Project Title: Exploring Hop Agrivoltaic Systems

Project Summary: This innovative project will explore the potential of shared land use with the co-location of agriculture and solar photovoltaics, also known as "agrivoltaics". Specifically, we propose evaluating the feasibility, benefits, and challenges of installing novel wind resistant solar modules over the hops yard utilizing the existing infrastructure of the trellising system. Ahead of installation we will predictively model the shading pattern and light microenvironment created by the modules. We will evaluate total yield impact(s) as well as the developmental, quality, and phytochemical impacts of photovoltaics over the hop yard. We will use this information to describe any crop phenology changes that may be beneficial to hop growers. Lastly, we will predict the electrical power generation potential of the systems, and therefore additional farm revenue, generated by a hops agrivoltaics installation. By studying hop growth patterns, yield, and resource requirements in presence of solar modules, we aim to provide valuable insights into the feasibility and benefits of hops agrivoltaics systems.

Proposed Duration: New proposal with a duration of one and half years.

Project Leader: Dr. Mark Uchanski, Colorado State University, 970-491-4885, mark.uchanski@colostate.edu, Department of Horticulture and Landscape Architecture, 301 University Ave., 1173 Campus Delivery, Fort Collins, CO 80523.

Cooperator: These proposed studies will take place at the Irrigated Agriculture Research and Extension (IAREC) hops yard in Prosser, Washington under the management of Dr. Doug Walsh and his support staff. They will support hops crop growth, training, fertilization, pest management, harvest, and post harvest yield data collection.

Amount Requested: $40,987

Other Funding Sources and Support: Colorado State University's unrecovered indirect costs calculated per CSU's federally negotiated indirect cost rate agreement for on-campus research.

Send Funding To:

Colorado State University
Catherine Douras, Senior Research Administrator,
200 W. Lake Street, Fort Collins, CO 80521-4593
Catherine.douras@colostate.edu
970-491-2375

Project Title: Exploring Hop Agrivoltaic Systems

Statement of Problem: Our proposed project aims to explore the symbiotic relationship between hops and solar energy production, with a specific focus on enhancing crop productivity, resource efficiency, and environmental sustainability.

Justification and Importance of Proposed Research:

1.) Per acre impact: Varies depending on solar module density.
2.) Total acres impacted by the problem: Reduction of farm/industry carbon footprint has the potential to impact as many grower acres as voluntarily adopt the system.
3.) Aggregate impact to industry, including aggregate value of the potential percentage of the crop affected: To the extent acres and practices voluntarily participate across the supply chain.
4.) How does success in accomplishing this project benefit growers/processors/brewers? This project will describe the potential microenvironment, yield, crop development, quality, and economic conditions created in a hops agrivoltaics system in Washington state. That will allow growers/processors/brewers to evaluate their energy, carbon, and sustainability goals in the context of this proof-of-concept project.

Objectives:

1.) Predictively model the shading and light microenvironment in an agrivoltaics hops yard system utilizing novel wind-resistant modules/panels. Completion date: March 2024.
2.) Evaluate total yield impacts of photovoltaics modules installed over the hop yard. Completion date: November 2024.
3.) Evaluate developmental, quality, and phytochemical impacts of photovoltaics over the hop yard. November 2024.
4.) Describe the crop phenology (e.g. staggered cone development and maturity at the end of the season potentially widening the harvest window) in an agrivoltaics hops yard system. Completion date: October 2024.
5.) Predict the electrical power generation potential of the systems, and therefore additional farm revenue, generated by a hops agrivoltaics installation. What does that mean for the economics of the farm? Completion date: December 2024.

Procedures/Methods to Accomplish Objectives:

1.) Model the shading and light microenvironment with novel "Toyko Oasis" (PvFoundry, Singapore), wind-resistant photovoltaic modules:
    a. Location: Fort Collins, Colorado and remote work with SPADE Agrivoltaic Design + Development.
    b. Experimental procedures: Consulting service SPADE will use local weather station data, publicly available climate data, and computer modelling software to predictively analyze the crop microenvironment (light/shading level and patterns produced by the modules, plus Watts/m^2) the elevated modules installed on top

    of hops trellising infrastructure in the field in Prosser, Washington (see draft graphic [Fig. 1] below).
  c. Plot design: Row spacing will be 29 ft (9m) with solar modules running east to west. Module/panel height from ground level will be commercial 19 ft (5.85m).
  d. Methods: The modules will be installed on top of a portion of the experimental hops yard in Prosser, Washington. Three replications of solar modules will be paired with three replications without modules (i.e. control plots).
  e. Data will be analyzed and reported through computer modeling and some direct measures of the light environment to "ground truth" the report.
  f. Potential pitfalls and limitations: Ensuring the safety and structural stability of the modules and trellising system will be of primary interest for this proof of concept.

2.) Evaluate total yield impacts of photovoltaics modules installed over the hop yard:
  a. These proposed studies will take place at the Irrigated Agriculture Research and Extension (IAREC) research hops yard in Prosser, Washington.
  b. The experimental hops yard is under the management of Dr. Doug Walsh and his support staff. They will support hops crop growth, training, fertilization, pest management, harvest, and final yield data collection.
  c. Plot design: Control hop yields will be compared with plots with the photovoltaics modules installed overhead.
  d. Methods: At the end of the growing season bines will be cut and cones will be measured for total yield.
  e. Means will be compared statistically to determine if a significant yield increase or decrease was observed, or no significant change, and will be reported.
  f. Potential pitfalls and limitations: The number of replications and total area under photovoltaics will be a limiting factor since there are limited resources for procurement and installation (i.e. research plots will be relatively small), which could make it difficult to detect yield differences if they exist.

3.) Evaluate developmental, quality, and phytochemical impacts of photovoltaics over the hop yard. November 2024.
  a. These proposed studies will take place at the Irrigated Agriculture Research and Extension (IAREC) hops yard in Prosser, Washington.
  b. The experimental hops yard is under the management of Dr. Doug Walsh and his support staff. They will support hops post harvest quality and phytochemical analyses using their standard protocols.
  c. Plot design: Same as described above.
  d. Methods: At the end of the growing season bines will be cut and cones will be measured for post harvest quality indicators and phytochemical composition.
  e. Data analysis and interpretation: Quality indicators and phytochemical compositions in cones post harvest will be compared statistically to determine significant differences between treatments.
  f. Potential pitfalls and limitations include incomplete development and/or maturity of the bines or cones, which could make comparisons in the final analysis difficult.

4.) Describe the crop phenology (e.g. staggered cone development and maturity at the end of the season potentially widening the harvest window) in an agrivoltaics hops yard system.
    a. These proposed studies will take place at the Irrigated Agriculture Research and Extension (AREC) hops yard in Prosser, Washington.
    b. Experimental procedures: Days to top wire, days to flowering, and days to crop maturity will be recorded as the growing season progresses.
    c. Plot design: Same as above.
    d. Methods: We anticipate that crop growth and maturity will be delayed, leading to a staggered harvest window. We will compare the control plots to those grown under photovoltaics to determine this difference, if it exists.
    e. Data analysis: Mean days to each critical developmental stage will be compared separately statistically. Significant differences (e.g. increased or decreased attainment of each developmental stage) will be reported.
    f. Potential pitfalls: If the development is delayed in a substantial way the risk of frost is increased, which would jeopardize harvest and post harvest analyses.

5.) Predict the electrical power generation potential of the systems, and therefore additional farm revenue, generated by a hops agrivoltaics installation.
    a. Location: Fort Collins, CO.
    b. Experimental procedures: Inputs such as electrical output of the modules under different solar radiation intensity levels will be incorporated with microenvironment modelling outputs.
    c. Plot design: same as above.
    d. Methods: Watts/m^2 and local electricity sale prices will be used to estimate electrical output, and potential dollars/day/acre of hops yard.
    e. Interpretation: The estimates from d. above can be used by the industry to determine if the additional farm income generated is sufficient to justify photovoltaics infrastructure installation costs.
    f. Limitations: The proposed economic analysis will be limited in scope for this proof-of-concept project.

Outcomes:

1.) A visual representation of the agrivoltaics hops yard will aid in decision making about whether this system will work for individual growers and the larger industry in the Pacific Northwest.
2.) Yield results will allow an individual grower to weigh if the other costs/inputs are suitable for their enterprise.
3.) Cone quality may be impacted positively or negatively, and growers/brewers can make decisions based on these trends.
4.) Agrivoltaics in hops may lead to staggered development, allowing for the harvest window to be extended and widened.
5.) Economic outcomes: Taken together, we hope that even a limited economic analysis will allow the industry to determine whether to pursue this novel approach in the short, medium, or long term.

Extension and Outreach Activities:

The project leader, cooperator, and post doc will disseminate research results, outreach and extension, reporting to funding agency, and manuscript preparation/publication: January 2025-June 2025.

Time Frame for Objectives:

Objective 1: January 2024-March 2024.

Objective 2: May 2024-November 2024.

Objective 3: May 2024-November 2024.

Objective 4: May 2024-October 2024.

Objective 5: May 2024-December 2024.

Key Literature:

The field of agrivoltaics is relatively new to the United States, however many different photovoltaics configurations, crop species, and geographic locations have been studied worldwide in recent decades. This includes annual cropping systems (e.g. annual vegetables, annual grain crops, etc.), forage systems, & perennial woody food crops (e.g. grapes, peaches, etc.). However, to our knowledge, there is no published research related to perennial, non-woody climbing species such as hops in agrivoltaics systems. With pre-existing infrastructure (i.e. trellising), proximate grid tie-in points for most hops yards in Washington and Colorado, and a relatively low light saturation point (i.e. shade tolerant) hops are strong candidate for evaluation. The grower can gain from additional income from electricity generation on the farm, the processor can benefit from reduced carbon emissions, and the brewery can increase their supply chain sustainability.

On an average day in the western U.S., including Washington and Oregon, solar irradiance can reach approximately 2,000 $\mu mol.m^{-2}.s^{-1}$, but hops tissues have a saturation radiance of 341 $\mu mol.m^{-2}.s^{-1}$ for lower strobili, to mid-canopy leaves (415, 447, and 499 $\mu mol.m^{-2}.s^{-1}$), and upper leaves (612 $\mu mol.m^{-2}.s^{-1}$)(Bauerle, 2023; Bauerle, 2021; Hnilickova et al., 2007). Therefore, hops could hypothetically tolerate shading levels of 30-60%. This presents an opportunity to utilize excess photons in the hops yard by converting them to electricity that, in most cases, can be sold back to the grid for additional farm revenue. We propose evaluating crop yield impact, crop development and maturation, as well as a basic economic analysis of hops in agrivoltaics systems in Washington.

Bauerle, W.L. 2023. *Humulus lupulus* L. strobilus photosynthetic capacity and carbon assimilation. Plants 12(9): 1816.

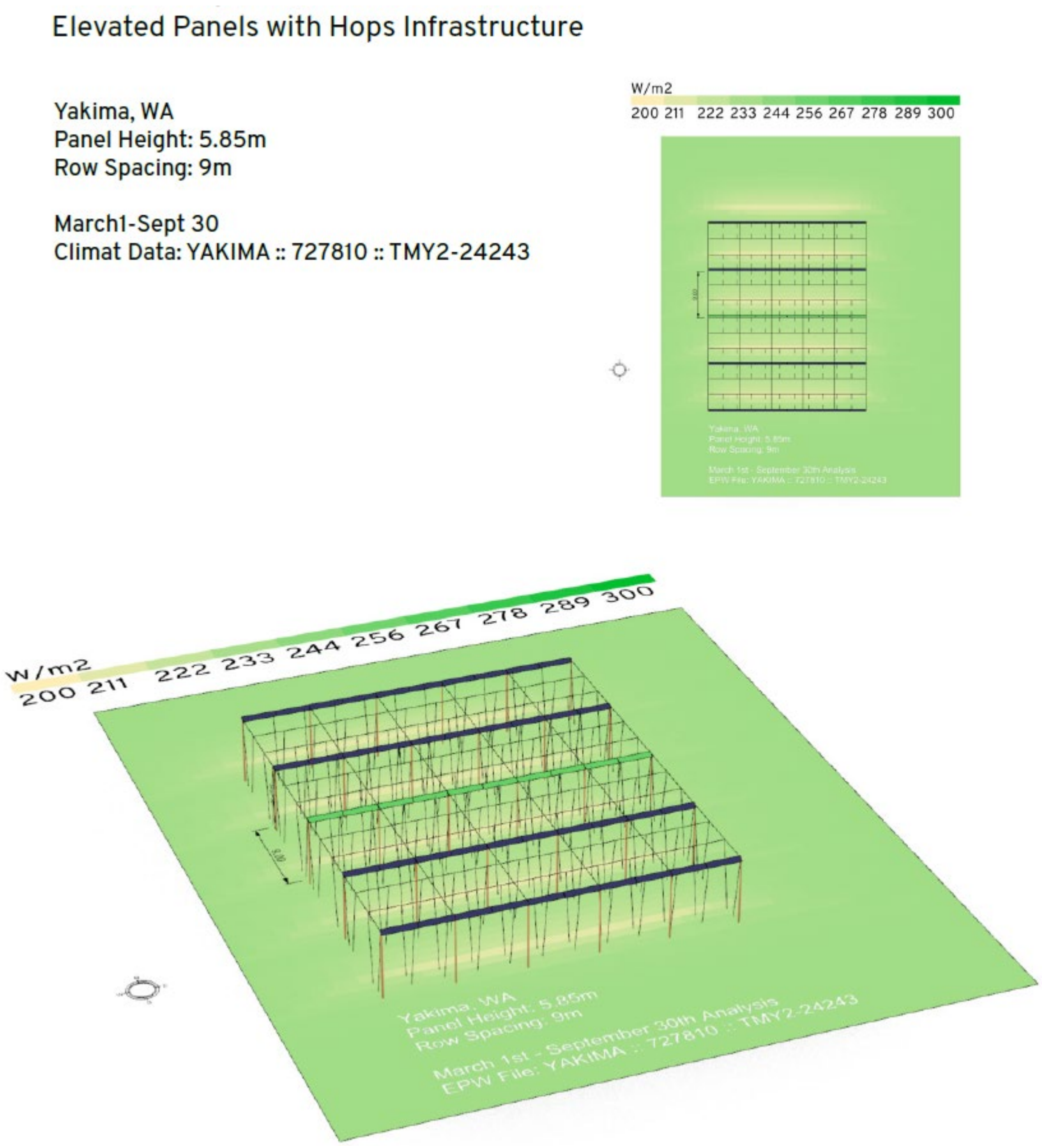
Bauerle, W.L. 2021. Intracanopy CO_2 and light interactions on *Humulus lupulus* L. net canopy carbon gain under current and future atmospheric CO_2 concentrations. Agricultural and Forest Meteorology. Vol 301: 108621.

Hnilickova, H., F. Hnilicka, and K. Krofta. 2007. Determining the saturation irradiance and photosynthetic capacity for new perspective varieties of hop (*Humulus lupulus* L.). Cereal Research Communications: A Quarterly of the Cereal Research Non-Profit Ltd. Company. 35(2): 451-464.

Curriculum Vitae:

CSU offers a B.S. in Fermentation Science and Technology and is embedded in a rich beer and brewing community in both Fort Collins and across the state.

<u>Figure 1</u>: Example SPADE shade and lighting environment analysis report.



Project Budget:

Expenditure	Hop Research Council Request	Commission/Other Request (specify)		Total Amount Requested
		State:	Other: CSU	
		Amount (cash or in- kind)	Amount (cash or in-kind)	
Salaries: - PI Faculty Salary (1% FTE, Y 1-2) - TBN Post Doc Salary (4.17% FTE, Y 1-2)	$2,362 $3,810			$6,172
Employee Benefits: - PI Faculty (28.6%) - TBN Post Doc (28.6%)	$675 $1,090			$1,765
Temporary or hourly workers	$0			$0
Travel: - PI to Prosser, WA for team meetings (Y 1 and 2) - PI to American Hop Convention (Y 1) - Post Doc to American Hop Convention (Y 1)	$3,350 $1,500 $1,500			$6,350
USA Hop Convention Registration (Y 1)	$1,600			$1,600
Equipment	$0			$0
Other (specify): Materials and Supplies: - Photovoltaic Panels (Y 1) - Weather Station Node plus Sensors (Y 1) Other Direct Costs: - Shipping Photovoltaics from Japan to U.S. - Facility/Land Use Fee (Y 1) - Publication Costs (Y 2) - Professional services: Installation of photovoltaics (Y 1) - Professional Services: SPADE Crop Modeling (Y 1)	$6,500 $800 $3,300 $1,500 $1,500 $9,000 $2,500		Unrecovered Indirect Costs: $21,616	$25,100

Total	$40,987		$21,616	$40,987

Budget Justification:

Personnel: $6,172

- Faculty salary for the PI, Mark Uchanski, is requested at 1% FTE ($13,052/month base salary) as required by CSU policy in Years 1-2. PI will coordinate partners in Washington state, Colorado, and abroad for the project. He will prepare reports on the project's outcomes and present them at hops meetings. Uchanski will oversee overall project construction and execution.
- Salary for the Post doctoral research fellow is requested at 4.17% FTE ($5,049/month base salary) in Years 1-2. The Post Doc will assist with field research design and manage project data at harvest. The Post Doc will conduct statistical analysis and assist with report and manuscript preparation.

Employee Benefits: $1,765

Employee benefits are calculated on requested salary per the University's federally negotiated Indirect Cost Rate Agreement. The benefit rate used is as follows: faculty and Post Docs 28.6%. Employee benefits will be charged at the rate in effect when salary is incurred.

Travel, domestic: $6,350

- PI to Prosser, Washington for team meeting(s) and photovoltaics installation guidance, in years 1 and 2 (2 trips per year). Costs are based on reasonable estimates for airfare, lodging, per diem and ground transportation for a 4-day trip.
- Travel for PI and post doc in year 1 to annual hops convention, Frisco TX in January 2024 (required by RFA). Costs are based on reasonable estimates for airfare, lodging, per diem and ground transportation for a 4-day trip.

USA Hop Convention Registration: $1,600

Registration fees for the PI and the Post Doc for the American Hop Convention in Frisco Texas in January of 2024 as required by the RFP in year 1.

Other: $25,100

- Materials and supplies: $7,300
  - Photovoltaics modules materials costs: $6,500 in year 1.
    - Four units of photovoltaic (PV) modules for a 4kW DC installation at $1,625 per unit are required for the project to demonstrate the use of wind-resistant PV modules installed in a hops yard. We will conduct research to evaluate growth, quality, and phenology of the established hops crop growing immediately below the modules.
  - Weather station node plus sensor for characterizing microclimate conditions created by the agrivoltaics array. $800 in year 1.
- Other direct costs: $17,800

- Shipping and associated overseas permits: $3,300 in year 1.
    - Shipping 4 photovoltaic panels from Japan to Prosser, Washington USA at $825 per panel.
- Equipment, facility rental/user fees: $1,500
    - Facility/land use fee for ½ acre research hops yard located at the Washington State University Irrigated Agriculture Research and Extension Center (IAREC) in Prosser, Washington for 12 months in year 1.
- Publication costs/documentation/dissemination: $1,500
    - Academic publication fee, open access, in year 2.
- Professional services/consultant: $11,500
    - Installation of photovoltaics over hops yard in Prosser Washington, and small local site at ARDEC South in Fort Collins, CO. $9,000 in year 1.
    - Computer crop modeling (SPADE): $2,500 external partner in year 2. Professional services agreement with SPADE Agrivoltaic Design + Development for 50 hours at $50/hour.

Indirect Costs (F&A): $0

Indirect Costs (F&A) are not allowed per sponsor's guidelines.

Total Request: $40,987

CSU In-Kind Support: $21,616

Unrecovered indirect costs are calculated at CSU's federally negotiated indirect cost rate agreement for on-campus research of 53.5% for FY24 and 54% for FY25 and beyond of Modified Total Direct Costs (MTDC). In this budget nothing is excluded from the base when calculating indirect costs.

Other Funding Sources and Support:
Colorado State University's unrecovered indirect costs calculated per CSU's federally negotiated indirect cost rate agreement for on-campus research.

BIOGRAPHICAL SKETCH

DO NOT EXCEED THREE PAGES

NAME: Mark Uchanski

POSITION TITLE: Associate Professor of Horticulture

EDUCATION/TRAINING

INSTITUTION AND LOCATION	DEGREE	Completion Date MM/YYYY	FIELD OF STUDY
University of Illinois at Urbana-Champaign (UIUC), USA	B.S.	05/2002	Horticultural Sciences, Spanish minor
University of Illinois at Urbana-Champaign (UIUC), USA	Ph.D.	05/2007	Horticulture, Vegetable Crops

A. Personal Statement

Mark Uchanski was born and raised in the far western suburbs of Chicago, Illinois – where the suburbs meet rural America, corn, and soybeans. He fell in love with vegetable farming systems and food systems in his backyard and grandfather's garden in Chicago. His graduate project involved testing and removing pathogens from horseradish propagation stock to provide pathogen-free planting materials. Shortly after graduation in 2008, Uchanski moved to New Mexico to serve the chile pepper and onion industries as Assistant Professor of Horticulture at New Mexico State University. That work soon expanded to include small farm, diversified, and organic operations. In 2015, Uchanski moved to Fort Collins to serve as the Colorado State University Specialty Crops Program Coordinator. There he continues his work with vegetable and other specialty crop producers, including conducting research on sustainable and organic practices and inputs that are applicable to Colorado. He continues to blend his background, research and teaching interests in horticulture, ecology, and sustainable cropping systems.

B. Positions and Honors

2018-present Associate Professor of Horticulture and Extension Specialty Crops Specialist,
Dept. of Horticulture and Landscape Architecture, Colorado State University

2015-2018 Assistant Professor of Specialty Crops, Department of Horticulture and Landscape Architecture, Colorado State University

2014-2015 Associate Professor of Horticulture (Vegetable Crops) with tenure, Department of Plant and Environmental Sciences, New Mexico State University (NMSU)

2008-2014 Assistant Professor of Horticulture (Vegetable Crops), Department of Plant and Environmental Sciences, NMSU

2002-2007 Graduate Research and Teaching Assistant, Department of Natural Resources and Environmental Sciences, University of Illinois at Urbana-Champaign

2022, Western Regional Center to Enhance Food Safety USDA NIFA Multistate Efforts Award, October 2022. "For working collaboratively to provide continued food safety education, training, extension, outreach, and technical assistance to the food industry in the Western region." E. Gutierrez-Rodriguez & **M. Uchanski** at CSU.

2021, CSU College of Ag Sciences (CAS) Renewable Energy Research Team Award (Jennifer Bousselot, Scott Carman, Thomas Hickey, Mark Uchanski, Kurt Barth [CSU Mech. Eng.], Sophia Linn, and Ian Skor)

2021, CSU CAS Hemp Biology Research Team Award (J. McKay, P. Nachappa, A.C. Fulladosa, W. Cranshaw, M. Uchanski, J. Prenni, W. Bauerle, A. Berrada, R. Fletcher, J. Pitt, J. Chiginsky, C. Hayes, J. Bowen, B. Mitchell, D. Thilmany, D. Mooney, R. Hill, K. Ravet, S. Pearce, and M. Hazlett)

2020, Colorado State University Alumni Association's Best Teacher Award (student and alumni nominated award)

2018, Western Region USDA Multistate Project Award, Managing Onion Pests and Diseases (W2008; W3008)

2017, Team Research Award: Food Systems, Colorado State University, Fort Collins CO

2016, Outstanding Education Publication Award, American Society for Horticultural Science, Atlanta GA

2013, Organic Educator of the Year, New Mexico Organic Farming Conference, Albuquerque NM

2012, New Mexico State University College of Agricultural, Consumer, and Environmental Sciences & North American Colleges and Teachers of Agriculture Teaching Award, Las Cruces NM

C. Contributions to Science

Uchanski, M., T. Hickey, J. Bousselot, and K.L. Barth. 2023. Characterization of Agrivoltaic Crop Environment Conditions Using Opaque and Thin-Film Semin-Transparent Modules. Energies: 16(7), 3012, **https://doi.org/10.3390/en16073012**.

Ballard, T., J. Bousselot, S. Conrad, B. Gornick, C. Hayes, T. Hickey, R. Meyer, and M. Uchanski. 2023. Agrivoltaics in Colorado. CSU Extension Fact Sheet 0.306.

Freeman, J. with M.E. Uchanski. 2022. Adapting to the Land: a History of Agriculture in Colorado. University Press of Colorado: Louisville, CO. Book length manuscript (pp. 276).

Machado-Burke, A., M. Uchanski, and J. Davey. 2022. Evaluation of bactericides to manage slippery skin in onion in Colorado, 2021. Plant Disease Management Reports (PDMR), the American Phytopathological Society (APS), V128: accepted and in press.

Mason, T.J., H.M. Bettenhausen, J.M. Chaparro, M.E. Uchanski, and J.E. Prenni. 2021. Evaluation of ambient mass spectrometry tools for assessing inherent postharvest pepper quality. Nature: Horticulture Research. 8:160 (01 July 2021). https://www.nature.com/articles/s41438-021-00596-x

Hickey, T., M. Uchanski, and I. Skor. 2021. Specialty crop growth under three semi-transparent photovoltaic panel types. Abstract and presentation (online event) at AgriVoltaics Conference and Exhibition. 14-16 June 2021.

Fulton, J.C., F.O. Holguin, R.L. Steiner, and M.E. Uchanski. 2021. A microscopic and metabolomic description of stip-affected tissue in New Mexico pod type pepper. The Journal of ASHS. 146:3 pp. 169-177 (20 Apr 2021). https://doi.org/10.21273/JASHS05004-20 **Cover article.**

Fulton, J.C., R. Steiner, J. Colee, and M.E. Uchanski. 2021. The development and progression of stip, a reputed physiological disorder, in two pepper (*Capsicum annuum*) cultivars grown in a greenhouse. European Journal of Horticultural Science. 86(3): 243-251.

Chavez, M. and M. Uchanski. 2021. Insect left-over substrate as plant fertilizer. Invited review: insect biofertilizers- Journal of Insects as Food and Feed. Published online 25 Feb. 2021.

Johnson, S., J. Prenni, A. Heuberger, H. Isweiri, J. Chaparro, S. Newman, M. Uchanski, H. Omerigic, K. Michell, M. Bunning, M. Foster, H. Thompson, and T. Weir. 2020. Comprehensive evaluation of metabolites and minerals in 6 microgreen species and the influence of maturity. Current Developments in Nutrition: Published online 18 Dec. 2020. Volume 5, Issue 2, Feb. 2021.

D. Additional Information: Research Support and/or Scholastic Performance

2022-2025 Building Resilient Pest Management Strategies for Organic Hemp Systems, USDA OREI $266,196

2019-2023 Stop the Rot (onions), USDA Specialty Crop Research Initiative (SCRI) $153,391

2022-2023 Agrivoltaics Innovation for Colorado: Providing Solutions to Commodity Challenges by Exploring Agronomic Crops and Solar Modules of Varying Transparencies, CSU SCCC $31,000

2019-2020 Agrivoltaics: Integrating Horticulture and Photovoltaics, USDA SBIR grant $100,000

2018-2021 Next Generation Tech. for Monitor. Edge-of-Field Water Quality in Org. Ag., NRCS CIG $686,214

2019-2020 Sustainable and Sensible Weed Management For CO Spec. Crop Growers, SCBGP $24,995

2018-2020 Microgreens for Health, CSU Agricultural Experiment Station $60,000

2019-2020 Prod. Potential of Cool Season Legumes in Colorado, SCBGP $52,640

2018-2023 Northern Organic Vegetable Improvement Collaborative (NOVIC III), USDA OREI $93,499

2018-2019 Control Options for Mex. Bean Beetle in Org. Pinto Prod. Systems, CO Dry Bean Comm. $15,000

2018-2020 Integrating Comm. and Modeling Efforts to Eval. Impacts of Food System Interventions, $1,000,000 Foundation for Food and Agriculture Research (FFAR): Tipping Points

2018-2019 Impacts of the Soil Amendment Azomite on Pepper Growth, Azomite Mineral Products, $18,037

2018-2019 Field Irr. Resp. of Aronia, a New Multi-Product CO Fruit to Enhance Diversity, SCBGP $37,868

2018-2019 Rural Wealth Creation: Exploring Food Systems-Led Devel. Strat., CSU Provost Office $200,000

2018-2019 Specialty Crop Production Research & Tech. Support for CO Growers, CDA SCBGP $68,520

2018 Agrivoltaics: Integrating Horticulture and Photovoltaics, CSU Energy Institute $4,000