Outdoor Low-Cost Volumetric Urban Farming

a. Introduction

Typical urban farming available to most urban residents, such as rooftop gardens, offer limited growing area relative to the number of residents. Further, pressure on agricultural land from a rising global population is necessitating the maximization of food production per unit area of cultivation. (Beacham, 2019). In an average ten-story building, most residents will only have 100 sq. ft. of outdoor surface area available per apartment. One possible solution to this issue is the same as city densification, vertical farming (Kalantari, 2018), that develops a 'volumetric thinking' (Klauser, 2021) related to agriculture. "Vertical farming" in its simplest definition is the multilayered production of plants to increase yield per surface area (Van Gerrewey, 2021). However, current vertical approaches tend to focus on high tech, large warehouse grow structures, or "plant factories" (Beacham, 2019), with significant initial capital and utility costs. A 37-floor skyscraper growing system costs $200 million of equipment (no land or building cost), requires 80 million liters of water, and 3.5 GWh of power per year. (Banerjee, 2014) The land costs can also be prohibitive, starting at $5000 / m2 in many urban areas (Benke, 2017), while apartment roofs are structurally sound and often undeveloped. The initial investment / m2 for a vertical farm can be up to 10 times higher than a greenhouse and operating costs 2 to 5 times higher (Butturini, 2020). For normal residents, a simpler, less intensive method is necessary with minimal capital investment and utility costs comparable to vegetable beds, that still takes advantage of multilayered plant production, and where food can be grown close to home.

The project goal is to convert a 2,200 square feet suburban area into a three-layer vertical farm with space for approximately 15,000 plants with a focus on simple, low-cost methods that can be adapted to existing apartment roof area and available suburban land by common citizens. This project aims to achieve triple the normal density of many farms at 75 plants/m2 (approximately 300,000 plants/acre) and track all inputs and outputs of the growth process from bare land to harvest and sale, while minimizing the initial capital and inputs necessary. This project is designed to meet all USDA UIE 2022 program priorities:

1) ***identifying*** and promoting the ***horticultural, social, and economic factors*** that ***contribute to successful urban, indoor, and other emerging agricultural production systems***
2) developing new crop varieties and ***agricultural products to connect to new markets***

3) ***analyzing the means by which new agricultural sites are determined***, including an evaluation of soil quality, condition of a building, **or local community needs.**

This project is also targets three of the systems of interest:

A) ***community gardens and farms located in*** urban areas, ***suburbs*** and urban clusters

B) rooftop farms, ***outdoor vertical production,*** and green walls

C) ***other innovations*** in agricultural production (***extensive automated data collection***)

To meet goal 1) listed above, the horticultural, economic, and social factors will be measured and tracked for at least three chosen crops grown in a layered, volumetric, outdoor growing environment.

Horticultural factors tracked will include: respiration (automated before, during, after CO_2 & O_2 monitoring), maturation rates (camera monitoring of growth, one picture per day), root development (see through containers), flowering times, pollinator interactions (fixed time camera frames, computer pollinator recognition), harvest duration, harvest quality (imagery of all produce with time history), harvest yield (number and weight measurement), pests and disease occurrence (fixed time camera frames, computer pest/disease recognition), and rate of senescence (imagery of leaf shedding and seed germination). Each of these horticultural factors will also be cross referenced with automated data on rainfall (automated rain meters), shade and sunlight conditions (automated light meters, varying shade conditions {buildings, trees}), temperature (automated thermometers), and layer effects (plant locations within a three-dimensional volume, varying spacings in row, between row, and between layers).

Economic factors tracked for a volumetric outdoor growth system will be divided into two groups of inputs and outputs. Input factors tracked will include: construction cost (materials and labor time per area), Plant costs (starter and seed cost), and long-term input costs (irrigation costs, monitoring labor time, harvest labor time). Output factors will include: volume of crops produced and sold, price per carton weight (cwt =100 pounds), and sale interest in chosen crops at local farmers markets (purchases per species will be compared to attendance).

Social factors tracked will focus on population interactions with outdoor volumetric farming in a suburban area (records of comments, questions, interest, volunteers, pre-sales). Extension work will also support social factors with integration into the UI Extension activities including annual tours of the vertical farm, workshops, and a video on vertical growing methods, County Fair Exhibition, Palousafest, and showcases at other local and regional farm-related events. These activities will also help apply the work at both a local and regional level.

To meet goal 2) listed above, at least three crop species of vegetables will be chosen and grown based on: low availability (area planted, based on USDA, 2019 & USDA, 2022), lack of current vertical methods (such as beans on a trestle), and high price per cwt (USDA, 2019 & USDA, 2022). The three species chosen for growth testing in an outdoor, volumetric farming system will be selected from Crop Selection Table, Appendix 4.0 and may include: peppers*; cauliflower; leaf lettuce, cabbage; spinach; carrots; beans, and/or broccoli* depending on growth potential, for nutrient density and for marketability. The horticultural and growth conditions of these plants are also further detailed in Crop Selection Table, Appendix 3.0. We will implement two crop types known to grow well in a container system such as various herbs and lettuces and experiment with at least one crop that is unknown as to how it would grow in a container environment. A more compact variety or "baby" variety will be attempted. We will plant multiple types of herbs and will evaluate growth data based on various conditions such as shade/sun. In years two and three, more varieties may be added depending on successes and limits. Per the horticultural and economic factors noted above, statistics such as maturation rate and harvest yield will be calculated per plant and per species with cross references to layer conditions, sunlight & shade conditions, pollinator interaction and other variables.

To meet goal 3) listed above, the process of adapting a common suburban area to a farm with outdoor vertical production filling a three-dimensional volume will be documented so that potential farmers and gardeners will have evaluation criteria and data (economic, social, horticultural) available for the determination of new agricultural sites. This process will include outlining the cost of materials used for construction, steps necessary for site prep, steps necessary for construction, local zoning and legal issues encountered, imagery documentation of the construction process, imagery documentation along with automated data monitoring of growth and site conditions in the suburban area, and an evaluation of the suitability of the suburban area to qualify as "organic" farming.

b. Rational and significance

The project will strengthen UIE agricultural and food-production systems:

- ***By identifying the horticultural factors that can lead to an increase in vegetable production for outdoor vertical farms in suburban and urban areas***

Using extensive automated data collection with digital imagery, automated pollinator and pest recognition, thermal monitoring, rainfall monitoring, CO2/O2 monitoring, and light intensity monitoring, this project will identify the horticultural factors affecting volumetric, vertical farms in suburban areas. See section d. Approach, Objective 1.

- ***By identifying the economic factors that can lead to profitability for outdoor vertical farms in suburban and urban areas***

Tracking inputs and outputs of the plant growth process, this project will identify the economic factors affecting volumetric, vertical farms in suburban areas. Our economic approach will use primary data and secondary data (e.g., enterprise budgets from WSU, UI, other universities, and data from USDA National Agriculture Statistics Service (NASS), Economic Impact Analysis of Planning (IMPLAN), and the US Census, to (1) evaluate and prioritize crops for vertical farms in suburban areas, (2) conduct a sensitivity analysis on input factors that will affect financial outcomes, and (3) complete an input-output model using a social accounting matrix framework to evaluate economic impacts associated with greater adoption of vertical suburban agriculture at county, regional, and national scales. This project will provide data for input factors for the construction costs of materials, the construction labor expenses, the cost of the plants grown, the irrigation costs, operations and management costs, and all other construction and operations costs. The analysis will examine potential local and regional markets for the products, examine value added opportunities, and revenue projections at price points.

- ***By identifying the social factors for outdoor vertical farms in suburban areas***

Focusing on the social interactions with a new vertical outdoor farm in a suburban area, as well as integrated Extension work and county event participation, this project will identify the social factors for these farms by documenting social interactions and issues. See section d. Approach, Objective 3.

- ***By developing new sources for low-availability, high price, high yield crops***

Working with at least three species of crops that are currently available only in limited quantities at high prices, yet offer the possibility of high yields, this project will develop methods for producing high demand crop varieties to connect to new markets. The species chosen will be based on published USDA market data for vegetables from the Vegetables 2019 Summary (USDA, 2019), and will be selected primarily based on a ratio of Yield Price * Yield Per Acre / Planted Acreage with an additional consideration of adaptability to a volumetric growing arrangement. Per the horticultural and economic factors noted above, extensive data will be made available on the growth rates/phases and yields relative to rain, light, temperature, and volumetric positioning (row spacing, column spacing, and layer spacing). See section d. Approach, Objective 1.

- ***By documenting the means by which suburban agricultural sites are developed***

This project will document and publish the development process of outdoor vertical farming, while purposely minimizing capital expenditure and expensive growth inputs such as fertilizer, pesticide, hydroponics setups, or artificial lighting use. This will help provide what is often an isolated, high-tech growth method to common citizens along with data about the prospective performance, return on investment, and labor effort necessary. Documentary style imagery of each of the steps will be made available so that with little to no background knowledge a standard American consumer could purchase the components and assemble a similar volumetric farming operation in a suburban or urban area. Commonly available components and construction materials will be used wherever possible to facilitate this availability.

Application at local level

This project will be applied at the local level through work with the UI Extension program and integration with their existing recurrent activities. See Section d. Approach, Objective 3.

Application at regional level

This project will be applied at the regional level through two methods: interaction with the above-mentioned Extension and County scale events, as well as reaching out to local media with the use of television clip friendly imagery of vertical production and its integration with suburban neighborhoods (time-lapse construction imagery and time-lapse crop growth imagery). In-person educational programs offered in the region, as well as online statewide UI Extension workshops and UI Extension Tribal education programs will provide regional impact. Also See Economic Impact Analysis (Case Study on Saturday Farmers Market, section d. Approach, Objective 2) and engagement under section d. Approach, social factors under Objective

Application at national level

Application at the national level will have a multi-part strategy combining: publishing project data in machine readable format; publishing project videos to public websites; publishing

Extension bulletins, papers, and books on the project; submitting journal and conference papers of the results for peer review; as well as reaching out to national media with the use of television clip friendly imagery of vertical production and its integration with suburban neighborhoods. The full data list (shown later in the Data Management Plan) will be published to long term repositories with links from the Ag Data Commons in known machine-readable formats with a nod toward making the data relevant for machine learning applications.

Several of the data outputs will be in the form of videos (instructional, construction progress, growth, pollinator/pest interaction) which can then be published to public websites and social media to raise awareness and increase reach.

Much of the data and results will be appropriate for publication in conferences and journals, with possible topics on: implementing suburban vertical farming, yields from such farms, pollinator/pest interactions with volumetric growth, growth rates / phase development in volumetric outdoor conditions, and economic results of sales of marginally utilized crops. At least one book will also be created as an instruction manual, and results guide for implementation of outdoor vertical farms in suburban environments.

Finally, similarly to regional outreach, attempts will be made to connect with relevant national media to raise awareness and reach with possible targets being America's Heartland, Small Town Big Deal, This Old House, U.S. Farm Report, AgDay, and Discovery.

c. Objectives

The overall objectives of the project are:

1. Construct and document construction of vertical growing system as well as implement plant production and install automated data collection system.
2. Evaluate economic facets of the project including marketability of products, economic impact assessment and financial feasibility of low-cost vertical farming.
3. Implement and evaluate education program consisting of farm tours and workshops. Survey potential stakeholders via the national Master Gardener network of professionals regarding constraints and potential adoptability to inform education program.
4. Publicize project results to targeted stakeholders such as gardeners and farmers as well as the general public.

d. Approach

Objective 1: Construct and document construction of vertical growing system as well as implement plant production and install automated data collection system.

Convert 2,200 square feet of suburban area into a three layer vertical farm

An existing suburban outdoor area composed of a mixture of bare lawn and dirt garden measuring approximately 2,200 square feet will be transformed into a volumetric outdoor growing farm with the addition of a three-dimensional lattice mesh rope framework suspended from regularly spaced steel supports. At measured growing intervals within the lattice, see-thru baskets with soil will be suspended creating a three-dimensional set of growing locations. An image comparison of the landscape prior to application of the growing system, and the proposed footprint can be seen in Figures 1 and 2 in Appendix 1. A two-dimensional slice of the lattice, and the three-dimensional mesh structure formed by successive slices can be seen in Figures 3 and 4 (Putnam, 2021). Plant quantity within the region will target 15000 plants, and plant density will target 75 plants / m2. Spacings will be varied due to the property geometry and interest in exploring differing layer configurations, yet on average this will result in 25 plants / m2 / layer stacked in three layers with average plant spacing of approximately 8" x 8". Supports are expected to have 7' of exposed height above ground, offering 2' 4" of vertical space per plant on average, and allowing the uppermost plants to be examined by an average height human. All materials purchased for the construction will be documented with available cost alternatives, projected lead time quotes, and actual delivery lead times. Site prep, construction material assembly, and lattice basket network installation will all be documented with before, during, and after imagery with a focus on producing documentary, TV, or social media friendly video segments.

Instrument growing region with automated data collection systems

The growing system noted above will be instrumented with rainfall gauges, light meters, temperature meters, CO_2 & O_2 monitors, one image / day outdoor cameras, and pollinator & pest camera traps at multiple locations. Each of these systems will be chosen with a focus on automated data collection, and preferably wireless connectivity to a local area network. It is expected that the rainfall gauges, light meters, temperature meters, and CO_2 & O_2 monitors will each be activated four (4) times a day. In the interest of avoiding night vision systems, the pollinator & pest camera traps will be activated three (3) times a day. The gauges and meters will each take a single reading while the camera traps will take a short series of images to track objects near the plants and their movement. Camera traps will be used as recent work has shown that automated machine learning image recognition can efficiently catalog a wide range of plant insect interactions using only image-word source databases with video (Naqvi, 2022). Most commercially available camera traps are at least 1920x1080 pixels, resulting in approximately 1 MB per image, and 9 MB of image data per camera per day. It is expected that 40 cameras will be necessary to provide at least 10' coverage spacing of the growing volume, resulting in approximately 360 MB of image data per day. Based on a current average growing season length of 90-150 days in Moscow, ID, this would result in at least 32-54 GB of pest/pollinator interaction imagery data.

Plant and grow at least three crop species and identify horticultural factors

To meet the need of developing new crop varieties to connect to new markets, and identifying UIE horticultural factors, at least three vegetable varieties with marginal use in the American economy will be chosen from publicly available USDA data for trials within a volumetric, outdoor, suburban growing region. To evaluate the effects of the three-dimensional growing environment, crops will be spaced in a variety of layers (top, middle, bottom) and layer configurations (in-row spacings, between-row spacings, layer spacings). Further, crops will also be grown across a variety of UIE relevant shade & lighting profiles (hard building shade, soft tree shade, no shade) to evaluate the effects of these common urban & suburban terrain features on crop growth. Using the above noted automated sensor systems, numerous horticultural features about the crop growth will be collected over the growing season. Plant respiration will be measured with CO_2 & O_2 sensors. Maturation rate, flowing timeframes (where appropriate), and rate of senescence (leaf loss, bolting to seed) will be measured using image/daytime lapses recording plant development. Root development will be measured using similar methods, except with the addition of see-thru growing containers to image root growth. Pollinator/pest/disease interactions with the crops will be measured using multi-image camera traps taking short videos at specified time lapse intervals. These video results will then be subject to computer vision object detection, recognition, and motion estimation systems to evaluate the specific types of pollinators & pests interacting with the plants and the short-term movement of those interactions.

Harvest at least three crops and identify horticultural and economic factors

Evaluate the effects of the three-dimensional growing environment on the at least three chosen crops will identify both horticultural and economic factors. The harvest duration will be recorded with image/daytime lapse results and data entry of plants at "harvest stage", cross referenced with differences in data (lighting, temperature, CO_2 & O_2, pollinators/pests, three-dimensional position). The harvest yield will be recorded with quantity, weight, and images of the harvested produce. The images of harvest products will be further used to evaluate harvest quality while compared with subjective human evaluations and notations. Finally, the value of the products will be evaluated using the USDA produced charts of import / export unit / cost, and experimental evidence of sales (noted below).

Objective 2: Evaluate economic facets of the project including marketability of products, economic impact assessment and financial feasibility of low-cost vertical farming.

Economic Methods

Our economic methods will involve developing vertical suburban agricultural system scenarios upon which to base subsequent financial modeling and economic impact assessment activities. Specifically, we will use the primary data we collect along with secondary data sources to evaluate vertical suburban agricultural opportunities and strategies for producers by (1) defining a range of realistic vertical suburban agricultural operation scenarios; (2) analyzing the financial feasibility of operations for each scenario, including a dynamic sensitivity analysis of cost and availability of input factors; and (3) estimating the broader regional economic impacts of increased vertical suburban agricultural production with an input-output model using a social accounting matrix (SAM) framework.

Vertical suburban agricultural operation scenario building

Based on primary data gathering and analyses, vertical suburban agriculture-related case studies, and existing secondary data (enterprise budgets from WSU and UI and data from USDA National Agriculture Statistics Service (NASS), US Census, and CDC we will define 4-6 production scenarios. These scenarios will each represent different technological pathways, scales, and strategies. Scenario building will be an iterative process involving the project team.

Financial and business analysis

To evaluate suitability of different technologies and systems, we will conduct a thorough financial sensitivity analysis around key decision points for vertical suburban agriculture production for a suite of crops, including those that drive profitability. This will involve creating an economic and financial model for each of the scenarios developed through activity The scenarios will represent a variety of vertical suburban agriculture operations and supply chains to help understand feasibility, profitability, impacts, constraints, and opportunities. Using a benefit-cost framework, we will conduct a full financial analysis for each of the following variables and produce a matrix of outcomes for each scenario:

1. Capital costs–we will evaluate vertical suburban agriculture facilities ranging from small inexpensive facilities to multi-million-dollar facilities, including comparing both adaptation of existing buildings and new construction. We will also examine the substitutability of capital and labor.
2. Crops–to identify crops to study, we will adapt existing crop lists for vertical suburban agriculture production based on data from previous projects, co-PI experience, data from the project analyses. Additionally, we will create three crop-specific enterprise budgets for vertical suburban production. These enterprise budgets will be available for producers via extension activities described below and will feed into the economic impact assessment.
3. Scale of operation–we will examine economies of scale and scope, costs per unit of output by scale, and cost differential by product mix.
4. Energy costs and type–we will analyze the overall financial sensitivity of vertical suburban agriculture to energy costs.
5. Labor costs and availability–we will evaluate sensitivity of small and mid-scale agriculture to labor availability, training, and costs.
6. Technology–we will evaluate financial tradeoffs of at least three types of vertical suburban agriculture technologies.
7. Distance from consumer markets–we will evaluate the financial sensitivity of vertical suburban agriculture to transportation costs and storage facilities. For example, we will evaluate the relative importance of location, including if it is more important to be proximate to energy or labor.
8. Complementariness to outdoor agriculture–we will examine (a) financial feasibility of vertical suburban agriculture to extend the growing season and (b) to provide crop-specific production stability for variances in weather and the effects of climate change.

9. Marketing channels−we will examine the availability of current retail and wholesale outlets such as local food cooperatives, farmers markets, and local wholesalers to purchase vertical suburban agricultural products. This will include identifying scale, seasonal variation, and annual variation of demand for vertical suburban agriculture crops.

This part of the analysis will provide an investment analysis of vertical suburban agriculture and key investment metrics, including internal rates of return, benefit-cost ratios, net present value, and payback periods. After calculating these metrics, we will conduct a sensitivity analysis, similar to principal component analysis, to ascertain the variables most critical to the investment results and how sensitive those metrics are to each variable. Data on facility infrastructure and agricultural commodities being grown along with their associated enterprise budgets, distance from production inputs and markets, labor availability, and the other variables listed above will be used in developing the investment analysis. This analysis (activity 3b) will also enable us to build a comprehensive production function in our input-output model in the economic impact analysis (activity 3c).

Economic Impact Analysis

We will create an input-output model using a social accounting matrix (SAM) framework for the broad regional economy and selected sub-regions, counties, and cities. The modeling databases and software we will use are IMPLAN (IMPLAN Group 2022) and Lightcast (formerly Economic Modeling Specialists, International) (Lightcast 2022). As part of this analysis, we will develop a production function for vertical suburban agriculture, which will include the percent of total budget that vertical suburban agriculture purchase from all local sectors. We will also determine percent of sales to local and regional markets to analyze how expansion of vertical suburban agriculture will substitute local production for imported fruits and vegetables and how opportunities vary by season. We will conduct an economic impact assessment of scaling up of vertical suburban agriculture on selected county or multi-county regions that will include both the construction and operation of the facilities. Analyses will identify thresholds of scale of vertical suburban agriculture development that will have meaningful economic effects at local and regional scales. We will also identify specific crops or suites of crops with the most potential for impact, including for export from the region as well as import substitution.

Case Study: Evaluating Suburban Vertical Products in Local Market

Economic and social factors for the sales of the crops will be evaluated using direct sales of products grown with the proposed vertical farming in a person-to-person sales environment at a recurring local Farmer's Market with known demographics and attendance. The Saturday Farmer's Market in Moscow, ID regularly attracts 5,000 shoppers every week. It is active, with estimated annual attendance at 130,000 shoppers. Shoppers regularly spend approximately $30 per shopper, with total spending being roughly $6,000,000 and total receipts/vendor being $1850/market day (Argona, 2015; Pfiffner, 2016; Peterson 2018). Products will be offered at the USDA recommended wholesale price, and sales volume will be recorded, noting number sold, weight sold, value sold, and quality preference among buyers. Further, non-monetary social interactions such as comments, questions, and interest in the farm will be recorded with anonymous statistics.

Objective 3: Extension and Sociological Methods. Implement and evaluate education program consisting of farm tours and workshops. Survey potential stakeholders via the national Master Gardener network of professionals regarding constraints and potential adoptability to inform education program.

Integrate suburban vertical farm with University of Idaho Extension activities

To broaden local and regional outreach, the activities of the suburban vertical farm will be integrated with the UI Extension activities, including an annual farm tour, workshops and instructional video. UI Extension has education programs with the Coeur d'Alene Tribe and the Nez Perce Tribe. Vertical Farming workshops will be offered via each of their existing gardening programs and farmers markets. The Master Gardener program is a certification program that helps educate Idaho's citizens about the art and science of growing and caring for plants and landscapes in a scientifically sustainable way. This low-cost vertical farming education curriculum will be offered to the County Master Gardener Program nationwide.

Identify social factors for crops grown in vertical farms in suburban areas

To identify the social factors for crops grown in vertical farms in suburban areas, the comments, questions, interest, volunteers, and pre-sales of people who interact with the farm will be tracked with anonymized statistics by time & topic. If any zoning or regulatory issues impacting the suburban vertical farm are encountered, these will be tracked by time and topic, along with the resolution path. Finally, advertising, and social interaction booths will be obtained at the local Palousafest street fair and the Latah County Fair, with anonymized statistics documentation of social interactions by time & topic. Handouts of instructional and time-lapse videos as well as documentation will be made available for attendees to increase stakeholder outreach.

1a. Master Gardener and Small-Acreage Producer Program Survey

In year one, we will conduct a web-based survey of current and aspiring small-acreage producers and Master Garden program participants to gather information needed to inform extension workshop development and to answer the following research questions:

- What are producers' interests (e.g., system types, crops), motivations, barriers, educational needs, and preferred educational delivery format for adopting or strengthening vertical agriculture?
- What are the characteristics of farmers and gardeners who have adopted or are interested in adopting different types of vertical systems?

The survey sampling frame will consist of all current and aspiring producers included on the UI Extension Small Farms and Horticulture contact lists. The UI Extension Small Farms team, of which Mayes is a part, has contact information for all participants in small farms and horticultural extension programming in the last 20 years. These contact lists include those who have participated in Cultivating Success™ Idaho (CS), which include small-acreage farmers who are just beginning with up to 10 years of experience and those with 10-20+ years of experience. In the last three years, over 300 current and aspiring farmers have participated in a CS Idaho program specifically for beginning farmers: 59% of CS students have prior experience in farming, 46% are farming with their family, 62% are women, and 10% are veterans. While no perfect sampling frame for those interested in adopting vertical agriculture exists, these contact lists capture a large segment of the target population in Idaho. To broaden the sampling frame, we will work with our contacts at Small Farms Extension Education and Master Garden programs throughout the United States to send the request to participate and survey link to their program participants and contact lists.

We will implement the survey using a tailored design approach following Dillman et al. (2014). We will email a first request to take the survey with a link to participate via Qualtrics online survey platform and will send two reminder emails. To increase the likelihood of success, survey participants will be able to opt into a drawing to win one of two iPads or one of 20 $25

Amazon gift cards.

1b. Extension Workshop Evaluation

To evaluate the two extension workshops, we will develop two post-workshop evaluation surveys, one for each workshop. The post-workshop surveys will be as short as possible and will gather information to assess learning, anticipated behavior changes, and the content and quality of the training. The results of the Year 2 workshop evaluation surveys will be used to formatively evaluate, modify, and immediately improve the workshops for year 3. The surveys will be gathered on paper in person and via Qualtrics for those participating remotely via Zoom. We will gather the evaluation data during the workshop before participants leave to maximize the participation rate.

In the first quarter of Year 3, the Extension project assistant will follow up with Year 2 workshop participants to identify 5-10 who adopted a vertical growing system and would be willing to participate in an interview. We will interview these Extension program participants to learn about the practices they implemented along with their successes, challenges, and support needs. Interviews will be semi-structured to allow for flexibility and exploration of novel and unanticipated information as it emerges (Rubin and Rubin 2012). Interviews will last approximately 60 minutes and be conducted in person or by phone. Interviewees will be offered a $50 stipend for their participation.

In the third quarter of Year 3, we will conduct a web-based survey of the UI Extension program participants to document and evaluate their implementation of specific mid-term changes in behavior and conditions resulting from program participation.

Objective 4: Publicize project results to targeted stakeholders such as gardeners and farmers as well as the general public

Apply results through outreach to local, regional, and national media

To apply the results locally, regionally, and nationally, the first step will be compiling the data results in machine learning suitable formats. These results will then be hosted in publicly accessible repositories with the initial targets being CERN Zenodo, Kaggle, and Github Public Datasets with cross-reference links to the Ag Data Commons. A network of project related social media accounts will then be established on Youtube, Vimeo, Twitter, Instagram, Facebook Pinterest, SlideShare, and TikTok and links to the datasets will be provided. Next, TV and social media friendly clips of construction, growth, and harvest will be created from time-lapse or other imagery sources and hosted and cross-referenced on social media. Finally, local, regional, and national media will be contacted to explore interest in stories related to the research work, focusing mostly on the mass market acceptable imagery content and wider consumer applications.

Publish results in peer-review formats

The final step of applying the results for national level outreach will be preparing and submitting the results for publication in peer review formats. Papers on the automated data collection and machine learning aspects, volumetric farming, machine learning pollinator / pest identification from imagery, economics of marginal use crops, quality evaluation of suburban crops and desirability, suburban farming conversion, suburban farming growth conditions (air, rain, light, temperature), economics of small market commerce, social interaction with research topics, and project overview results for general science forums will be produced. Conferences targeted will include: IEEE/CVF Conference on Computer Vision and Pattern Recognition; International Conference on Learning Representations; IEEE/CVF International Conference on Computer Vision; International Conference on Machine Learning; International conference on Intelligent computing, Instrumentation and Control Technologies; and the International Conference on Precision Agriculture. We will target professional journals such as Journals targeted will include Nature, Science, Computers and Electronics in Agriculture, as well as any other publication appropriate to the subject matter. We will propose to publish a Journal of Extension article on the impact of the vertical farm education program. Results of the low-tech system will be published through the UI Extension bulletin process. Finally, a long form book on identifying the horticultural, social, and economic factors involved with developing marginal use crop species in outdoor vertical farms in suburban areas will be published.

Project Roles

Iris Mayes Ph.D., Project Director will oversee the project, managing subcontractors/consultants and supervising new UI staff: a horticultural graduate student and a program assistant. Mayes will also organize and co-host the annual farm tours as well as implement and co-teach vertical farming workshops and educational videos. Mayes served as the Educator for the Coeur d’Alene Tribe Extension program and will work with the current Tribal Educators to offer vertical farming workshops on the two nearby reservations.

Steve Peterson (UI) will implement the economic impact study and supervise Tim Nadreau (consultant) on the financial feasibility and modeling studies.

Gabriel Putnam, Co-Project Director (consultant engineer) will construct the vertical growing system and plant the seeds and starts with the UI horticultural graduate student on Putnam's property. Additionally, Putnam will install an intricate camera system that will collect plant growth data, insect data, presence of plant problems, sun, shade, and all other facets of the experimental low-cost system. Putnam and the horticultural graduate student will harvest, weigh, sell and distribute (to local food banks) all of the produce grown in the system. Putnam will also co-teach workshops with Mayes. Putnam will produce videos for promoting the system for social media.

Soren Newman and Darin Saul (Arrowleaf Consulting) will implement an initial survey to Master Gardeners nationally to gather a data set regarding willingness to adopt the system. They will implement educational evaluations of the annual farm tours and workshops and also carry out a mid-term evaluation for Year 2 participants to find out if any have implemented their own system and what results participants have had.

e. Project timeline (see page 22)

f. Cooperation and institutional involvement

The Project Director will convene a monthly meeting of the horticultural and engineering team and convene a quarterly meeting of the entire team to review results and make any course corrections throughout the project. Per the steps noted in the Approach: "Integrate suburban vertical farm with UI Extension activities," the project will implement an annual farm tour at the vertical farm site, host vertical farm workshops and create an educational video to broaden local and regional outreach. The sociological consulting, Arrowleaf will support the educational evaluation data collection.

g. Data Management Plan

Does not count towards page limit, per NIFA Application Guide. The data management plan will comply with all USDA rules and regulations.

Data Management Table: expected data type and format

Data Type	Format
Site documentation imagery, digital, primary	JPG and MP4, camera imagery, time-lapse videos of project site and bills of materials imagery, digital, primary, JPG and MP4, camera imagery and compiled videos of construction materials and inputs
Site prep and construction process imagery	digital, primary, MP4, time-lapse videos of project site during construction process from multiple site cameras
Image/day (used for maturation, root development, sunlight, flowering, senescence), digital, primary	MP4, compiled time-lapse videos of project site created from image / day during growth from multiple cameras
9x image a day (pollinator / pest / disease, secondary sunlight, rainfall),	digital, primary, MP4, 3 frame videos of project site from multiple cameras capturing pollinator / pest movement and interactions
Summarized emergence and root development data	digital, primary, comma-separated value (CSV), summaries in text of plant emergence times, maturation states, root development data will be created from image/day time-lapse.
Image recognition data with identified pollinator/pest interactions	digital, primary, CSV, three-dimensional position and plant interaction of species with time
CO2/O2, Rainfall, Temperature, and Light intensity data	digital, primary, CSV, readings with time from multiple sensors around the growing region, compiled into a bulk format with all sensor types cross-referenced by location
Irrigation data	digital, primary, CSV
Harvest yield imagery	digital, primary, JPG, images of produce each day
Market price and sales data	digital, primary, CSV, price data for three to seven species with time and attendance
Social interaction data	digital, primary, CSV, social interactions by category (comments, questions, interest, volunteers, pre-sales) with time and location
Construction labor data	digital, primary, CSV, time worked per construction task
Monitoring labor data	digital, primary, CSV, time worked per monitoring task
Harvest labor data	digital, primary, CSV, time worked harvesting crops
Summarized National Agricultural Statistics Service metrics/species	digital, primary, CSV, summary statistics (area planted, area harvested, yield/acre, total production/crop, value of utilized production/crop) compiled for species grown
Extension Activities	digital, primary, CSV, activities held and type of activity
Extension stakeholders	digital, primary, CSV, attendance to Extension activities with social interactions on-site, at farmers markets, and Palousafest, Latah County Fair

Data storage and preservation

Data that is intended to be shared such as plant growth data will be stored in a machine-readable format in separate repository locations and then cross referenced to the Ag Data Commons with links to the repositories.

Evaluation and Interview Data will be kept secure and will not be combined with any personally identifiable information per ethical research human subjects standards and pertinent laws.

Data repositories

- CERN Zenodo, ref-link on Ag Data Commons (repository liftime, 60GB, >20 years)
- Kaggle with ref-link on Ag Data Commons (repository lifetime, 60GB)
- Github Public Datasets with ref-link on Ag Data Commons (repository lifetime, 1GB)
- Social Media, video, with ref-link on Ag Data Commons (repository lifetimes, 1GB).

Data storage preservation

Data will be stored across repositories with known lifetimes (CERN has at least 20 years of funding) and stored in several formats to avoid data loss, degradation, or damage.

Data sharing, protection, and public access

Data will be shared publicly, with provided references and a DOI number ref. It will be stored in the above listed repositories (Zenodo, Kaggle, Github, social media). There are no planned confidentiality privacy issues. There are no planned access restrictions.

Roles and responsibilities

The DMP implementation will be ensured by the PD, Iris Mayes, and there are no costs for long term storage beyond those for the project itself.

g. Logic model

The logic model table (last page) illustrates the situation, proposed inputs, proposed activities, predicted outputs and resulting short-, medium- and long-term impacts. The education evaluation process will serve to inform and refine the vertical farm education program. The automated data collection system will innovate outdoor horticultural observations and advance the field of vertical farming and machine learning for the field of horticultural.

h. Summary of previous work

Related projects explore complementary strategies for scaling up local and regional food systems, including increasing land access for small- and mid-scale producers, developing infrastructure (e.g., food hubs), and developing value-added food products.

Newman, Saul, and Peterson were PIs on an AFRI-funded project (#2011-67024-30075) that examined feasibility of small-scale USDA-inspected livestock-processing for producers in northern

Idaho and eastern Washington. They found a variety of feasible options and provided research that influenced USDA-inspected processing in the area (Saul et al. 2014).

Related projects explore complementary strategies for scaling up local and regional food systems, including increasing land access for small- and mid-scale producers, developing infrastructure (e.g., food hubs), and developing value-added food products.

Newman, Saul, and Peterson were PIs on an AFRI-funded project (#2011-67024-30075) that examined feasibility of small-scale USDA-inspected livestock-processing for producers in northern Idaho and eastern Washington. They found a variety of feasible options and provided research that influenced USDA-inspected processing in the area (Saul et al. 2014).

Newman and Saul were PIs on an AFRI-funded project (#2014-68006-21866) that optimized small- and mid-scale producers' access to restaurant and grocery markets in Idaho. Research activities included surveying and interviewing producers, distributors, restaurants, and retailers about opportunities and barriers; estimating demand for local and regional food products at restaurants and grocery stores; estimating the market size for a small number of vegetable and livestock products; and conducting supply chain analysis.

Newman, Saul, Peterson, and Mayes are PIs on an AFRI-funded project (#2018-68006-28102) to help farmers in northern Idaho and eastern Washington overcome land and water constraints to increasing vegetable and fruit production. That project is focusing on understanding constraints, including landowner interests and goals, to recruiting new land for beginning, small, and mid-size farm production. Newman, Saul, and Peterson were also PIs on an AFRI-funded project (#2013-67010-20399) that evaluated wood-based bioenergy as a community and economic development strategy in rural communities in the context of stakeholder interests and concerns (Jacobson et al. 2016, Newman et al. 2017, Saul et al. 2018).

Newman, Saul, Peterson, and Nadreau were recently PIs on a contract with Nez Perce Tribal Enterprises for feasibility studies and business plans for a winery, value-added mixed berry and fruit processing, and a metal manufacturing facility in the study area. Peterson has conducted numerous relevant economic impact assessments, including most recently for the Moscow Farmers' Market (2016, 2018), Moscow Food Co-op (2017), and all Idaho non-profits for the Idaho Nonprofit Center (annually 2014-2018). Newman is currently co-PI on a project (#2017-68006-26228) focusing on community development in Idaho, Montana, and Wyoming. Newman, Saul, and Peterson are co-PIs on a contract with Blue Mountain Action Council to evaluate the feasibility of developing a food hub in the Walla Walla Valley, Washington, as part of expanding a regional food bank facility.

Mayes was a Project Director and Newman was a PI on a USDA-NIFA Beginning Farmer Rancher grant project, Cultivating Success™ Idaho (#2015-70017-23932). Cultivating Success™ has provided education for small-acreage farmers and ranchers in Idaho and Washington for 17 years, reaching more than 900 students. Most students that became farmers operate on very small acreages, most on 1-2 acres, and use direct marketing channels. UI Extension has established extensive collaborations with local agencies. Since 2018, Mayes has been teaching indoor growing to various stakeholder groups including Idaho Master Gardeners, within the community garden education program, and via Harvest Heroes (a UI Extension farm education program for U.S. Military Veterans).

Mayes served for five years on the Backyard Harvest board. Backyard Harvest works to gather extra fresh produce to distribute to food-insecure residents in four counties. These existing relationships can be used to donate extra produce from the vertical farm project.

Gabriel Putnam is a former program manager and contract manager for NASA with responsibility for an engineering services contract to NASA worth approx. $5 million / year and a board seat on a larger umbrella contracts (ESTS and ESSSA) for technical services worth $150,000,000 / year, while simultaneously responsibility for NASA’s debris analysis team and head of the debris working group for the Space Shuttle, principal Investigator for supercomputing in fluid dynamics and acoustics worth $5,000,000 / year, and lead developer and liaison to external contractors for efforts to improve modeling and simulation capabilities of fluid dynamics, debris, and acoustics for Space Launch System and Space Shuttle.

<u>Please see Appendices for additional pertinent information</u>

Appendix 1 – Landscape and Proposed System Imagery

Appendix 2 – Crop Selection Table

Main	Sub-Taks	Project Timeline (Months from Start) 1 - 12	13 - 24	25 - 36
Convert area into vertical farm				
	Convert to 3D growing region			
	Track all inputs & outputs			
	Document construction process			
Instrument growing region				
	Rainfall gauges			
	Light meters			
	Temperature meters			
	CO2/O2 monitors			
	Image / day cameras			
	Pollinator / Pest camera traps			
Plant and grow crop species				
	Choose crops and purchase			
	Plant and grow crops			
	Measure respiration			
	Measure maturation rate			
	Measure root development			
	Record flowering			
	Record pollinator / pest / disease			
	Measure rate of senescence			
Harvest seven crops				
	Measure harvest duration			
	Measure harvest yield			
	Evaluate harvest quality			
	Track time-history of unit/cost			
Person-person sales				
	Farmer’s market			
	Provide crops at wholesale price			

	Table - continued	1 - 12	13 - 24	25 - 36
Main	**Subtasks**			
	Track interest in crops			
	Track non-monetary interactions			
Investigate social factors				
	Track social interactions			
	Document regulatory issues			
	Palousafest			
	Latah County Fair			
University of Idaho Extension				
	Vertical Farm Tour			
	Vertical Farming Workshops			
	Educational Vertical Farming Video			
	Collect Master Gardener & Participant Data			
Outreach to media				
	Compile data results			
	Host compiled data			
	Compile video clips			
	Develop social media accounts			
	Post links to datasets			
	Host video clips			
	Contact media outlets			
Publish results				
	Conference papers			
	Journal articles			
	Extension bulletins			
	Project book			

Logic Model Table						
Situation	Inputs	Activities	Outputs	Outcomes - Impact		
				Short-term Knowledge Gained	Medium-term	Community Level Conditions Change
Urban dwellers have access to limited or no garden space. Suburban dwellers may need a denser growing system. Potential growers may not know how to use vertical farming systems.	Space for vertical growing demonstration. Research time to measure volumetric output and determine best varieties for vertical growing. Hanging baskets, soil medium and system parts to test and demonstrate vertical growing space. Automated camera system and other devices (scale, water meters, etc.) to take growth & system data. Faculty time to teach vertical growing.	Set up vertical growing system. Measure outputs. Set up control raised bed control plots and hydroponic vertical comparison systems and measure outputs. Teach vertical farming methods via an annual farm tour and annual workshops. Evaluate educational program. Present vertical farming methods at conferences. Write and publish journal articles on results.	Up to 15,000 plants within the growing system demonstra tion. 50 students per year in person and online will learn about outdoor vertical farming for a total of 150	Researchers will learn which vegetables grow well in an outdoor vertical environment under this specific growing season on the Palouse. Farmers will learn how to use a low-cost vertical system to grow vegetable crops. Journal articles will inform readers as to project specifics and which systems and vegetable may grow well in other geographic areas under which conditions.	Actions taken/new methods implemented: Growers will implement vertical growing practices learned from workshops. More produce will be available locally. Gardeners will grow their own produce for their own consumption saving resources that are used to grow and ship produce from further distances.	Environmental improvements: Water and soil will be conserved growing in vertical systems. Social improvements: More produce will be available locally. Publication of journal articles will share project results beyond the immediate community. Economic improvements: this project will provide business opportunities for new farmers or a new revenue stream for existing growers. Economic data will inform other food system-related activities
Evaluation: collect data, adjust activities, report.						