**Project Title: Integrated Management of Mites on Hops**

**Project Summary:** The two-spotted spider mite *Tetranychus urticae* has proved to be a difficult pest to control in the hop agroecosystem. Through laboratory bioassay, field trials, and molecular analysis we will study the efficacy of registered and candidate acaricides against pest mites. Over the past 5 years we have identified molecular markers associated with resistance to the synthetic acaricides abamectin, acequinocyl, bifenazate, bifenthrin, clofentezine, cyflumetofen, etoxazole, fenazaquin, fenpyroximate, hexythiazox, and spirodiclofen. We will collaboratively develop multiplex methods for monitoring the resistance status of mite populations infesting hop yards, focusing on acaricides for which we have found direct point mutations associated with acaricide resistance in mites collected from PNW hop yards. We will initially focus on abamectin, bifenazate, and hexythiazox in 2022 and then move on to the additional acaricides bifenthrin, etoxazole, hexythiazox, fenpyroximate, pyribaden, fenazaquin, cyflumetofen, and acequinocyl in future years. Point mutations have been observed in association with abamectin resistance in mites collected from California strawberry fields. To date we have not observed any of these mutations in spider mites collected from PNW hop yards. Going beyond traditional acaricide chemistry we will also continue to evaluate candidate alternative acaricides, several of which are commercially available natural plant extracts or oils. We have observed positive efficacy with several of these alternative pesticide treatments on mites and other pest insects. Concurrently, we plan to continue to work at the farmscape level with a grower cooperator to test commercially available alternative acaricides. We will also test to see if we can reduce residues of acaricides with a wash off of ozonated water through an airblast sprayer. Finally, we would like to develop a method to add automation to our mite quantification methods. Comprehensively we will continue to conduct our extensive outreach and engagement program and to proactively support the hop industry in research and regulatory affairs.

**Proposed Duration:** Year 15 complete. Year 16 proposal.

**Project Leader:**

Douglas B. Walsh, Professor of Entomology

Washington State University

Irrigated Agriculture Research and Extension Center

24106 N. Bunn Rd., Prosser, WA 99350

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**Cooperators:**

Sally O’Neal, Sr. Extension Outreach Specialist David Gent, USDA-ARS

Dan Groenendale, Field Research Director Laura Lavine, WSU Entomology

Tom Shellhammer, OSU Food Science Justin Clements, U of Idaho, Parma

Kayla Altendorf, USDA-ARS/ WSU IAREC

**Amount Requested:** $68,497 ($41,386 from HRC, $27,111 from WA Hop Commission)

**Other Funding:**

1. Enhancing Supply Chain Sustainability and Global Competitiveness for Pacific Northwest Hops, USDA-NIFA Specialty Crop Research Initiative. $4,853,907. 10/1/21 through 9/30/25. Features the usual suspects among hop researchers and a few new scientists working on data analysis and project evaluation.

2. Washington State IPM Extension Implementation Program 2021-2024. USDA-CIFA CPPM

$757,206. 9/1/2021 through 8/31/2024. A substantial proportion of these funds are used to support Senior Communication Specialist Sally O’Neal. Extension in specialty crops including hops is an objective for this program and Ms. O’Neal will continue to participate with the hop industry in the production of outreach and educational outputs.

3. Evaluation and development of hop germplasm for the WA hop region. USDA-Pass Through for hop breeding 9/1/21 to 8/31/21. $74,449. These funds support IAREC Facility Hops Manager Mr. Dan Groenendale and Farmer II Mr. Tony Moreno at roughly 37.5% and 50% FTE, respectively. Some funds are provided for miscellaneous expenses, land use charges, local travel, maintenance pesticides, and miscellaneous hop growing supplies.

3. Washington State Commission on Pesticide Registration. I will submit a request of about $20,000 for their funding consideration using Washington Hop Commission and Hop Research Council funds as matching funds. The $20,000 in WSCPR funds received in 2021 have been expended on Mr. Tony Moreno and Mr. Miguel Leon’s salaries for September, October, and November 2020. We will ask for a renewal for 2022.

4. USDA-NIFA-IR-4. Magnitude of Residue and Product Efficacy Studies 2021.

9/1/20 to 8/31/21. $84,500. These funds are paid as piece work by IR-4 at $6,500 for each MOR study. In most years we have 2 to 4 MOR studies on hops. These funds are used primarily to cover salary and benefits costs for Ag Research Technologist III, Mr. Wilson Peng. Mr. Peng participates in pesticide application to hops and he completes pseudo-commercial pesticide residue trials at the direction of the Hop Industry Plant Protection Committee.

**Send Funding to:**

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**Project Title: Integrated Management of Mites on Hops**

**Statement of Problem:** As detailed in the Hop Research Council Research Priorities in 2021 for research to be conducted in 2022, this proposal directly covers priority 1 of “Insect Pest Research” by conducting research to develop and refine control strategies for the two-spotted spider mite and also addresses priority 3 of “Hop Breeding Research” in collaboration with Dr. Kayla Altendorf, a USDA Research Geneticist by screening and testing via bioassay the male germplasm at WSU IAREC for the presence of genetically-based tolerance to spider mite infestation. The year 2022 will also be the second full year that we will be collaborating on spider mite management with the University of Idaho’s Assistant Entomologist, Dr. Justin Clements in Parma, Idaho.

**Justification and Importance of Proposed Research:** Feeding by and/or contamination of hops by infestation of spider mites has resulted in millions of dollars in decreased crop value. Biological regulation of spider mites is an appreciated component of integrated pest management (IPM) in hops, but bioregulation rarely provides stand-alone control for spider mites. Acaricide application is therefore used as a risk management tool to prevent economic loss or reduce the risk of loss to an acceptable level. We have found market factors to influence mite management decisions. When specific hop varieties are in short supply some moderate level of mite damage is accepted by merchants. When there’s a glut of hops, mite damage can be used as a cause for rejection of hops by merchants. The work detailed in this proposal will focus on providing the information required to make recommendations for the evolving hop spider mite management program. In the studies outlined in this proposal we plan to look at acaricide efficacy, fine-tune treatment thresholds, ground-truth techniques for monitoring spider mite resistance to acaricides at the landscape level and ground-truth cost effective, robust, and rapid mechanisms for qualifying and quantifying acaricide resistance. We also plan to collaborate with the new USDA Hop Research Geneticist to discern if there is any genetically based tolerance to spider mites in the male germplasm located at Washington State University’s Irrigated Agriculture Research and Extension Center (IAREC). We also plan to conduct field efficacy studies with alternative acaricides including plant extracts and oils. We also plan to collaborate with entomologists at the University of Idaho and Cal Poly San Luis Obispo on developing a cost effective and rapid method for qualify and quantify acaricide resistance in field-collected mites. We will use an existing airblast sprayer equipped with an ozone injector to quantify if spraying hop bines near harvest with ozonated water can reduce pesticide residues. We also plan to develop a thermal imaging system for quantifying spider mite, spider mite egg, and predatory mite abundance in our mite brushing mite managing system to speed our throughput while quantifying mite abundance on field collected hop plant materials.

 Efficacy studies, resistance management, and impacts on non-target species are mainstays of any IPM program including our program in hops. We are presently developing a position announcement to recruit a new PhD student to work on mite management on hops. This PhD Research Assistantship will be supported by our recently awarded USDA-SCRI grant. We have made substantial progress toward development of techniques that will pre-screen spider mites for the presence or absence of genes conferring resistance to conventional acaricides. This objective will be led by research collaborator, Dr. Justin Clements at the University of Idaho Parma Research Center moving forward from here. We will see if mites can develop resistance to acaricides and, if they do, determine the mechanisms the mites employ to confer this resistance. For conventional acaricides, a technology that can rapidly quantify resistance in the field will benefit hop growers by indicating population susceptibilities within individual hop yards, paving the way for the adoption of less disruptive, more selective acaricides for control of the key direct pests of hops and the reduction of instances of field failures of specific acaricides as experienced by some growers with abamectin, bifenazate, and hexythiazox. We propose to use the molecular markers we generated in our previous studies along with recently validated detection methods to develop a validated, sensitive, rapid, and cost-effective method to predict multiple acaricide resistance mutations on an economical, portable platform that will potentially be practical for in-field use.

Acaricide resistance may impose some sort of fitness cost to spider mite individuals and populations. We have noted that spider mites appear to be most susceptible to being killed by acaricides for the first several generations following winter. We plan to investigate whether increased mortality occurs in acaricide-resistant populations of mites compared to susceptible mite populations, creating small mesocosms in which we will initiate diapause and quantify winterkill among the populations.

 In 2020 there were 58,641 acres of hops harvested in the PNW. Yields were below average at 1,770 pounds per acre. Prices remained high and gross returns were calculated to be $10,563 per acre. Spider mite feeding can vary substantially among hop yards, but in extreme circumstances mite feeding can lead to complete crop failure. With super alpha varieties, mite feeding has a negative impact on the amount of alpha acids produced per acre. In our studies on Cascade we found that mite feeding must be at fairly high levels late season to cause significant damage. Unfortunately, in preliminary studies the newly released variety *cv.* ‘Triumph’ appears to be fairly susceptible to mite infestations under Yakima Valley conditions. The 2015 WSU Hop Enterprise budget listed the cost of pesticides at $750 per acre per year in a mature hop yard. Of that $750, 2 to 3 acaricide application per year would cost roughly $200 per acre. If 50,000 acres of hops were treated 2 to 3 times this would calculate out to $10 million spent on acaricides alone annually. The molecular aspects of this project will develop methods to inform growers when acaricides become ineffective due to mites developing resistance. The field studies in this project will contribute to the registration of new acaricides, most likely through advancement into the IR-4 residue program. Evaluating the male hop germplasm for mite resistance could result in improved breeding of mite-tolerant varieties. Evaluating augmentative biological control and its efficacy may aid growers in establishing their own biocontrol programs. Decreasing residues of acaricides will likely ease export restrictions and provide for greater market access and labor-saving automation of mite counting will ease labor demand and increase efficiency in the Walsh laboratory.

**Objectives**

1. Field test candidate compounds and recommended commercial blends of acaricides for their efficacy against spider mites. (This will be an ongoing objective)
2. Conduct field trials in grower collaborator fields with candidate alternative acaricides. This will include plant-based extracts and oils. (Year 1 of 3)
3. Develop a sensitive, rapid and cost-effective method to predict multiple acaricide resistance on a portable platform. (Depending on progress and industry assistance 2024)
4. Screen and then bioassay selections from the male germplasm for any genetically-based tolerance to mite infestation. (Year 2 of 5)
5. Complete augmentative releases of the predatory mites *Neoseiulus fallacis* and *Galendromes occidentalis*. (Year 2 of 5)
6. Determine if broadcast applications of ozonated water degrades acaricide residues. (Year 1 of 3)
7. Develop a multispectral/ thermal imaging method to quantify mite abundance in

association with our mite brushing mite abundance quantitation method. (Year 1 of 1)

**Procedures/Methods to Accomplish Objectives**

**a) Field tests for efficacy**. Research plots will be set up in hop yards on the WSU Prosser Irrigated Agriculture Research and Extension Center (WSU IAREC). Grower standard treatments including the insecticide/acaricide active ingredients abamectin, bifenazate, etoxazole, and fenpyroximate will be compared to candidate compounds with some emphasis on numbered experimental compounds. Bayer Chemical Company has a new experimental acaricide. We will ask for some samples to screen on hops. We will also screen candidate alternative acaricides that have shown promise in our controlled laboratory bioassay studies. Protocols, if received from registrants, will be followed. If no protocols are received, published and/or registered label rates will be applied. All applications will be made by airblast sprayer. Ten to fifteen leaves will be collected from each plot once per week and transported to the laboratory, where the number of motile spider mites, spider mite eggs, predatory mites, and other relevant arthropods will be quantified. As the vines mature, cone samples will be taken and the spider mite and other arthropod population abundance on and in the cones will be quantified. Spider mite and other arthropod populations from treated plots will be compared with those from nontreated control plots. Spider mite abundance will be analyzed by repeated measures analysis of variance and population means of spider mites in treated plots will be compared in pairwise tests with populations in the control plots.

**b) Conduct field trials in grower collaborator yards with candidate alternative acaricides. This will include plant-based extracts and oils.** A number of “alternative” plant-based extracts and oil-type products are being marketed as having acaricidal properties. Most of these products are exempt from tolerance and many target the cannabis market where, as with hops, growers have substantive issues with spider mite management. We have tested many of these alternative acaricides in controlled laboratory bioassays and in our small plot efficacy trials. Some of these products warrant commercial-scale trialing. This work will be conducted in grower collaborator hop yards. We will acquire alternative acaricides from vendors and provide them to our grower collaborators where they will be applied commercially. We have been approached by several registrants to test their candidate products. To date these include rosemary oil-based EcoRaider and Tetracurb, citric acid-based NukeEm, *Beauvaria bassiana*-based BotaniGard, organic stylet oil, neem oil, canola oil, mint oil, dill oil, and garlic oil. Plot size will be determined by the quantity of each product received. Prior to and following application we will sample 100 leaves taken at random from each of the treated blocks. We will also take samples from blocks not treated with these alternative acaricides. The mites on these leaves will be quantified under a dissecting microscope in the Hop Building in the Environmental and Agricultural Entomology Laboratory.

**c) Develop a sensitive, rapid and cost-effective method to predict multiple acaricide resistance on a portable platform. (Depending on progress and industry assistance 2024). S**HERLOCK, a Cas13a-based molecular detection platform, is a highly sensitive and

specific single-base detection method that can detect multiple mutations associated with acaricide resistance in hop fields (Broad Institute 2018). We will purchase recombinant Cas13a protein from NovoPro Bioscience Inc. This protein, ssRNA target 1, crRNA, and reporter (quenched fluorescent RNA) will be incubated for RPA. The SHERLOCK will be used to detect three of the most common single nucleotide polymorphism (SNP) mutations linked with acaricide resistance in PNW hop fields (G126S in the cytochrome b gene, F1538I in the voltage-gated sodium channel gene, and I1017F in the chitin synthase 1 gene) from 20 field populations of spider mites with a history of acaricide input. Populations will further be bioassayed for their resistance status to commonly used acaricides by quantifying lethal concentrations (LC10, LC50, and LC90) required to kill 10, 50, and 90% of each population via methods detailed by Piraneo et al. (2015) to validate molecular markers. The SHERLOCK fluorescence data will be calculated by crRNA ratios for SNPs. A subset of the DNA extracted will be amplified with established PCR methodology and sequenced to validate the SHERLOCK technology. For robustness, we will concurrently develop a lab-based multiplex assay to detect acaricide resistance mechanisms. We will characterize the genetic structure of mite populations infesting regional hop yards. Individual mites will be collected from 20 representative hop yards, flash frozen, and stored at -80 C for DNA extraction by Qiagen-based kits. Individual females (~25) will be analyzed from each hop yard to assess local genetic population structure.

**d) Screen and then bioassay selections from the male germplasm for any genetically-based tolerance to mite infestation.** Our hop germplasm repository at WSU IAREC contains over 421 male hybrids among which some have served as the primary parentage of many variety releases and advanced selections in the repository. In 2021, a subset of the male hops from the USDA-Prosser and USDA-Corvallis breeding programs were propagated into three replications using softwood cuttings, allowed to establish for eight weeks, and transplanted in a randomized complete block design in a hop yard at IAREC. In spring of 2022, these male hop plants will be strung and trained in early spring on a 15' trellis. In June and in August of 2022, four leaves from each replicate plant will be collected and bagged. TSSM will be removed from the leaves under a dissecting microscope with a fine camel- hair brush and placed on 10-cm leaf disks. Leaf disks will be imaged under a microscope to quantify trichome density. Disks will then be placed on moist cotton in petri dishes and ten gravid adult female and three adult male TSSM will be placed into each arena. The number of eggs laid will be quantified five and ten days post-placement. Also at ten days post-placement, adults will be removed and the number of eggs that have hatched and developed into larvae and protonymphs will be quantified. A cohort of 25 newly laid (translucent) eggs per replicate arena will be transferred to fresh leaf disks and held for five days and the percent hatch will be quantified. TSSM that leave the leaf arena will be sexed and quantified to adjust reproduction rates. Flowering time will also be recorded to control for plant maturity in mite fecundity. The study will be repeated over three growing seasons to evaluate differences attributed to year and plant age. Male lines that appear to be resistant or susceptible after several years of evaluation will be entered into crossing blocks to begin the development of segregating populations.

**e) Complete augmentative releases of the predatory mites *Neoseiulus fallacis* and *Galendromes occidentalis*.** We will establish four ¼-acre plots in two separate Yakima Valley grower-cooperator hop yards with similar climatic characteristics and TSSM pressure. Into one set of plots, we will release 12,500 *N. fallacis* predatory mites twice in late spring / early summer in each project year. In the other set, we will release 5,000 *G. occidentalis* biweekly starting in late spring for a total of 5 times. Rates are based on recommendations and successes in other cropping systems and on the basis of being commercially affordable if successful. If practicable (currently under investigation), we may establish a similar program with *Stethorus punctillum,* the “Spider Mite Destroyer beetle.”

**f) Determine if broadcast applications of ozonated water degrades acaricide residues.** Multiple studies in other crops and in stored product facilities have demonstrated that the application of ozone can degrade pesticide residues and lead to less pesticide being detected in analytical laboratories. Just prior to harvest in September we will borrow an airblast sprayer presently equipped with an ozone injection system from the Center for Precision Agriculture and Automation and treat one half of our Tomahawk block from the acaricide efficacy studies (Objective a, above) with ozonated water. Following harvest and kilning we will send 2 samples of from specific acaricide treatments in Objective a that were treated with the ozonated water treatments and 2 that were not treated with the ozonated water to the pesticide analytical laboratory. Candidate acaricides for residue analysis include abamectin, bifenazate, fenazaquin, hexythiazox, and spirodiclofen due to current or pending MRL issues in the European Union.

**g) Develop a multispectral/ thermal imaging method to quantify mite abundance in association with our mite brushing mite abundance quantitation method.** Presently when sampling acaricide efficacy and other field studies that require the quantitation of the abundance of mites we run a specific number of hop leaves, usually 10 or 20, through a “mite brushing machine” that brushes the mites onto a round glass plate. The mites on this glass plate are visually quantified by counting the mites under a stereomicroscope. This is labor-intensive and Washington State is increasingly making it more difficult and expensive to hire temporary laborers to perform routine seasonal labor. In 2022 we will borrow a multispectral camera from the WSU Center for Precision and Automated Agricultural Systems and take videos of the circular glass plates with mites and mite eggs on them. Using a computer and some preexisting software we will determine which wavelength most accurately detects mites and mite eggs on the plate. Once this is determined we can work with a software developer to develop a software program that will “count” the mites and mite eggs on the glass plate. If this is successful, we will include a funding request in our 2023 budget for the purchase of a multispectral camera with a thermal imager. At a cost of ~$4,000, this will result in substantial savings over the current methods of quantitation.

**Outcomes**

**a) Field test candidate compounds and recommended commercial blends of acaricides for their efficacy against spider mites.** Short-term, we will have an indication of the relative efficacies of the various compounds. Medium-term, we may seek and achieve registrations of promising candidate compounds to expand the mite management toolkit. Long-term, we hope to achieve sustainable mite management under a wide range of conditions and infestation levels.

**b) Conduct field trials in grower collaborator fields with candidate alternative acaricides. This will include plant-based extracts and oils.** Some growers are already using these products. Demonstration plots and sampling by our scientific staff will quantify the efficacy of these trials with alternative acaricides.

**c) Develop a sensitive, rapid and cost-effective method to predict multiple acaricide resistance on a portable platform.** Short-term, we will field-test the SHERLOCK platform on the 3 most common SNPs and get an indication of its practicality. Medium-term, we will expand its use and ascertain its applicability for growers, toward the possibility of commercial availability. A substantial part of our success will be determined by Sherlock Biosciences’ ability to pivot away from focusing almost exclusively on developing testing methods for human disease towards conducting research in other fields including agriculture.

**d) Screen and then bioassay selections from the male germplasm for any genetically-based tolerance to mite infestation.** Short-term, we can begin to discern whether mite tolerance is apparent in any of the male genotypes. Medium-term, we can refine these studies and focus on the pedigrees of any tolerant genotypes. Long-term, resistant genotypes identified could play a role in mite management and overall IPM in hop if mite tolerance in a male genotype is heritable and if this heritability can be quantified.

**e) Complete augmentative releases of the predatory mites *Neoseiulus fallacis* and *Galendromes occidentalis***. This will permit us to quantify if augmentative biocontrol of mites is economically possible.

**f) Determine if broadcast applications of ozonated water degrades acaricide residues**. If successful, this may improve mite management and overcome some MRL issues with some important acaricides.

**g) Develop a multispectral/ thermal imaging method to quantify mite abundance in**

**association with our mite brushing mite abundance quantitation method**. This could provide some substantial labor savings as hiring seasonal temporary laboratory help is becoming increasingly difficult.

**Extension and Outreach Activities.** Walsh and his team have a strong track record of two-way communication with hop industry leaders and stakeholders. We plan to continue our collaboration with Hop Growers of America, utilizing usahops.org as a tool for communication as well as making presentations at the American Hop Convention and meetings of HRC, Washington Hop Commission, Hop Industry Plant Protection Committee and other state and regional hop commissions and representative groups in addition to extensive one-on-one communications with growers and consultants.

**Time Frame for Objectives**

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  | **JAN** | **FEB** | **MAR** | **APR** | **MAY** | **JUN** | **JUL** | **AUG** | **SEP** | **OCT** | **NOV** | **DEC** |
| **OBJ A$27,586** |  |  |  | Establish IAREC plots |  | Analyze data |  |
|  |  |  |  | Make applications per protocols or labels |  |
|  |  |  |  |  | Collect leaves, quantify arthropods |  | Prepare report |
|  |  |  |  |  |  | Collect cones, quantify arthropods |  |
| **OBJ B$6,516** | Finalize grower collaborator arrangements, obtain supplies of alternative acaricides, finalize protocols and plot sizes | Grower application of products |  |  |  |
|  | Obtain leaf samples, quantify mites |  |  |
|  |  |  |  | Analyze data |  |
|  |  |  |  |  |  | Prepare report |
| **OBJ C$10,100** | Finalize protocols | Incubate, detect mutations |  |  | Prepare report and next steps in collaboration with industry |
|  | Assign and train personnel | Bioassay mites for resistance status |  |
| Purchase Cas13a protein and other materials for both field- and lab-based assays | Validate molecular markers | Amplify DNA subset |
| Mite collection | Analyze data |
| **OBJ D$11,131** |  |  | String and train male hop plants | Collect leaves and field data, remove mites, establish disk arenas |  |  |
|  |  |  |  |  | Quantify trichome density, eggs, adults, sexes, and % hatch |  | Prepare report and plan for next season |
|  |  |  |  |  |  | Analyze data |
| **OBJ E****$5,750** | Determine grower cooperator(s) | Establish plots | 2x *N. fallacis* release |  |  |  |  |
| 5x *G. occidentalis* release |  |  |  |
| Determine feasibility of *S. punctillum* augmentation and conduct if practical |  |  |  |
|  |  |  |  |  |  | Analyze results | Prepare report |
| **OBJ F****$4,500** |  |  |  |  |  |  |  | Treat ½ block w/ ozone H20 |  |  |  |
|  |  |  |  |  |  |  |  | Treated and control samples in for analysis |  |  |
|  |  |  |  |  |  |  |  |  | Analyze data, prepare report |
| **OBJ G****$2,914** |  | Arrange use of camera |  |  |  |  |  |  |  |  |
|  |  |  |  | Take videos of mites and eggs |  |  |  |  |
|  |  |  |  |  |  | Develop counting application with existing software |  |  |
|  |  |  |  |  |  |  |  | Validate automated counts against visual |  |
|  |  |  |  |  |  |  |  |  |  | Prepare report |

**Project Budget**

|  |  |  |  |
| --- | --- | --- | --- |
| Expenditure | Hop Research Council Request | Commission Request (specify state) | Total Amount Requested |
| State: WA | State: |
| Amount (cash) | Amount (cash or in-kind) |
| Salaries1 | 21,624 | 15,057 |  | 36,681 |
| Employee Benefits2 | 9,604 | 6,615 |  | 16,219 |
| Temporary or hourly workers3 | 4,680 | 3,120 |  | 7,800 |
| Travel4 | 2,181 | 654 |  | 2,835 |
| USA Hop Convention Registration | 800 |  |  | 800 |
| Cell Phone4 | 360 | 240 |  | 600 |
| Supplies5 | 2,137 | 1,425 |  | 3,562 |
|  |  |  |  |  |
| Total | 41,386 | 27,111 |  | 68,497 |

1/ Sally O’Neal (Extension Coordinator Specialist) 0.05 FTE is $3,844; Dan Groenendale (Scientific Assistant) 0.15 FTE is $11,374; Deborah Brooks (Assoc. in Research) 0.15 FTE is $6,990; Antonio Moreno (Farmer II) 0.35 FTE is $14,473

2/ O’Neal benefits @ 33.12% is $1,274; Groenendale @ 33.19% is $3,775; Brooks @ 45.44% is $3,177; Moreno @ 49.84% is $7,213; PhD student (below) @ 10% is $780

3/ PhD student hourly summer wage 40 hrs/wk for 13 wks @ $15/hr $7,800

4/ Summer and winter HRC meetings $1,200 plus project mileage 3,000 miles @ $0.545/mi is $2,835

5/ Dan Groenendale and Sally O’Neal cell phone stipend @ $25/mo each for 12 mos is $600

6/ Maintenance pesticides $2,400; land charges 2 acres @ $581/acre

**Publications since 2021 proposal was submitted**

1. Henning, J.A., M.S. Townsend, D.H Gent, M. Wiseman, D. Walsh, D. Groenendale and A. Randazzo

Registration of High-Yielding Aroma Hop (*Humulus lupulus* L.) cultivar,‘USDA Triumph'. Submitted. Plant Registrations, J. Crop Sci. Soc Am.

2. Adesanya, A. W., M. J. Beauchamp, M. D. Lavine, L. C. Lavine, Fang Zhu, & D. B. Walsh. 2021

Mechanisms and management of acaricide resistance for *Tetranychus urticae* in agroecosystems. J Pest Sci doi.org/10.1007/s10340-021-01342-x

3. O’Hearn, J. & D. Walsh. 2020. GLRaV-3 Vectored by Grape Mealybug, *Pseudococcus maritimus*

(Hemiptera: Pseudococcidae), at low population levels. J Entomol Sci doi.org/10.18474/0749-8004-56.1.106.

4. O’Hearn, J. & D. Walsh. 2020. Effectiveness of imidacloprid, spirotetramat, and flupyradifurone to prevent

spread of GLRaV-3 by grape mealybug, Pseudococcus maritimus (Hemiptera: Pseudococcidae). J Plant Disease and Protection. DOI https://doi.org/10.1007/s41348-020-00359-1

5. Adesanya, A. W., T. D. Waters, M. D. Lavine, L. C. Lavine, D. B. Walsh & Fang Zhu. 2020. Multiple

insecticide resistance in onion thrips populations from Western USA. Pesticide Biochemistry and Physiology. https://doi.org/10.1016/j.pestbp.2020.104553

6. Adesanya, A. W., M. J. Beauchamp, M. D. Lavine, L. C. Lavine, Fang Zhu, & D. B. Walsh. 2020.

RNA interference of NADPH-Cytochrome P450 reductase increases susceptibilities to multiple acaricides in *Tetranychus urticae*. Pesticide Biochemistry and Physiology. https://doi.org/10.1016/j.pestbp.2020.02.016