Increasingly we are starting to do more extensive testing, actual leaf testing. But the problem is that it is expensive to run too many of those tests.

Question: So it is more of a visual thing if there is a deficiency in nutrients at the base elements level.

Answer: Yes, it is visual. Usually though, if you are seeing the symptoms you have let it go too far. There is the soil test early on that kind of gives us the broad picture. We can get a strong acid extraction on our soil to see what is available in the soil. Basically determine what we have in the bank. We will also do a paste analysis. We'll take a sample of our water and our soil; analyze those together to see what kinds of nutrients are available. Then we will run tissue testing throughout the season for nitrogen levels. Regarding the other nutrients, part of that is just an anecdotal program. We know that a certain leaf feed at a certain time is beneficial. Part of it is just knowing that this plant is going to demand this nutrient at a certain time. So we'll give it a little bit. Maybe not the full amount that the soil test says we need but with drip irrigation we can almost run it like a hydroponic type system, where you can give on demand right at the root zone.

Question: If you didn't use drip irrigation, could you still use a dry or liquid fertilizer, and would you just put it right where the plant is, or fertilize the whole area?

Answer: We still do some dry and we will generally band that right over the top of the hill. Occasionally we will shank it but shanking is a pain. I would rather just band it over the top and water it in.

Question: So you try not to fertilize anything in the aisles or anything that is not necessary?

Answer: That depends on your plant spacing, but generally you don't want to put too much fertilizer out in the middle because it is a waste of money. You are not really growing anything out there except your cover crop if you have one.

Question: When do you do your root cutting?

Answer: For planting material? That would generally be done in February or end of January. It depends on when we can get in the fields. As soon as we can get in the field we will start digging roots. You don't want to wait too long because they start growing in March. If you have growth then it is too late. We try to get out there before they start growing. They need a minimum of eight weeks of dormancy. If you can get out there and dig on them after it has been frosting for eight weeks, by all means if you need to dig, dig. But the way we try to time it is that we can go out and dig, and they might go into cold storage for just a little bit, and then we'll go directly back out to the field to plant them right away. I don't like to store them for too long, you will run into storage mildews and molds.

Question: Do you prune them back annually?

Answer: Not always annually. There are a couple of different ways we can do that. We can prune the roots back and get cuttings at the same time. We are serving the purpose of getting some propagatable material, but we are also serving the purpose of pruning that root crown back. There you have two reasons why we might go through by hand and do that. But generally our actual root pruning will happen with a disc, mechanically. We'll go through lengthways and crossways and it kind of blocks that hill.

Question: You have mentioned mostly nitrogen when you're talking about fertilizer. But what other nutrients do you find are needed by hops?

Answer: It is similar to any other fixed crop, where your N, P, and K are obviously important and depend on where you are at. A lot of soils have a sufficient amount of P and K where you don't have to add any. In our case we generally need it. It depends, we go field by field, we will soil sample and we'll make a decision on what each field needs. Generally speaking we will have a little bit of phosphorus going on and a little bit of potassium. Calcium is also key; it will usually come in a fertilizer blend. It will come on with one of our other fertilizers.

Question: Is there a particular time when you would apply those?

Answer: Generally speaking, calcium would go on in the same peak period as your nitrogen, the vegetative growth stage. You want to get it on before your potassium because the potassium will actually antagonize the calcium, make the calcium unavailable. You have to watch your timing and get it just right. Otherwise, you could be tying up one or the other.

We are going into dormancy. What is going on in the field? Well we are picking hops. On a typical operation in Yakima Valley, the vines are cut and transported to the picker. Alternatively, there are field strippers that will strip the vines out in the field and carry just that material back. Regardless, that material has to be shipped back to the stationary picking machine and then that is where the cones are separated from the rest of the material. We then dry the cones for eight to ten hours down to 10% moisture. Then

we cool them using ambient temperature air for twelve to twenty four hours in big piles. This allows cooling, but also is a kind of mixing action, and it allows us to equilibrate the moisture level within that pile so that we are not getting real dry pockets mixed with real wet pockets. Then immediately after that twelve to twenty four hour period we bale and immediately transport them to cold storage.

Question: How cold do you store them?

Answer: Generally, just below freezing is the ideal temperature, between 27 – 32° F, depending on the varieties. Some varieties don't store very well. In fact some are a hazard in storage. Take the CTZ's, once you compress those into a two hundred pound bale, if they weren't dried properly to the right moisture level, it would become a fire bomb hazard. They could actually blow up. It doesn't matter, they could be too wet and blow up, or they could be too dry and blow up. If they are too dry, it is like an oil soaked rag problem...it will combust. If they are too wet, it is like a wet bale of hay, same type of spontaneous combustion. You have it on both sides. That is why with certain varieties, we want to get them into cold storage as soon as possible, but also if they are a risk, they go into pellets as fast as possible.

Pictures regarding harvest. Mechanization is key. We mechanically sort the leaves from the vine. Rick mentioned his time frame for hand picking and he is right. We used to do that for the breeding program. We used to hand pick everything. We had a crew of five or six people and it would take about an hour per vine. It was a pain. The mechanical picking is key. Back when my great grandfather first started growing hops it took a hundred people thirty days to harvest thirteen acres of hops. Mechanization is needed if you are going to do anything on any type of commercial scale.

We are drying them in forced air at fifty cubic feet per minute at 130 – 150° F, the lower the temp the better. If you are high volume, you run into problems. If you are harvesting a lot of volume on high yielding varieties sometimes you fill your kilns up. It costs you a lot of money to shut everything down and stop and wait for your kilns to empty out to start picking again. Sometimes, you'll fill them a little more than you'd like.

Question: Can you air dry them if you are doing small batches?

Answer: Yes, if you are doing small batches, you can air dry, but you should be moving air through them. You have to watch your humidity level. If it is really humid out, you are not going to get them down to the proper moisture level.

Comment from the Audience: We are drying canola and sunflower seed. Just air drying.

Jason: If you can pull that off you should be able to do hops. I've done hops air dried before. It can be done. But I prefer the heated method because you can get it down to the precise level that you want. We compress the dried hops down to two hundred pound bales, ten to twelve pounds per cubic foot. Each bale requires about five and a half yards of burlap. This is a machine we developed on our farm. It is kind of a new method. The old method was to bring the vines in whole, and then you would have guys called vine hangers who would hang them on a chain that would take them up through a stripper. Strip everything off, and then there was a whole series of belts and other things that would clean the cones. We

have the same equipment behind this where we are running through the same belts and everything but at our front end we actually come in and dump the load completely. We don't have the vine hangers. It saves us about ten people per shift. This whole load comes off at once and then it is cut into eighteen inch sections by a big blade. The whole vine is still coming in, but we are able to unload all of them at once and then cut those vines into eighteen inch sections. That cleans it out. You can see that it is a whole process. We have fans and all these other things that blow out leaves. These are dribble belts. These are inverted belts to where the cones roll down but the leaves and everything else stay on it and go through. So it is a whole big process. The machine is in a huge sixty foot tall building. To build a brand new Dauenhauer machine with this capacity would be a million dollars plus.

Question: How many acres do you have on your farm?

Answer: On the home family farm is 600 acres of hops. We also partner with another farm and harvest another three hundred acres. So, a lot of hops run through this machine. It has been close to a thousand acres of hops run through this machine each year. We are running at full tilt, and we are usually the last ones done picking. We get laughed at a lot because we are still picking on October 15th. That is just wrong. These are the kilns. As you can see we have our beds. This bed has been dumped at about 30 inches deep or so. In the morning you can see the steam rising up off of the big kiln bed. Back here is our kiln layer. The cones come in on this belt from the picking machine and it is dumped across here. There's this belt. It lays it out evenly. It is done automatically. Traditionally, we would have to fork it by hand. That was the generation before me. I've done it before when the kiln layer breaks down, and it is a lot of work.

This is the next step. This is the big pile of hops I talked about that is equilibrating. This is what we call our cooling room. This is an example of a bale. These particular hops are from one of our organic yards.

Question: How do you move your hops from the dryer to the kiln?

Answer: Inside the kilns we have what we call kiln cloth across the floor. So the floor is just a grated floor so that the hot air can come up from underneath and on top of that grated floor we have kiln cloth. It is almost like burlap but it is a wider mesh than burlap. The hops are laid on top of that. When we are done we have the kiln cloth hook to a drum at the end that rolls it up and it slowly rolls those hops into a conveyor belt at the end. They dump into there and take the belt over to the cooling room. You really have to be careful with the dried hops, handling them as gently as possible. You have to be realistic, there is going to be some tumbling. There is going to be some damage of product. At that point they are going to be really susceptible, especially if you have over-dried them, to shattering and losing lupulin glands. Every gland that you lose is losing active product out of that cone.

Final comments on development.

We need to fully understand these growth stages if we are going to be successful as growers. Each stage has its own unique characteristics so you need to tailor your management strategies for each stage. Then you have to remember that your yield is being determined when your plants are only a few feet high. To complicate things further, and I've said this all along, much of this is variety dependent. Our physiology and development are impacted already and so is crop management. On top of all of this, there is a strong genetic by environmental interaction when it comes to hops. Some varieties just will not grow in some

areas. Our goal is to realize our maximum genetic potential of each of these hops plants. The problem is, in certain environments the maximum genetic potential cannot be reached. The solution that farmers and researchers have been coming up with for years is to breed varieties to match your environment.

This is an example of yields from the new US aroma hops varieties. The far left bar here is our noble European aroma hops. The average yield in the US is below a thousand pounds per acre. It makes it very difficult to actually grow those hops and still be economically viable. So the answer over the years was to start breeding better and better varieties. All of these were developed in the US, derived from the noble aroma hop varieties. The latest one of these releases was Palisade which came out of our breeding program. We have seen yields as high as three thousand pounds per acre, but it averages around twenty four hundred pounds per acre, versus Mount Hood and Glacier which are just over fifteen hundred pounds per acre. You can see that over time we have been able to take these hops, hopefully with similar characteristics that the brewers are looking for, from the noble aroma hops and make them a little more economically feasible to grow. Take a look at it from the economics and the hops supply chain. This is our typical supply chain. You consider that each of these steps will affect the subsequent steps. On the farm you have the cost per acre. That will affect a number of things down the road. The yield of the hop will impact the cost per unit, the harvest, all of this impact the return to the grower. The variety impacts the storage stability of the variety: pellet recoveries, extract recoveries, and shipping. At the brewery, different varieties will affect the efficiency at the brewery, the quality of the final product, the flavor of the final product and ultimately the cost of the final product. You can see that there are all these different factors kind of linked together that impact each other. What we have really seen is that we have put the breeding program kind of on the front end of that supply chain. We are looking to supply the varieties that can maximize our efficiencies or our returns for each stage of the industry. As a breeder you need to base your objectives on the needs of the whole industry, not just one segment. We have a tendency to look at things from just an agronomic stand point, or just a quality stand point. Depending on whose angle you are looking at it from, neither one works. If you are just trying to grow it from the agronomic stand point, I throw hundreds of great looking hops away a year, the yield is awesome, looks great, but the problem is they don't have the quality parameters that brewers are looking for that would be successful in the brew kettle. So they get thrown out. It has to have the whole package.

We are really breeding for two distinct markets. The alpha or bittering market, these are generally processed hops. Yield is measured in kilograms of alpha per acre, rather than pounds of hops per acre. These are typically the high alpha varieties, the super alphas, you could kind of call them the Walmart hops. They are just all about mass production and efficiencies. Then you have the aroma. Here there is minimal processing. Yield is measured in pounds per acre versus kilograms of alpha per acre. In some cases, some of the major breweries are still using some aroma hops, but will buy them based upon their kilograms alpha per acre. Because they are using them for not only their flavor profile, but also as a component of their bittering profiles as well. It can vary from brewery to brewery. But this is very important when we are setting our breeding objectives. In terms of setting specific objectives, we are looking for those high-yielding, high-alpha cultivars. Generally, we are looking for those super alphas but we are also looking for those varietal alphas. Some of you might be familiar with the hop called Citra. I think most of us are familiar with Simcoe. Both of them are fairly high alpha hops but they have this really interesting aroma profile that kind of puts them in both categories. It can be used for a bittering hop but they are also great for their aroma profile. Then you have your high yielding aroma cultivars. I have showed you the slide of the comparison of the noble aromas versus the US aromas. Here we are

looking at the specialty or dual purpose hop. Then increasingly we have started a program within our breeding program breeding specifically for organic varieties. The goal is to combine all of these quality parameters with pest and disease resistance, good storage stability, and desirable brewing characteristics. A typical breeding scheme would run through a parental selection and crossing, early selection, intermediate selection, advance selection and cultivar release.

Question: How long does that take?

Answer: It's about a ten year process.

In terms of parental selection, remember hops are dioecious. We have to select a male and a female. In terms of the male, unfortunately, we don't have a clue what it is going to provide in terms of brewing quality. We can check its alpha, relative to the other males, we can check cohumulone, even its storability, but still we don't have a great idea, even from its yielding standpoint.

Question: Is there a germplasm of male hops?

Answer: We maintain a collection within our program and the USDA has a collection of male germplasm as well. So there are collections around the world of different male plants.

Question: When you order a rhizome from someone are they usually all females?

Answer: They had better be females. If it is going into commercial production, generally speaking, you can be sure that what you are getting is what it is labeled. If it is labeled as Cascade and you end up with a male plant, then they screwed up, or it is the off-chance that they dug off the wrong plant or something like that. For the most part, if you buy a rhizome from someone it will be female.

Question: Can females turn male?

Answer: No, there are certain varieties like Cascade and CTZ that will do this where, under certain environmental conditions, they'll put out male flowers but they aren't viable and it is just a temporary thing.

Here are some examples of crossing. This is actually our pollen collections system. We are cutting the flowers off the males putting them in the plastic tubes, allowing them to sit overnight and the pollen is dropping off and then we sieve that and we are able to collect our pollen. We are able to store that then for quite a while, for a few months in a desk crate or even longer in liquid nitrogen. We can store the pollen and use it at any time.

This is making the crosses. We go out and put these bags on prior to the plants becoming viable for pollination so that we aren't getting any cross pollination from any males that may be about. These female plants aren't very picky, they get around. It looks like a big candy wrapper. I will climb up on a ladder and blow the pollen in onto the respective flowers and then we seal it back up for a few more days. Then we can take it off. At the end of the year we will harvest those and collect the seed that was created.

We enter them into a ten year selection process that is separated into early selection, which are seedling and single hill year, intermediate selection, which are our yield trials, and then into advanced selection. So basically, you have your cross, that is year one, and the early selection the first year, which is your

seedling year. This is a high density planting which is meant to be what we call "fail fast". With our "fail fast" philosophy, we are trying to get rid of as many as we can the first year. In year one, that seedling year, I'll eliminate probability 80-90% of the population. In year two, we go into the single hill. This is a single plant nursery where the plants are evaluated for three years. Then we have three more years on top of that, so we are now into year five. At the end of that we'll make selections. So we might end up with maybe about 3,500 – 4,000 plants per year going into that single hill nursery. Out of that I might select ten. At the seedling stage, we probably started with 50,000 seeds, got that down to a manageable number through greenhouse screening and other techniques, and went to the field with them. By the end, that 50,000 becomes a much lower number. So you can see what we are trying to do. We are trying to get rid of as many possibilities as fast as we can. In the intermediate stage, these are yield trials expanding out anywhere from 10 – 80 hills. Just to get a better idea of the stability of the selection and how well it is going to yield under a more commercial setting. This is three more years: We are up to year eight. Then we will make another round of selections, and we are lucky if anything makes it to the next stage which is our elite trials. This is where we are going into a half acre, maybe a one acre size plot. Something has to be really good and have a lot of potential to make it to this stage. That is at least a three year evaluation. We are into year eleven, from crossing, clear through to release.

Question: What are your evaluation tactics?

Answer: We start out first with agronomics. We will have thousands of plants. We are looking for disease resistance. We are looking for yield. Those have to be the first things we look at. Then of the best of the best from there we look for the quality aspects.

Question: So you are brewing at this stage?

Answer: We can start brewing at the intermediate stage. We work with quite a few craft brewers in the Northwest, and a few other regionals, getting them material and doing either a sensory panel, they'll do it in-house and then give us feedback, or they will actually brew with it if we have enough material. Generally, if we are excited enough to send it to breweries for brew trials we'll harvest as much as we can from it. We'll get thirty pounds just knowing we will be sending that off to a brewery. It is here where we get a good test of its brewing capability. Because that's where we can go to either several smaller breweries or a handful of larger regional breweries, or in some cases, if it is something a major macrobrewery might be interested in, we might ship them the whole production from that trial so they can run a larger brew trial. It just depends on what the ultimate use of that hops will be and what market we are targeting.

Wrapping up... Here are some pictures of clipping, this is the seedling nursery, like I said, high density. Here is what I talked about: fail fast. These are yield trials, and elite lines. After eight to ten years of evaluation, we will consider it for release. A whole other level of work begins, we have done all the foot work as far as testing it and we know it is a great variety in the field. Then it has to be accepted into the market place, and that is the difficulty. The beauty that we have in the US is that we have such a thriving craft industry, and so many brewers are willing to give a hop a chance, or to try it just because it is something different. In other regions in the world it is more difficult to get a hop in the door if it doesn't have the right characteristics. Right from the get go they just say "We don't want it." At least we are able to get it out there and get it tried by a number of different people.

Question: How many different breeding programs are there in North America?

Answer: In North America right now there are four private programs and two public programs. They're all out west.

Just to give an example of breeding efforts. These are both examples of Palisade grown under conventional conditions and this is Palisade grown under organic conditions. Here we bred this for our conventional system. It is our highest yielding aroma variety out there, but we put it in our organic system with the expectations that it would perform very well, but the best we have been able to do is a thousand pounds per acre. Less than half of what we can get under conventional. Here is a comparison. Here is our yield. Our conventional Palisade yielded almost three thousand pounds per acre. We were less than one thousand pounds per acre on our organic. Our conventional cost us just over five thousand dollars per acre to grow. Organic cost us sixty five hundred dollars an acre to grow.

Question: Is it disease pressure that is the problem?

Answer: This is actually mites. Mites and lower nitrogen use efficiency.

We went in a few years ago and made some crosses and are evaluating those specifically in our organic yard. We had some parent plants that seemed to have some insect and mite resistance. Here are our top ten genotypes compared to Palisade in terms of green pounds per plant. We have had some success growing significantly better yields. Here is a picture of a plant that has been devastated by the same mite pressure, in the background is a commercial planting, and here is a selection from the breeding lines.

Question: Could it be because of pesticide use?

Answer: No. Well, conventional versus organic, yes. We are using pesticides to fight the mites in the conventional yard, and in the organics we weren't using them. Actually, that's not true. We use sprays on the organics. We spray them more than our conventionals. If you ask me if organic, just for the sake of organic, is the most sustainable way to grow hops, my answer is "No," but that is discussion for another time. Organic production has to reach another level for it to be successful. Organics just for the sake of organic, it doesn't work. The other issue is marketing. You have seen some agronomic success but can you market them? Hops are listed under the USDA's NOP section 205606 which allows conventional hops to be used in a beer labeled organic, which means that most beers that are labeled organic are not made with 100% organic hops. From a marketing standpoint it is a nightmare. Is anyone interested in buying some hops? Because I have a few thousand pounds of organic hops sitting in storage right now. There is no real desire for them and so it is a difficulty. What we are doing right now is really starting to push hops off the exclusion list. We have formed an organization called The American Organic Hop Grower Association. The main intent in the beginning was to petition the government to get hops off that list. The second goal was to just increase the awareness of organic hops.

Question: Have you experienced in other countries a similar situation, where hops are on an excluded list?

Answer: No, I believe in the European Union they need to be organic.

We are going to work really hard to get hops off that list. It will be a shake up at the start to actually bring this into a situation where we actually require organic hops to be used in beer. But I think that the pain will only be felt for a short period of time. If the demand increases, so will the acreage of organic hops. We are forming that association. It is the American Organic Hop Grower Association. Look us up on line.

From the conventional stand point I will leave you with this. Keep this in mind. This is the average price of hops from 1991 to 2006. Up until then 2006-2007 the price of hops was below \$2.00 per pound. On our highest yielding varieties, the best we can achieve as a cost per unit is about \$2.00 per pound. We were barely breaking even in those years. Most years we were losing money. That has to be taken into consideration. If you are going to seriously consider hops as a commercial endeavor you have to know the plant and the environment you are putting it in. That's key. It goes back to all the things that we have discussed. But also know your market. Are you targeting organic? Are you targeting local? Are you targeting sustainability? Basically look for the niche where you can fit in and create your niche. Hops are a commodity. How we are farming in the Yakima Valley just doesn't work on a small scale. You need economies of scale if you are going to make it work. If you are going to grow hops commercially on a small scale you have to find your niche. You have to develop a relationship with the brewers, which we have been forced to do on the organic side. From the grower's standpoint, get out there and talk to your brewers. From a brewer's stand point, it is going to take the brewer to step up and say, "Let's work together on this" because it is an expensive endeavor. In the long run it will be worthwhile.