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First Steps Toward Understanding the Regional Identity of Hops Grown in the Willamette Valley, Oregon

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ABSTRACT

Regional identity, or terroir, is the concept whereby the unique flavor and quality characteristics of different crops or products relate to their place of origin, and it is well-studied in winemaking. This study presents preliminary evidence of regional differences in two hop cultivars, Centennial (two locations) and Sterling (three locations), that were managed similarly in the Willamette Valley during 2018 via a collaborative effort among Oregon State University (OSU) (Corvallis campus and Marion County Extension), the Indie Hops-OSU Aroma Hop Breeding Program, Coleman Agriculture, and Red Hill Soils. Soil chemistry and morphology, local weather data during the growing season, and regional climate data were gathered to quantify differences among the sites. The hops harvested from each site were examined via ASBC standard methods for hop acids, total oil, and oil composition. The same hops were used in brewing trials, and the resulting beers were subjected to sensory analysis by a panel of professional brewers and hop growers as well as a panel of trained sensory assessors. Differences were observed in soil and local weather characteristics, plus chemistry and sensory qualities of both the hops and the resultant beers. These results point to the potentially important effects of soil and weather on hop characteristics and open the door to a broader discussion and further inquiry of the regional distinctiveness of hops.

The Concepts of Regional Identity and/or Terroir as They Apply to Hops

Key to regional identity is the concept that unique flavor and quality characteristics of different crops or products relate to their place of origin. These unique characteristics may result from differences in climate, geology, soil, local management practices, or processing practices. In this regard, regional identity is very similar to, and perhaps is synonymous with, the concept of terroir. The wine industry has a long history of utilizing the terroir concept to help characterize and classify different wines, to identify current and future production regions, and for product marketing. The creation of American Viticultural Areas was based in large part on the premise that regional differences in wine grapes exist, and these differences are perceivable by winemakers and consumers. Beyond wine, other examples of regional identity can be found in a wide variety of food products such as cheese, fruit, coffee, and olive oil (3,22). Indeed, consumers, producers, and buyers have long held preferences for products coming from certain regions. This has grown as consumers in developed countries increasingly have access to products from around the world and are eager to explore, understand, and develop their tastes for products coming from specific regions.

In this same vein, brewers and hop producers are interested in knowing how different production regions and practices influence hop cone chemistry and aroma profiles. In the production of beer, hops not only provide bittering and preservative qualities to beer but also flavoring and aroma components. The production and use of aroma hops have risen steadily, driven by craft brewing demand (8). This increase in aroma hop use has potentially opened up new opportunities for regional differentiation and identity. The overarching question is, can hop quality such as chemical profile, flavor properties, and aroma properties be related to specific sites, and if so, what site properties are important? Although evidence linking hop aroma chemistry to production regions is limited, three recent studies conducted on a global scale have begun to address this question (2,16,20).

The exact variables measured to delineate a region or define terroir are not standardized; however, they generally include measures of climate, geology, geomorphology, and soil type (5,21,22). The set of variables should reflect attributes known to influence the final product (for instance, timing of fruit maturation, ratio of acid to sugar, and concentrations of specific aroma or flavor compounds). For many products, we do not know the precise variables or the interactions among them that influence the end product. A suite of variables considered important for defining wine grape terroir can provide us with a

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starting point, but one should remember that hops are a very different crop, so the same variables may not be as useful for defining hop terroir.

Aroma hop production targeting the craft beer industry is still a relatively new endeavor, and little data exist describing best management practices for influencing hop aroma (besides cultivar choice). However, to begin thinking about the most influential variables of hop quality, we looked at the most studied production aspects—irrigation, growing season temperature, and harvest timing—and also looked at additional variables that are used to describe wine terroir. On a global scale, we also know that latitude plays a strong role in hop development because the initiation of flowering is day length sensitive, and most hop cultivars need sufficient chilling during dormant months for optimal regrowth. For these reasons, hop production has historically occurred between 30 and 52° latitude N or S (7,14). Some studies have shown no effect of irrigation on α-acid and β-acid contents (6,13). However, Srečec et al. (19) did find a negative correlation between evapotranspiration (an indicator of water and/or heat stress) and hop cone yield and α-acid content. In general, it is difficult to decouple heat and moisture stress in these studies. Air temperature can affect bine maturation. High air temperatures during cone development, particularly during the third to fourth week of flowering, might be most critical. Srečec et al. (18) found that the onset of bloom and the time between secondary branching and flowering affected both yield and α-acid content. They found that increased heat units negatively affected cone yield and accumulation of α-acid. In a drought year, yield was halved from 1,800 to 900 kg/ha, and α-acids decreased from 11.5 to 6.2%. Similar patterns were observed over a 6-year period in other work (19). The authors emphasize that temperature, heat units, and rainfall are most critical during cone development (July to August in the United States).

Three recent studies show that hop essential oils are sensitive to harvest timing (10,11,17). In each study, hop oil content increased with a delay in harvest. Lafontaine et al. (10) noted that this increase in oil content was associated with increased aroma intensity and citrus quality in Cascade hops. Their analysis of sensory attributes also showed that samples from a given year tended to clump together, suggesting that unique aroma chemistry developed in a given year. Hop acid content may be less sensitive to harvest timing than essential oil content (12,17).

Aside from the variables used to define terroir, the scale at which terroir is defined can vary. To date, studies on hop cone chemistry have all been conducted across large geographical domains: for example, comparing hops produced in different U.S. states and in different parts of the world (Europe, Australia, and the United States most frequently) (2,16,20). For instance, comparing Cascade hops from the United States, Germany, Italy, and Slovenia, Rodolfi et al. (16) observed differences in bitter acids and xanthohumol content and distinct aroma profiles among samples; however, no relationships among rainfall, temperature, or latitude were observed. A study by Barry et al. (2) compared Cascade, Mt. Hood, Golding, and Nugget cultivar hops from Germany, the United States, and Nova Scotia and found differences in aroma attributes of both whole-leaf hopped and dry-hopped lagers among panelists. Yet, this study did not examine climate, soil, or any other variables related to terroir among the sites. Similarly, Van Holle et al. (20), evaluated Amarillo hops grown in Idaho and Washington (U.S.A.) and found distinct differences between the production regions and between years at the same location. The size of the geographical domain likely impacts the relative importance of different variables that might affect regional differences. When examining differences at the farm or field level, for example, climate factors become less important relative to soil properties and drainage.

There is growing evidence that regional differences in hop chemistry and consumer-detectable aroma hop characteristics may exist, at least at the national and global levels. However, we cannot yet tease out specific climate effects among regions or years if they exist, nor do we understand the impact soil variation and management practices might have. Studying these factors at the farm level may provide insight into the effect that these variables might have and guide management decisions for high-quality aroma hop production.

The study described herein examined two American hop varieties, Sterling and Centennial, grown at three different locations within the Willamette Valley. The work began at the request of Coleman Agriculture, Oregon's largest hop producer and one with over 120 years of continual hop growing experience. Aware of consumer interest in regional identity, its use in the wine industry, and growing interest among hop buyers and brewers, Coleman Agriculture wanted to better understand their own farm sites and gain insight into what variables might affect hop quality at the farm level. They wanted to characterize the soil variability among farm locations and within a field to help guide management decisions. This work has begun a longer journey toward understanding and characterizing regional differences of hops grown in the Willamette Valley, Oregon.

Methodological Approach to Assessing Regional Identity for Centennial and Sterling Grown in 2018

Identification, Description, and Characterization of Locations within Coleman Agriculture Farms

Coleman Agriculture is the largest hop grower in Oregon and produces hops in three distinct regions within the Willamette Valley: St. Paul/Gervais, Mt. Angel, and Independence (Fig. 1). One Sterling and one Centennial field at each of these locations was studied with cones harvested in 2018.

Homeplace Farm (St. Paul and Gervais, OR). The Homeplace farm consists of disconnected plots scattered around St. Paul and Gervais, OR, totaling about 900 acres (364 ha). This agricultural area is where most Willamette Valley hop producers are found. The two fields observed for the study are 8 miles (13

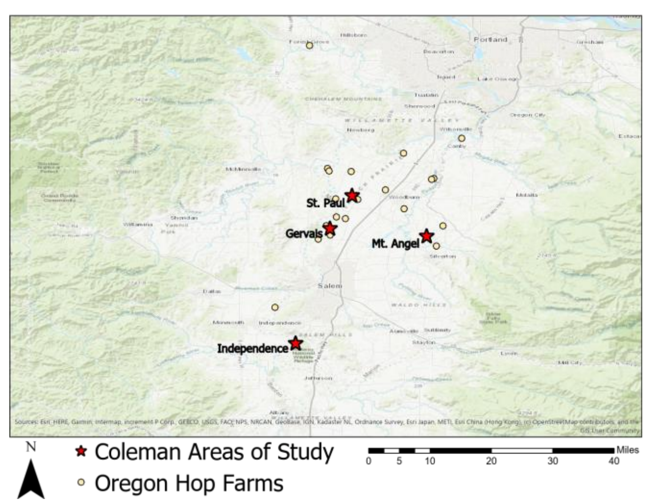

Figure 1. Hop growing sites.

km) apart. For this reason, the St. Paul and Gervais fields have been viewed as sharing the same growing area for the sake of this study. The two fields studied were Goulet 72 (Gervais, OR) growing Sterling and Aunt Dora 7 (St. Paul, OR) growing Centennial. See Table 1 for detailed descriptions.

Alluvial Farm (Independence, OR). The Alluvial farm is located about 40 miles (64 km) south of the Homeplace farm in Independence, OR. The farm sits in a flood plain of the Willamette River; hence, it is named the Alluvial farm. It is the largest of the Coleman Agriculture hop farms at more than 1,000 contiguous acres (405 ha). The Alluvial farm is the furthest south of any of the commercial hop yards in the Willamette Valley. The two fields studied were Alluvial 40 growing Centennial and Alluvial R3 growing Sterling (Table 1).

Mt. Angel Farm (Mt. Angel, OR). The Mt. Angel farm is located 15 miles (24 km) east of the Homeplace farm in Mt. Angel, OR. A majority of the hops are spread over three blocks that total nearly 300 acres (121 ha). Fields are positioned along the base of the Mt. Angel Abbey and are irrigated via wells and also from Abiqua Creek. The two fields studied were Mt. Angel 80 growing Centennial and Mt. Angel 84 growing Sterling (Table 1).

Farm Management Practices

Approach to Management. Each hop field at Coleman Agriculture is managed with the goal of maximizing harvested cone yield (bales/acre) and quality (high cone integrity, low hop storage index, appropriate moisture, etc.). Fields at all locations are generally managed on the same timeframe and with the same methods; however, small adjustments are made on a field by field basis when needed to compensate for differences in soil, environment, and pest pressure. Some key management variables considered in this study included fertilization rate and timing, irrigation, pruning dates, and pesticide application frequency.

A similar fertilization program was used at each farming location, with slight adjustments made from field to field based on soil and tissue nutrient samples taken in the spring, summer, and winter. Each field was treated with a dry fertilizer blend once in the spring and then given five liquid nitrogen applications of fertilizer from June to July to promote vegetative growth. Any lime or other soil amendments were applied in the fall after harvest. Soil and tissue nutrient levels were considered in part with the growth stage of the plant to inform adjustments in fertilizer applications.

Irrigation decisions were made by considering soil moisture, soil type, and weather. Soil moisture probes and site-specific weather stations were used to track this information. Irrigation timing was determined using moisture probes that track when soil moisture had dropped below a set minimum level, at which point water was applied to bring the soils back up to an optimum moisture level. The minimum and optimum moisture levels are determined by the texture and water-holding capacity of the soil. The irrigation cycle during the growing season consisted of a 5 h set every 1–2 days.

Established hop yards were pruned starting in February to remove the previous year's growth and allow new shoots to emerge. This was carried out either chemically with herbicides or mechanically with a flail implement (Table 2). Pruning timing was based on the vigor of the plants and when they were scheduled to be trained.

Pesticides and fungicides are used only when necessary to maintain the vigor and quality of the crop. The type, amount, and frequency of spraying are determined primarily by observations within the fields by field scouts. The field scouts track pest and disease pressure in each field on a biweekly basis and report their findings. These reports are used by farm managers to diagnose how each field is treated.

Postharvest Practices

Harvest Date and Maturity. Like many crops, different hop varieties mature at different times in the growing season. In Or-

Table 1. Fields used in this study

Field	Variety	Description
Goulet 72 (Gervais, OR)	Sterling	The field is larger than average at 47.3 acres (19.1 ha) and has three soil series mapped (Chehalis, McBee, and Cloquato). These soils formed from a stratified river alluvium of the Willamette River that is 500 to 5,000 years old.
Aunt Dora 7 (St. Paul, OR)	Centennial	The field is average size at 26.7 acres (10.8 ha). This farm has four soil series mapped (Amity, Concord, Woodburn, and Willamette). The soils formed from Ice Age flood silts deposited in the cataclysmic floods over 13,000 years ago.
Alluvial 40 (Independence, OR)	Centennial	This field is medium sized at 24.9 acres (10 ha) and is about 200 yards (180 m) from the Willamette River. Cloquato and McBee are the two primary soil types in this field. The soils are formed from a stratified river alluvium of the Willamette River.
Alluvial R3 (Independence, OR)	Sterling	This field is a long-narrow, 5 acre (2 ha) field set about 0.25 mile (400 m) off the Willamette River. The field has diverse soils for its small size with three distinct soil types including Newberg, McBee, and Cloquato soils. The soils are derived from a stratified river alluvium of the Willamette River.
Mt. Angel 80 (Mt. Angel, OR)	Centennial	This field is average size at 19.7 acres (8 ha) and sits at the bottom of a gradual slope. It has four soil series mapped (Amity, Concord, Woodburn, and Willamette). The soils formed from Ice Age flood silts deposited in the cataclysmic floods over 13,000 years ago.
Mt. Angel 84 (Mt. Angel, OR)	Sterling	This field is surrounded by large hills on two sides and sits below surrounding fields at the farm. It is medium-large at 23.1 acres (9.4 ha). McBee and Waldo soils are mapped in this field, the only location where Waldo soils were mapped. The parent material is a stratified river alluvium deposited by a tributary creek of the Willamette called Abiqua Creek.

Table 2. Field management and kilning data

Field	Variety	Year planted	Pruning dates	Pruning method	Training dates	Harvest dates	Dry matter (%)	Average kiln time (h)
Alluvial 40	Centennial	2016	Mar 26–31	Mechanical	May 12	Aug 21 and 22	22.8	10.5
Aunt Dora 7	Centennial	2012	Apr 3	Chemical	May 12	Aug 21 and 22	21.9	10.3
Mt. Angel 80	Centennial	2013	Apr 9	Chemical	May 9	Aug 21 and 22	23.3	9.6
Alluvial R3	Sterling	2010	Mar 29	Chemical	May 10	Aug 27	23.5	8.9
Goulet 72	Sterling	2015	Mar 28 and 29	Chemical	May 10	Aug 29–31	23.3	7.4
Mt. Angel 84	Sterling	2015	Apr 9	Chemical	May 15	Sept 1–3	22.7	8.1

egon, early varieties typically ripen in mid-August and later varieties in mid-September, with most varieties falling somewhere in between. In addition to historic harvest timing, readiness can be determined by observing the way a hop feels, smells, and looks. A mature hop will often feel dry and papery and should be easy to split down the middle along the stem of the cone. The lupulin inside should be a deep yellow color and highly aromatic. Vegetal and grassy smells indicate immaturity, whereas garlic and onion aromas can be a sign of overripeness. In many varieties, the bract of a ripe cone will look slightly flared out and will have lupulin visible on the outside of the cone; however, this varies by variety. Some experienced growers report that a ripe hop makes a distinct sound when shaken. Another common and reliable tool for determining harvest readiness is dry matter testing. This test is performed by weighing a sample of wet cones, drying the sample down to 0% moisture, and reweighing to determine the weight of the dry plant matter. The ideal percent dry matter varies by variety and market preference; however, it is usually between 20 and 25%. Coleman Agriculture combines visual and tactile assessment with dry matter measurements to identify harvest dates for each hop variety that they grow.

Kilning and Cooling Processes. After cones are harvested and picked, they are dried to 8–10% moisture. Drying is carried out in hop kilns located at each site, in which hot air at 135°F (57°C) is pumped through a bed of hops to remove moisture. Typical drying times range from 8 to 12 h depending on variety (Table 2). Once dry, the hops are moved to a cooling room, where they sit for 12–24 h to reach appropriate baling temperature. The cooled hops are packaged in 200 lb (90 kg) bales for storage and customer delivery.

Hop Sampling Used for Chemical and Sensory Evaluation. The sites chosen for this study were planted with hops that were on average 5 years old at the time of the harvest for both varieties and were managed similarly. The pruning dates, harvest timing, and dry matter values were similar as well (Table 2). Hops from each site were collected directly from hop processors as opposed to on-farm collection. Due to low yield at the Mt. Angel Centennial site, we were unable to obtain a site-specific sample of these hops; thus, that site was excluded from the chemical and sensory analyses but was included in the soil and weather/climate comparisons. We obtained three 24 lb (12 kg) samples of Sterling hops that were in whole cone form and two 22 lb (10 kg) samples of Centennial hops that had recently been pelletized. All samples had been vacuum sealed in high-barrier foil material, and upon receipt at Oregon State University (OSU) they were stored at –10°C until chemical evaluation or brewing.

Soil Mapping, Physical Properties, and Nutrient Measurements

Soil classification and mapping were conducted by Red Hill Soils, a certified professional soil classifier based in Corvallis, OR. Mapping was realized by consulting historical soil maps, walking the hop yards, examining topography, and taking 5-foot-deep soil cores where unique soils were thought to occur. Soil cores determined to be unique were submitted for full analysis and identification to the soil series level; the coordinates of the soil cores were then combined with microtopography to create detailed soil maps (Fig. 2). For each soil series identified in a yard, a surface and subsurface sample was taken and submitted to A & L Labs Western Agriculture Labs (Portland, OR) for a standard soil analysis panel (organic matter, pH, cation exchange capacity, and all major micro and macro extractable nutrients). Additional data on soil productivity and available water-holding capacity were estimated based on Natural Resources Conservation Service soil survey values corresponding to the identified soil series. All soil mapping and sampling was conducted in February 2019.

Climate and Weather Data

For the purpose of this study we have defined climate data as 30 year normal data (30 year averages, 1981–2010) for each site and weather data as the actual recorded data during the 2018 growing season from weather stations maintained by Coleman farms at each site. Thirty year normal data are regularly used to describe the climate of different regions. Climate data were acquired from the PRISM Climate Group (15). The PRISM Climate Group is maintained by the Northwest Alliance for Computational Science; they provide high spatial resolution modeled climate data for a variety of research and end uses. Climate data consisted of annual and growing season (April to September) mean minimum, maximum, and mean temperatures and cumulative precipitation. The 2018 weather data consisted of daily and monthly mean, minimum, and maximum temperatures and cumulative precipitation. Growing degree day accumulation (base temperature 5°C) was calculated from 2018 minimum and maximum temperatures for the period from pruning to harvest.

Hops Chemistry

Hops were analyzed in the Shellhammer Lab at OSU following ASBC Methods (1) for moisture content (Hops-4A), total hop acids by spectrophotometry (Hops-6A), hop storage index (Hops-12), total hop acids by HPLC (Hops-14), total oil content

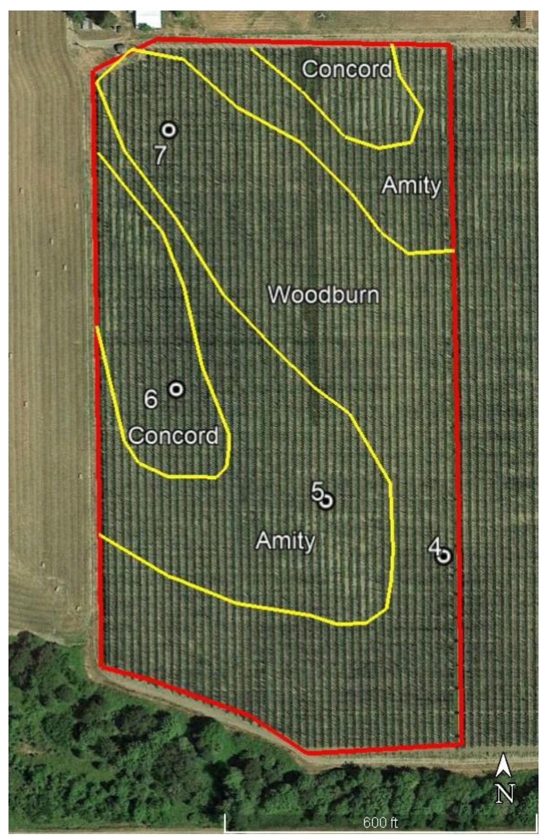

Figure 2. Soil map of Mt. Angel 80 (Centennial).

by hydrodistillation (Hops-13), and oil composition by capillary gas chromatography-flame ionization detection (Hops-17). Oil composition was characterized by examining 18 terpenes, terpene alcohols, and esters. Additionally, three thiols (3-mercaptohexan-1-ol [3MH], 4-methyl-4-mercaptopentan-2-one [4MMP], and 3-sulfanyl-4-methylpentan-1-ol [3S4MP]) and an ester (3-mercaptohexylacetate [3MHA]) were quantified in the hops by Nyseos, Montpellier, France.

Brewing and Sensory

Single-hop India pale ales were brewed using 100% pale lager malt (Rahr Premium Pilsner) targeting 14.8°P original gravity. Hops were added at the beginning of a 60 min boil (weight determined by target of 40 IBU), at whirlpool (2 g/L), and post-fermentation dry hopping (6.5 g/L). Beers were fermented at 20°C (68°F) with ale yeast (Wyeast 1056) for 1 week, during which acetolactate decarboxylase (Maturex) was added to aid in speeding diacetyl reduction. The beer was dry hopped near the end of fermentation when there was approximately 1–3°P of remaining fermentable extract. First, yeast was removed from the fermentor cone, and then the beer was dry hopped for 72 h, after which hop material was removed from the fermentor cone and beer monitored for diacetyl and acetaldehyde. Once diacetyl dropped below 35 ppb, beers were cooled to 1°C (34°F) and rough filtered (Pall HS6000). Beer was stored in 1/6 and 1/2 barrel stainless steel kegs at 1–2°C with 12 psi of CO_2 overpressure until sampling.

Sensory analyses were carried out on the finished beers in two different settings. In one setting, 13 professionals from the Oregon brewing and hop growing industries met at the OSU Food Innovation Center in Portland, OR, to evaluate the beers using both discrimination and descriptive testing. Pairwise comparisons were performed using a triangle test (ASBC Sensory Analysis-7) to make within-variety comparisons among the various growing sites. A check-all-that-apply approach was used to collect and compare the aromatic descriptors for all beers, whereby the panelists were given a lexicon of descriptive terms and were asked to identify which aromas/terms were present in the samples being evaluated orthonasally. In a second setting, a panel of 16 trained sensory assessors at OSU evaluated the beers using a modified descriptive analysis procedure as described by Lafontaine and Shellhammer (9). Over three 1 h training sessions, the panel reviewed the beers and refined an existing sensory lexicon for hoppy aroma in beer to include overall hop aroma intensity, citrus, resinous, floral, tropical fruit, and herbal/tea. The panel evaluated the beers by scaling the sensory descriptors on a 0–15 scale in three independent replicated sessions with samples blind coded and presented in a panelist-specific random order. Appropriate univariate and multivariate statistical analyses were carried our using XLSTAT (Addinsoft Co., New York, NY).

Summary of Regional Identity Assessment

Weather, Climate, and Soil Differences Among the Sites

When all weather, climate, and soil variables were mapped (statistical analyses and data not shown), the Independence site was the most unique of the three, with the largest differences occurring between the Independence and Mt. Angel sites (Table 3). Given the relative proximity of the sites in this study, we did not expect nor observe large differences in climate and only modest differences in weather. The largest weather difference was observed with the Independence site, which had slightly cooler mean temperatures historically and in 2018 than the other two sites. The Mt. Angel site had a lower day-night temperature fluctuation than the other sites, whereas Independence had the greatest fluctuation. The diurnal fluctuation in Independence was to be expected because this site is influenced by the Van Duzer Corridor, which is known for the cool breezes in the late spring and summer afternoons that flow eastward from the Pacific Ocean via a wind corridor gap through the Oregon Coast Range. This type of fluctuation may be an important factor as it is in other fruits, such as wine grapes (4). Additionally, dormant season temperature (i.e., sufficient chilling needed for good regrowth) might affect vegetative versus reproductive growth as well as hop brewing qualities.

Among the soil properties, the greatest variation among the sites was in soil texture (clay, sand, and silt content), which then related to drainage, water-holding capacity, and a few select subsurface nutrients, such as manganese. In some cases, drainage class was quite variable within an individual site. Soil formation is a complex process involving climate (temperature and precipitation regime), microorganisms, slope, geologic parent material, and time. Soil texture, including how it changes with depth across a soil profile, is one of the key features of a soil and is used extensively for its classification, to determine management strategies, and to determine crop species. Coarse, sandy soils hold less water and nutrients but can provide good drainage and aeration, whereas fine, clayey soils have the opposite properties. Thus, the main effect of soil texture on hop growth is likely to be in the provision of water and nutrients. If abundant irrigation is available and sufficient fertilizer applied, the effect of texture will be minimized and a well-drained sandier soil may perform best. If either of these are limited and plant stress occurs, yield and quality will likely be affected. In the present study, we believe that availability of water and nutrients were sufficient for plant needs.

Regional Differences in Hop Chemistry and Sensory Qualities

The chemical analyses of the two varieties revealed significant differences between the two, as was expected. Relative to Sterling, Centennial had higher α-acids, slightly lower total oil, and higher limonene, linalool, and especially geraniol concentrations. Despite the limited number of samples in this study, there were some apparent regional differences within each variety that were observed via multivariate statistical analyses and general summary statistics. When comparing hops grown in Independence (Alluvial farm) relative to the other locations, we observed that in both varieties the hops had lower total oil and myrcene levels (which is the most abundant oil component) but higher caryophyllene and humulene levels. For Centennial only, the hops from the Alluvial site were higher in geraniol and linalool, whereas for Sterling the hops from the Alluvial farm were higher in the thiols 4MMP, 3S4MP, and 3MH.

The sensory characteristics of the beers made from the hops selected for this study were noticeably different. Beer made from Centennial hops was more intense in hoppiness overall and had higher citrus, resinous, and floral characters, whereas the Sterling-hopped beers were harder to discern by the industrial panel due to lower aromatic impact. When examined within each variety for regional differences, the professional brewer and hop grower panel was able to discern regional differences via triangle tests within the Centennial samples but not the Sterling samples. We suspect that the lower aromatic intensity may have contributed to the challenge in discerning these differences. The Centennial hops grown at the Alluvial farm produced beers that were lower in aromatic intensity, less citrusy, and more herbal and peachy than the hops grown at the St. Paul (Aunt Dora) site. By comparison, the trained panel at OSU was able to detect statistically significant differences via the sensory scaling data among individual sites within both hop varieties. The beers made with hops from the Alluvial site (relative to the other locations) had lower overall hop aroma intensity and were lower in resinous quality, and specifically for beers made with Sterling hops, the Alluvial site was lower in citrus and tropical aromas. As described earlier, the Alluvial site consisted of sandier, river alluvium soil and had greater diurnal day-night temperature fluctuations. Although the accumulated growing degree days were lower for this site relative to the others, the dry matter measurements of the hops were similar across all three sites, irrespective of hop variety.

Strengths and Challenges of the Present Study

Hop chemistry and aromatic performance are likely to be influenced by many different factors such as plant age, vigor/health, and disease pressure. How a grower manages their farm will certainly influence these factors, and in turn, the resultant hop characteristics. Furthermore, harvest maturity/timing plays a very large role in hop chemistry (10,11,17). When attempting to tease out regional differences from farm management effects, awareness of and controlling these former factors, if possible, is important. That is, the grower-to-grower management variation must be separated from the weather, climate, and soil variation. One of the strengths of the present study is that we were working with a single hop grower, and therefore farm management, harvest timing, and kilning control were being carried out with a uniform overarching philosophy and approach applied to all

Table 3. Summary of regional identity/terroir observations

Characteristics	Example of variables considered	Observations from the present study
Site-specific		
Soil properties	Geologic origin, water table depth, surface and subsurface nutrients, texture, water-holding capacity, organic matter, and pH	• Soils of two geologic origins: Ice Age flood silts and Willamette River alluvium. • Alluvium soils were younger, less defined soil horizons, higher sand content, and lower water-holding capacity than Ice Age soils. • Drainage was quite variable within fields and between fields. • Organic matter, pH, and nutrients in the surface were relatively similar between sites. • Subsoil properties differed the most; at the Independence site this was driven by differences in texture, and at the Mt. Angel site differences were driven by nutrient concentrations.
Weather variables	Mean daily and monthly growing season temperatures and precipitation in 2018; growing degree day accumulation between pruning and harvest in 2018	• Average growing season temperatures in 2018 were highest at Gervais and lowest at Independence, although overall differences were modest. • Growing degree accumulation at harvest equated to approximately 10 days fewer heat units at Independence. • No difference in growing season precipitation was observed.
Climate variables	Historical mean annual and growing season minimum, maximum, and mean temperatures and precipitation; historical mean	• Climatic variation was relatively minimal. St. Paul and Gervais sites were the most related, whereas Independence and Mt. Angel were the most different. • Alluvial (Independence) site tended to be slightly cooler. The Mt. Angel site had slightly lower diurnal fluctuation (difference between daily maximum and minimum temperature) and slightly higher precipitation.
Farm management	Irrigation inputs, fertilization rates, dates of pruning and training, date of harvest, number of fungicide applications	• Irrigation inputs were nearly identical between sites. • Management dates were difficult to use because they reflected a mix of physiological maturity and logistics. Neither fertilization rates nor fungicide applications differed greatly between sites.
Harvest and postharvest practices	Hop maturity (dry matter %), kilning temperature, postkilning storage, and pelletizing	• Dry matter ranged from 21.9 to 23.5% and did not correlate to growing degree day accumulation. • Kilning and postkilning handling were the same for each site.
Hop		
Hop chemistry	Hop acids (via HPLC and spectrophotometry), hop storage index, hop oil content, and specific oil components (18 terpenes, terpene alcohols, and esters, plus three thiols and precursors)	**Varietal comparisons:** Sterling and Centennial were significantly different. • Centennial had higher α-acids but slightly total lower oil. • Centennial had higher limonene, linalool, and especially geraniol. **Regional comparisons:** Significant regional differences were apparent. Alluvial farm (relative to the other locations) had • lower total oil and myrcene levels (most abundant oil component) • higher caryophyllene and humulene levels (hydrocarbons) • higher geraniol (both varieties) and linalool (Centennial only) (terpene alcohols) • higher 4MMP and 3MH (thiols)
Sensory analyses of single-hop India pale ales made from selected hops	Brewery and grower professionals • Discrimination testing • Descriptive testing using check all that apply, single replication OSU trained panel • Descriptive testing, scaling intensity of six aromatic descriptors, three replications	**Varietal comparisons:** Sterling and Centennial were significantly different. • Centennial was more intense in hoppiness overall and had higher citrus, resinous, and floral characters. • Sterling samples were harder to discern by the industrial panel due to lower aromatic impact. **Regional comparisons:** Significant regional differences were apparent. Alluvial farm (relative to the other locations) had • lower overall hop aroma intensity and lower resinous quality • (specifically for Sterling) lower citrus and tropical aromas

growing sites. Thus, the differences we observed were potentially less likely a function of management, harvest timing, or kilning and more a function of regionality. Nevertheless, the study team is cognizant that we are working with a limited data set consisting of only three observations for Sterling and two for Centennial and only for a single harvest year. Furthermore, we have not assessed the microbial communities present in the soil or within the hop yards, nor have we characterized disease or pest pressures. An additional confounding factor is that we do not have the same soil types and/or degree of variation present equally in all sites. That being said, this study represents a pilot trial investigating whether regional differences in weather, climate, soil, hop chemistry, and beer sensory exist. And it appears there are significant differences in nearly every factor, with the exception of climate due to the relatively close spatial distances among the three sites. To strengthen these outcomes and to have broader inference, this study needs replication for each of the sites involved, and it needs broadening to encompass more growers with greater regional spatial variation. This pilot study has only scratched the surface. To fully examine this phenomenon, much more work needs to be performed in numbers of harvest years, hop varieties, and sites. To truly understand if and how regional variation impacts hops, we must extend the study to other sites within Oregon and across the United States in order to characterize and understand the drivers of micro and macro regional differences in hop characteristics.

Benefits Versus Risks of Characterizing Regional Differences or Hop Terroir

The team carrying out this study has been involved in intriguing conversations with curious, and in some cases skeptical, industry members. Exploring regional variation is not about searching for the "best" hop. Rather it is about understanding whether regional variation, or terroir, pertains to hops—and if it does, how it influences the expression of hop aroma and flavor. Much like the American Viticultural Areas concept for wine grape growing, regional variation in hops may allow hop growers to identify which hops grow best in which location and to market the site-specific characteristic differences of those hops to brewers and consumers. As we engage in these conversations, a topic that often surfaces is the risks versus benefits of characterizing regional identity of hops.

Potential benefits of hop terroir:

- There is a new energy that has emerged surrounding the hop industry, whereas formerly farms were producers of a behind-the-scenes commodity crop. Studies like this build on this new energy, and brewer awareness will showcase hop production and give consumers the ability to connect to each farm/state/region.
- In today's craft brewing world, regional distinction could create a new foundation by offering the brewer vast information to support his/her innovations.
- For brewers, regional diversity data can serve as selection verification and result in better-informed decision making as they work with hop merchants to identify hops best suited for their brewing goals.
- If future studies and data show significant regional differences among states, it could strengthen the hop community within each state.
- Terroir, culture, and regionality play a role in consumer choice and become a part of the story that defines and differentiates a brand. Very much like wine, cultivating the overall sense of place is what makes a beer crafted in Oregon different than one crafted in California, or Germany, or anywhere else.
- A longer-term, comprehensive study will lead to better-informed decision making for growing practices, planting locations, irrigation, and fertilization. Deeper knowledge and best practices give brewers confidence in the hop growers.

Potential risks of hop terroir:

- It will take considerable time to understand, characterize, and map regional diversity. Furthermore, the differences may not be geographical or climate related but rather a function of grower inputs through decades of farming. Some differences that ultimately define a plot of ground may be positive and some may be negative. In most cases, they likely will all vary in brewer preference.
- Although regional differences may be identified and characterized with science and data, there could be a point at which brewers and consumers will decide based on preference. Regional differences could then be misinterpreted as "better" or "worse."
- Regional distinctions could shake up state hop commission models that support all growers. Commission priorities are to work collectively in research and marketing efforts on behalf of all growers. There could be a risk of differentiating too much, and states could lose a sense of comradery, particularly if some farmers find their hops are grown in an area that is perceived as less than desirable.
- There are possible negative repercussions on land value with regard to acreage deemed less desirable for hops, or conversely, the triggering of inflated real estate prices for prime hop growing regions.
- Regional identity may identify possible limitations on what varieties can be grown at specific locations.
- There may be unknown and unintended consequences on the hop supply chain structure and hop selection processes.

As different regional distinction research teams engage in studying this topic, we encourage a collaborative thought-sharing approach so that collectively we can maintain constructive conversations focused on teasing out the various benefits and unforeseen risks for all. In doing so, we can raise the bar higher for both the hop growing and brewing industries.

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