## ****Project Title:****

Assessing nutrient uptake and accumulation in hop production

**Project Summary:**

**This project aims to improve our understanding of hop nutrient uptake and accumulation. Through this work nutrient accumulation curves for all macro and micronutrients will be generated and expressed relative to a range of plant development metrics designed to give growers a better idea of uptake in relation to plant development. We will look at nutrient accumulation in relation to days since pruning, days since training, growing degree accumulation (GDD), growth development stage (BBCH scale) and distance to trellis wire. Understanding nutrient accumulation rates for hops over time will allow growers to better time and adjust in-season fertilization thereby optimizing yield, disease and pest control, quality and environmental outcomes. This work will also examine the relationship of current in-season nutrient status testing methods (petiole tissue, petiole sap and soil tests) to nutrient uptake and critically examine the variability in petiole tissue and soil tests as indices of plant nutrient status.**

**Proposal duration:**

Continuing proposal, Year 3

## Project leader:

Betsy Verhoeven

Oregon State University Extension

(503) 779-8217

[betsy.verhoeven@oregonstate.edu](mailto:betsy.verhoeven@oregonstate.edu)

Marion County Extension Office

1320 Capitol St NE, Suite 110

Salem, Oregon 97301

**Co-PI’s**

David Gent

USDA-ARS and Oregon State University

Dave.Gent@ARS.USDA.GOV

(541) 738-4167

3450 SW Campus Way  
Corvallis, OR 97331

Amber Moore

Oregon State University

amber.moore@oregonstate.edu

(541) 737-2870

Agricultural & Life Sciences 3063

2750 SW Campus Way

Corvallis, OR 97331

**Cooperators:**

Tom Shellhammer

Oregon State University

(541) 737-9308

Wiegand Hall 232A

3051 SW Campus Way

Corvallis, OR 97331

**Amount requested:**

$20,000 (2021); $20,000 (2022)

**Other Funding Sources and Support:**

In-kind:

OSU Extension, Marion County (0.1 FTE Verhoeven)

Grower participants (20 hrs each)

**Send funding to:**

Betsy Verhoeven

Oregon State University Extension

(503) 779-8217

betsy.verhoeven@oregonstate.edu

c/o the Agricultural Research Foundation

1600 SW Western Blvd., Suite 320

Corvallis, Oregon 97333

**Project Title:**

Assessing nutrient uptake and accumulation in hop production

**Statement of Problem:**

Hop growers are lacking good information on the timing of nutrient uptake and accumulation under contemporary management practices. Current nutrient accumulation curves are only available for nitrogen (N). With an increasing ability to adjust nutrient rates in-season via drip irrigation systems, growers need more consistent methods of evaluating nutrient status during the growing season and for nutrient status from any measure to be more reliably linked to yield and cone quality.

**Justification and Importance of Proposed Research:**

The current Oregon State University nutrient management guide and fertilizer application recommendations are based on data collected in the early 1990’s and are almost 30 years old (G. Gingrich, J. Hart and N. Christensen 2000). Available data from Washington State is even older (Roberts, 1961;Evans et al., 1985). In the meantime, market forces and breeding efforts have led to a proliferation of new varieties, many of which are higher yielding than when this original nutrient work took place. At the same time, winters may be less severe and with altered precipitation patterns; together these factors have potentially shifted nutrient uptake profiles and demands. In parallel, management practices have evolved and many hop yards now use drip irrigation where they have the capacity to dose fertilizer throughout the growing season. Recent data shows that excessive or late (post-bloom) N applications may cause a decline in cone quality with a decrease in alpha and beta acids and an increase in cone NO3- (Iskra et al., 2019). In response to these changing practices and increasing knowledge, growers and the hop industry have expressed a need for improved methods of determining total and in-season nutrient application rates that will maximize yield and quality while minimizing losses. There is a need for practical decision making tools that can help growers adjust rates based on nutrient needs and soil supply in order to maximize yield and quality.

The current industry standard is for petiole tissue testing 2-4 times during the growing season for analysis of macro (N,P,K) and micro (Zn, Ca, Mg, Mn, B, S, Fe, Cu) nutrient concentrations, these tests may or may not be accompanied by soil tests to evaluate nutrient supply. In some cases petiole tissue testing has been reported to be quite variable, at the same time there are doubts as to whether soil tests accurately reflect where a plant is drawing nutrients from. More clarity on the variability of petiole tissue and soil tests as relates to specific growth stages will help growers improve sampling practices and interpret results. Previous work has shown that petiole N concentrations follow a curve, peaking near bloom, then declining as N is translocated from leaves to floral tissue. Roberts et al. (1985) provided critical nutrient ranges for N, P, and Zn at bloom based on leaf and petiole analysis. In order to better interpret petiole tissue tests a robust dataset across multiple years and linked with growth development and plant architecture is needed.

Petiole sap testing for NO3- and K+ has been used in annual vegetable and fruit production for crops such as tomatoes, potatoes and melons with some success (Hochmuth, 1994;Carson et al., 2016). Some of the petiole sap test methods are designed to be quick, cheap and implementable on-farm. For these methods fresh petioles are crushed up in garlic press or such device and the sap exuded can be directly measured with test strips, a test kit or ion specific electrode (Rosen et al., 1996). A secondary goal of this project is to generate preliminary data on petiole sap measurements as relates to their variability, cost and relationship to the more standard petiole tissue test.

Seasonal recommendations for P, K and micronutrients are given in the 1994 OSU Extension guidelines and 1985 WSU guidelines. These recommendations are based on total seasonal uptake and pre-season soil tests. Similar to N, there is a desire from growers to re-evaluate total seasonal nutrient demands and timing of demand, in particular for K, Zn, B and Fe under contemporary practices and varieties. The nutrient accumulation curves generated will allow for more precise management of these nutrients.

This work addresses agronomic research priorities outlined by the HRC relating to the timing and rates of macro and micronutrients, nitrogen and quality, improvement over petiole tissue nutrient analysis.

**Objectives:**

1. Generate nutrient uptake curves for macro and micronutrients under contemporary production practices
2. Express nutrient accumulation and petiole analysis in relation to different plant development metrics (i.e. GDD, BBCH growth stage, distance to trellis wire)
3. Evaluate the relationship between petiole tissue and soil nutrient tests and between these tests and bine and cone nutrient accumulation
4. Examine the variability in petiole tissue and soil tests nutrient tests and discuss their utility to assess in-season nutrition status
5. Generate preliminary data on the cost, variability and potential use of in-house petiole sap tests for NO3- and K+

**Procedures/Methods to accomplish objectives:**

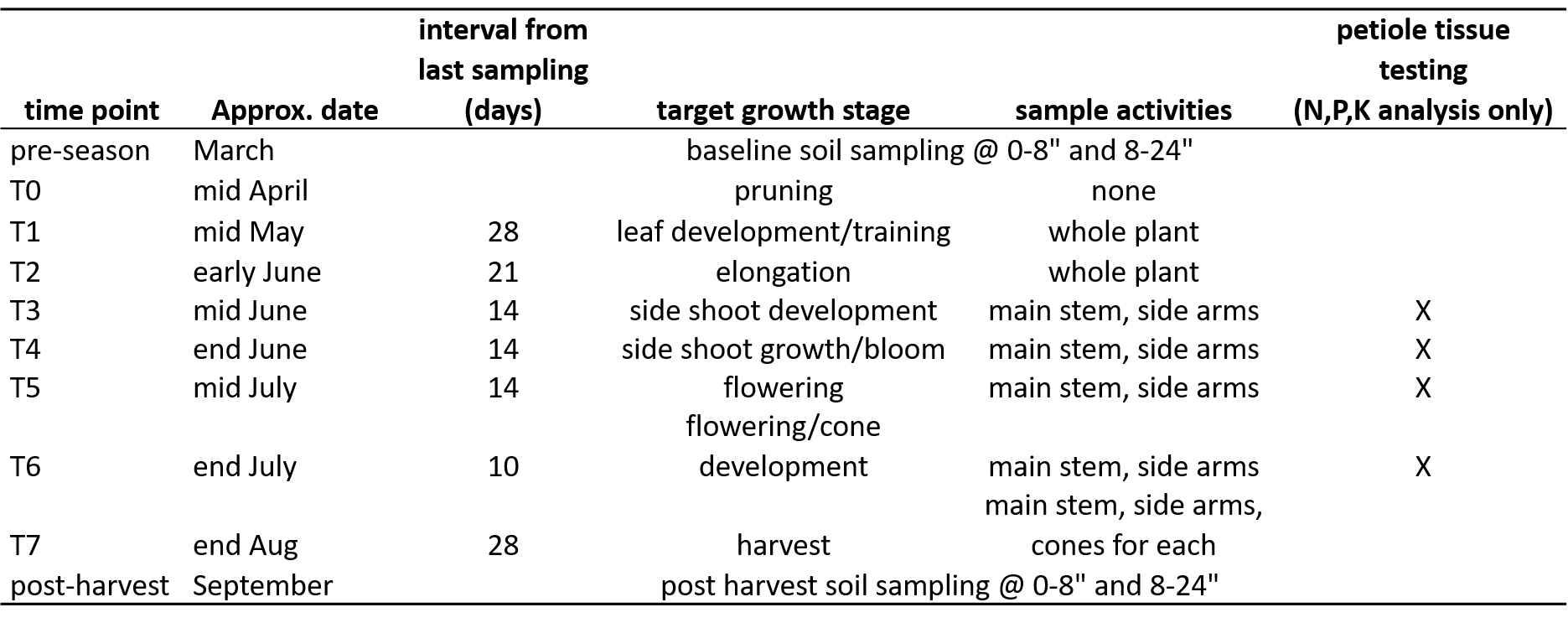
Experimental design and sampling methodology

This work will be conducted in a survey style with no plots established. Three Oregon hop yards of Cascade cultivar were selected. All yards are under drip irrigation. Each site will be sampled in the late winter to assess pre-season nutrient status. Growers follow their own nutrient program for rates and timing based on individual goals, soil tests, and consultation with agronomists. The goal is evaluate nutrient uptake and availability under business as usual standard practices.

Addressing objectives

1. Generate nutrient uptake curves for macro and micronutrients under drip irrigation

We will collect whole bine biomass samples at 7 time points throughout the season. See table below for the approximate schedule of sampling.



Biomass sampling will consist of destructive sampling of above ground biomass from nine strings per field per time point. Biomass from three sets of three bines will be combined together for individual analysis. Considering 7 time points, a maximum total of 63 strings would harvested per year per field. At harvest, biomass will be partitioned into leaves + bine and cones. Biomass will be analyzed for dry weight and N,P,K, S, Ca, Mg, Zn, Mn, Cu, Fe, B.

*Upon review of data from 2020 and discussion with grower group, we chose not to separate biomass into sidearms and main stem, but rather to separate into leaves and stems. This makes our data more comparable to biomass and nutrient work done within the industry as well as in other crops. Further this separation allowed us to use a mechanical harvester, expediating cone harvest and preserving quality. We will continue this in 2022.*

1. Express nutrient accumulation and petiole analysis in relation to different plant development metrics (i.e. GDD, BBCH growth stage, distance to trellis wire)

The exact stage of development at the time of biomass sampling will be recorded based on the BBCH scale. We will also calculate the growing degree days (GDD), GDD since pruning and training and distance to trellis and evaluate if these are relevant measures of plant development that relate consistently to plant nutrient status.

1. Evaluate the relationship between petiole tissue and nutrient accumulation. Evaluate the relationship between soil tests, petiole tissue, petiole sap and nutrient accumulation at key growth stages. *Upon final review of 2020 data and discussion with grower group we moved to traditional soil test extractions to assess plant available N and soil test K in 2021, rather than use plant root simulators which provided hard to interpret data in 2020. We will continue using traditional soil tests in 2022.*
2. Look at potential of alternative tissue tests: in-house ion meters and leaf sap analysis to assess in-season nutrient status

Petiole tissue samples will be sampled in parallel with biomass sampling at four time points. Petiole tissue samples will not be taken at the initial biomass and end biomass sampling points, as these do not reflect critical growth periods and do not align with standard industry practices. Regular petiole tissue sampling will follow standard procedures (collect 40-50 petioles at 5-6 ft. height) and include three replications. Petiole samples will be analyzed for N, P, and K status. We will also continue to compare laboratory petiole analysis with in-house petiole N determined by ion meter, which may be a cheaper and quicker alternative to sending off petiole samples to a lab.

*In 2021, we added measurements of leaf sap analysis at two time points, June 2 and June 15. We will continue this in 2022. Leaf sap analysis is supposed to allow earlier diagnosis of nutrient deficiencies compared to traditional petiole analysis. We will examine how leaf sap analysis relates to petiole analysis and nutrient uptake to help determine what additional and actionable information growers may get from the leaf sap analysis.*

**Outcomes:**

We will generate nutrient accumulation curves for macro and micronutrients relative to a range of metrics used to assess plant development. With more solid relationships between growth stages and nutrient uptake, growers will be better able to calculate seasonal nutrient demand and adjust fertilizer rates in-season, saving money while optimizing yield and quality. We will assess variability surrounding petiole tissue analysis as a means of determining in-season nutrient status and examine alternative methods for determining N status in the growing season. Putting these pieces together, we will provide recommendations for the most effective sampling procedures and provide preliminary data on relationships between petiole tissue and petiole sap analysis.

**Extension and Outreach Activities:**

New data will be used to update the OSU Hop Nutrient Management Guide. This work will be promoted through OSU Extension activities and through the Oregon Hop Commission. Specific guidelines for tissue and sap testing, GDD calculations and plant growth staging will be developed and demonstrated at regional workshops and field days. Results will be presented annually to the Oregon Hop Commission and at the Hop Research Council meeting on at least two occasions.

**Attachments:**

**Time Frame for Objectives:**

|  |  |
| --- | --- |
|  | **Year 1 - 2020** |
| **Jan** | secure sites, finalize sampling protocol |
| **Feb** | finalize sampling protocol |
| **Mar** | soil test |
| **Apr** | monitor weather for new growth |
| **May** | begin biomass sampling |
| **Jun** | biomass and in-season nutrient sampling |
| **Jul** | biomass and in-season nutrient sampling |
| **Aug** | biomass sampling |
| **Sep** | final sampling |
| **Oct** | complete all biomass analysis |
| **Nov** | data analysis |
| **Dec** | data analysis, prepare annual report |
|  | **Year 2 - 2021** |
| **Jan** | present 1st year of data at American Hops Convention, Portland |
| **Feb** | present 1st year of data to Oregon growers at monthly OHC meeting |
| **Mar** | soil test |
| **Apr** | monitor weather for new growth |
| **May** | begin biomass sampling |
| **Jun** | biomass and in-season nutrient sampling |
| **Jul** | biomass and in-season nutrient sampling, workshop at OHC field day on best sampling practices |
| **Aug** | biomass sampling |
| **Sep** | final sampling |
| **Oct** | complete all biomass analysis |
| **Nov** | data analysis |
| **Dec** | data analysis, prepare annual report |
|  | **Year 3 - 2022** |
| **Jan** |  |
| **Feb** | present 2 years data to Oregon growers at monthly OHC meeting |
| **Mar** | soil test |
| **Apr** | monitor weather for new growth |
| **May** | begin biomass sampling |
| **Jun** | biomass and in-season nutrient sampling |
| **Jul** | biomass and in-season nutrient sampling |
| **Aug** | biomass sampling |
| **Sep** | final sampling |
| **Oct** | complete all biomass analysis |
| **Nov** | data analysis |
| **Dec** | data analysis, prepare final report |
|  |  |
|  | Year 4-2023 |
| **Jan** | Present full three years of data at American Hops Convention |
| **on-going** | Prepare all data for publication and revision of OSU Nutrient Management Guide |

**Project Budget:**

|  |  |
| --- | --- |
|  | cost/yr ($) |
| salary 0.1 FTE FRA, 4 months1 | 1600 |
| FRA benefits1 | 920 |
| 0.5 FTE student employee, 3 months1 | 3600 |
| 0.5 FTE student benefits1 | 432 |
| local travel2 | 1254 |
| sample analyses3 | 7722 |
| generator rental for harvest | 500 |
| Basic cone chemistry + NO3- analysis4 | 1800 |
| USA Hops Convention registration + partial travel expenses | 2,000 |
| SUM | $19,828 |
| REQUEST | $20,000 |

1 4 months, 0.1 FTE faculty research assistant Moore lab at $48,000/yr salary + 57.5% of salary in benefits.

Student employee employed at $15/hr for 20hr/week for 3 months + 12% of wage in benefits.

2 local travel: cost of motor pool rental for student employee/FRA @ $21/day x 10 trips x 3 sites = $630; mileage = avg 130 miles roundtrip to campus, 10 trips x 3 sites x $0.2/mile = $780 in gas. No mileage or travel costs being requested by OSU Extension.

3 For details on sample number and individual analysis costs, see appendix

4 Basic cone chemistry costs at $200/sample, Shellhammer lab, OSU. Includes: total oil %, α-acid %, β-acid %, dry matter %, cone color and NO3—N.

**Other Funding Sources and Support**

The Marion and Clackamas county field crops extension program will provide in-kind support in the form of salary and reasonable local travel for the lead PI (Betsy Verhoeven) during the duration of the project.

**Literature Review**

Many aspects of the fertility work conducted in the 1990s and prior are likely still valid and relevant. This work showed that peak N uptake is about 3-4 lb N/a/day, the peak period of N uptake lasts about a month (typically mid June to mid July) and accounts for approximately 90% of N uptake and about 40% of N ends up in the cones versus the rest of the bine (Gingrich et al., 2000). This work found that cones contain 5-6 lb N/bale. This fertilizer guide also provides recommendations for P and K based on soil test levels and states that hops remove 20-30 lb P/a and 80-150 lb K/a. Recommendations for lime, sulfur, boron and zinc are also given, based on soil test levels. However, since this work was completed concerns have been raised about particularly low application rates that may have not have been sustainable in the long term for the perennial hop plant. Moreover, the variety, ‘Willamette’ is not as widely grown anymore, higher yielding varieties exist now, and production practices in general have significantly changed since the early 90’s. The work by Gingrich et al. (2000) is widely cited hop production guides from across the US and even internationally. There is a clear need to re-evaluate these nutrient accumulation numbers and to build confidence among growers and crop consultants that they reflect typical management.

There are well established negative environmental consequences of excessive nitrogen application (Davidson et al., 2011) and the hop industry is motivated to reduce surplus nitrogen application. Further, high nitrogen rates in hop have been linked to higher incidence of disease and pest pressure (Iskra et al., 2018). Very recent work has shown that nitrogen rates can also affect cone quality and aroma characteristics (Iskra et al., 2019). In this work the authors found that when aggregated across years, increasing N rates decreased α-acids, β-acids and total oil while increasing cone color and cone NO3- concentration. Yields tended to increase with increasing N rates, but the highest yield was not always observed in the highest N rate treatment. Together these results show that the highest N rate did not necessarily yield the highest quantity or quality. The authors also looked at timing of N applications and found that yield, oil content and cone color were independent of timing but bittering acids were influenced by N timing; both α-acids and β-acids decreased by 4% with late (post bloom) N application. The authors took cone quality to the next level and found that panelists could differentiate between hop samples in one of the four trials and could also differentiate beers brewed from different N treatments. This work shows the importance of being able to dial in N application to achieve the optimum quantity and quality as yields fluctuate annually.

Nitrogen utilization and uptake by the hop plant is complex. Bloom date is a variety dependent photoperiod response that also depends on the number of nodes (Neve, 1991). Once a plant blooms, the lateral branch length is set and cones begin to develop, so the number and length of branches at this time largely determines yield. Growers must navigate this complex relationship between weather, nutrient uptake and day length as they try to optimize yield while juggling pest pressure and quality concerns as well. Therefore, more accurate information on in-season nutrient status can be a useful decision making tool.

Petiole tissue testing is the most common method of assessing hop nutrient status during the growing season. In annual vegetable production growers have had mixed to positive experiences with petiole sap testing for NO3- and K+ levels in-season (Hochmuth, 1994;Peña‐Fleitas et al., 2015;Carson et al., 2016). There is interest to see if this may be a viable option for hop as well, particularly since many of the studies using this methodology have looked at inexpensive on-farm technologies for this analysis, either ion selective electrodes or quick strip NO3- tests for example (Rosen et al., 1996;Parks et al., 2012). Soil NO3- testing is also an option for assessing in-season nutrient availability. Soil nutrient testing in hop is likely to be confounded by a) the perennial nature of the crop which may result in potentially significant nutrient supply from root reserves, b) a large and diversely distributed root system and c) uneven nutrient and water distribution relating to fertigation. An excavation of a hop roots found that the total root volume was 4.1 m3 and could be divided into a row section of adventitious roots, a disk surrounding the rootstock with horizontal roots and a chunk of deep vertical roots (Graf et al., 2014). Using dye and electrical resistivity imaging, researchers working in an apple orchard where able to show that the majority of fertigated NO3- stayed in the A1 soil horizon, while fertigated water moved further down (Hardie et al., 2018). Putting these aspects together, accurately and consistently using in-season soil nutrient tests is challenging.

One of the goals of this work is relate nutrient accumulation to plant development stages so the work can be more translatable between years and hopefully varieties. Hop development is complex and not easily described by growing degree-days or other simple development models. The BBCH scale (derived from: Biologische Bundesanstalt, Bundessortenamt und Chemische) is a phenological development scale that is widely used in many crops to describe stages of development on a numerical scale, making comparisons across locations and varieties easier. A BBCH scale for hop is available (Meier et al., 2009). This scale divides hop growth into nine stages with up to 10 sub-stages within these (0:sprouting, 1:leaf development, 2:formation of side shoots, 3:elongation of bines,5:inflorescence emergence, 6:flowering, 7:development of cones, 8:maturity of cones, 9:senescence, entry into dormancy). In some cases this scale has been adapted to put the formation of side shoots coming after elongation of bines. We will use this formal scale to precisely describe the growth stage at each sampling time point.

**References**

Carson, L., Ozores-Hampton, M., and Morgan, K.: Correlation of petiole sap nitrate-nitrogen concentration measured by ion selective electrode, leaf tissue nitrogen concentration, and tomato yield in Florida, Journal of Plant Nutrition, 39, 1809-1819, 2016.

Davidson, E. A., David, M. B., Galloway, J. N., Goodale, C. L., Haeuber, R., Harrison, J. A., Howarth, R. W., Jaynes, D. B., Lowrance, R. R., and Thomas, N. B.: Excess nitrogen in the US environment: trends, risks, and solutions, Issues in Ecology, 2011.

Evans, R., Cone, W., Hang, A. N., Johnson, D., Kenny, S., Parker, R., Roberts, S., Skotland, C., and Stevens, R.: Hop production in the Yakima Valley, Washington State University, Cooperative Extension, EB1328, 1985.

Gingrich, G. A., Hart, J. M., and Christensen, N. W.: Hops: Fertlizer Guide, Oregon State University Extension, FM 79, 2000.

Graf, T., Beck, M., Mauermeier, M., Ismann, D., Portner, J., Doleschel, P., and Schmidhalter, U.: Humulus lupulus–The hidden half, BrewingScience, 67, 161-166, 2014.

Hardie, M., Ridges, J., Swarts, N., and Close, D.: Drip irrigation wetting patterns and nitrate distribution: comparison between electrical resistivity (ERI), dye tracer, and 2D soil–water modelling approaches, Irrigation science, 36, 97-110, 2018.

Hochmuth, G.: Efficiency ranges for nitrate-nitrogen and potassium for vegetable petiole sap quick tests, HortTechnology, 4, 218-222, 1994.

Iskra, A., Woods, J., and Gent, D.: Influence of Nitrogen Fertilizer Rate on Hop Looper, Journal of economic entomology, 111, 2499-2502, 2018.

Iskra, A. E., Lafontaine, S. R., Trippe, K. M., Massie, S. T., Phillips, C. L., Twomey, M. C., Shellhammer, T. H., and Gent, D. H.: Influence of Nitrogen Fertility Practices on Hop Cone Quality, Journal of the American Society of Brewing Chemists, 1-11, 10.1080/03610470.2019.1616276, 2019.

Meier, U., Bleiholder, H., Buhr, L., Feller, C., Hack, H., Heß, M., Lancashire, P. D., Schnock, U., Stauß, R., and Van Den Boom, T.: The BBCH system to coding the phenological growth stages of plants–history and publications, Journal für Kulturpflanzen, 61, 41-52, 2009.

Neve, R.: Hops. Chapman and Hall. London, 1991.

Parks, S. E., Irving, D. E., and Milham, P. J.: A critical evaluation of on-farm rapid tests for measuring nitrate in leafy vegetables, Scientia horticulturae, 134, 1-6, 2012.

Peña‐Fleitas, M., Gallardo, M., Thompson, R., Farneselli, M., and Padilla, F.: Assessing crop N status of fertigated vegetable crops using plant and soil monitoring techniques, Annals of applied biology, 167, 387-405, 2015.

Roberts, S. a. N., C.: Hop Nutrient Uptake and the Relationship Between Quality and Nutrient Content of Hop Cones, Washington Agricultural Experiment Station, Vol 630, 1961.

Rosen, C. J., Errebhi, M., and Wang, W.: Testing petiole sap for nitrate and potassium: A comparison of several analytical procedures, HortScience, 31, 1173-1176, 1996.