California Water Institute

Adoption of Site-Specific Crop Management and Precision Agriculture Technology in Central Valley Agricultural Practices

A Project White Paper

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Adoption of Site-Specific Crop Management and Precision Agriculture Technology in Central Valley Agricultural Practices

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Research Team

Florence Cassel Sharma

Dr. Florence Cassel Sharma is an Associate Professor of Irrigation and Water Management in the Department of Plant Science. She also serves as the Assistant Director of Research for the Center for Irrigation Technology. Dr. Cassel Sharma's research focuses on optimizing water use efficiency through low and deficit irrigation practices, improving irrigation scheduling, and utilizing remote sensing techniques for water resources management and crop water use. Her research also addresses the agronomic and environmental impacts of low-quality water applications on soil salinity build-up, contaminant accumulation, and crop production.

Dr. Cassel Sharma was the recipient of the 2015 Irrigation E3 Leader Award from the Irrigation Association and the 2016 Provost's Award for Promising New Faculty. This year, she was also awarded the 2021 Excellence in Education Award by the Irrigation Association. Dr. Cassel Sharma has been awarded over $6 million in research funding since joining the Department in 2012.

Jason Liang

Dr. Jason Liang received a B.S. in Electrical Engineering & Computer Science and an M.S. in Management from Tsinghua University in Beijing. He has many years of experience in business big data analysis. In 2016, he received his Ph.D. in Agricultural, Environmental, and Regional Economics from Pennsylvania State University and joined the Fresno State faculty. Dr. Liang teaches courses in financial markets, agricultural business, and applications of big data and artificial intelligence (AI). His research interests are in corporate finance, water and environmental economics, and big data and AI. Outside of work, Dr. Liang enjoys running marathons, playing instruments, and hiking in the national parks near Fresno.

Robert Lull

Dr. Robert Lull is an Assistant Professor in the Department of Communication at California State University, Fresno. He received his B.A. in psychology from Miami University and his M.A. and Ph.D. in communication from The Ohio State University. His research addresses the intersections of science communication, risk communication, and strategic communication, focusing on the influence of emotional arousal on information processing and risk perceptions. His current research emphasizes risk perceptions of Zika virus and biotechnology. His previous research has examined principles of effective strategic communication and has been featured in outlets such as the BBC, Harvard Business Review, and Bloomberg, in addition to informing advertising industry policy in the United States and Sweden.

Balaji Sethuramasamyraja

Dr. Balaji Sethuramasamyraja is a Professor in the Department of Industrial Technology of California State University, Fresno. He recieved his bachelor degree in Mechanical Engineering in 1999 from University of Madras, Chennai, India and his master degree in Industrial Engineering in 2003 from University of Cincinnati, Ohio. He earned his doctorate degree of Agricultural Engineering from University of Nebraska-Lincoln in the year 2006. He has had over 9 research projects since 2015. Dr. Sethuramasamyraja has co-written various publications.

Problem Statement

The goals of this project are to quantitatively and qualitatively estimate the adoption of Site-Specific Crop Management (SSCM) and Precision Agriculture Technology (PAT) in agricultural production and cultural practices in the Central Valley region of California. Specifically, the objective is to analyze the factors that influence the awareness and adoption of PAT and SSCM. The project will investigate the impact of various demographic, socioeconomic and farm factors on the adoption of PAT and SSCM and their economic profitability.

Technical Background

Precision agriculture (PA) or site-specific crop management consists of several technologies used to manage variability within fields. Precision agriculture technologies include enabling technologies, such as computers, Geographic Information Systems, and Global Positioning Systems, as well as various sensors with geo-referencing capabilities, such as grid soil sampling, yield monitors, remote sensing images (satellite, aircraft, UAV), and input applicators (e.g., water, seeds, fertilizers, pesticides) that can vary rates across a field.[1] These technologies give the farmer greater control over the various factors of agricultural production by helping them to make precise and timely decisions about input applications to avoid deficiencies and excesses in input-use and to reduce biological stress on plants.

Precision agriculture has been lauded for its potential to address problems of production and environmental impact.[2] Yet adoption is variable and influenced by a multitude of factors.[3] Only recently have efforts to systematically analyze such factors materialized. A 2012 review proposed 34 factors that could be classified into seven general categories: socio-economic factors (e.g., education level), agro-ecological factors (e.g., farm size), institutional factors (e.g., region), informational factors (e.g. consultant use), farmer perceptions (e.g., perceived profitability of implementation), behavioral factors (e.g., intention to adopt), and technological factors (e.g., computer literacy).[4] A 2021 review proposed 37 factors that fit roughly the same categories. That study also proposed a theoretical model useful for future research. Fusing diffusion of innovations and theory of planned behavior, the model conceptualizes adoption as a process including knowledge, persuasion, decision, implementation, and confirmation (see Figure 1).

Other systematic reviews have analyzed features of the literature itself, finding that the majority of studies are conducted in the United States and Germany, are typically regional rather than national in scope, and seldom address more than a few components of particular interest to the researchers; that is, most studies feature variable-level rather than systems-level analysis.[5] This is a crucial gap in the literature insofar as relationships between the many adoption

[1] Pierce, F., and Nowak, P. (1999). "Aspects of precision agriculture." *Advances in Agronomy* 67:1-85. https://doi.org/10.1016/S0065-2113(08)60513-1
[2] Bongiovanni, R. and J. Lowenberg-Deboer (2004). "Precision agriculture and sustainability." *Precision Agriculture* 5:359–387. https://doi.org/10.1023/B:PRAG.0000040806.39604.aa
[3] Shang, L., T. Heckelei, M. K. Gerullis, J. Börner, and S. Rasch. (2021). "Adoption and diffusion of digital farming technologies – integrating farm-level evidence and system interaction." *Agricultural Systems* 190. https://doi.org/10.1016/j.agsy.2021.103074
[4] Tey, Y. S. and M. Brindal (2012). "Factors influencing the adoption of precision agricultural technologies: A review for policy implications." *Precision Agriculture* 13:713-730. https://dx.doi.org/10.1007/s11119-012-9273-6
[5] Pathak, H. S., P. Brown, and T. Best. (2019). "A systematic literature review of the factors affecting the precision agriculture adoption process." *Precision Agriculture* 20:1292-1316. https://doi.org/10.1007/s11119-019-09653-x

factors could be especially instructive. Shang's 2021 review proposed such a model to address that gap, providing researchers with a framework to ground systematic approaches to the PAT adoption process.

Taken together, these three reviews suggest that while much is known about PAT adoption, there are persistent gaps in the literature. Namely, regional approaches mean that crucial agricultural locations remain understudied and variable-analytic approaches mean that systematic analyses are needed. Our proposed research addresses these two gaps.

This project will study PAT adoption within California's Central Valley. The area's status as the most productive agricultural region in the United States starkly demonstrates the need for a systematic study of PAT adoption. In 2019, California's 69,900 farms and ranches generated $50.1 billion of cash receipts, outpacing the next most productive state of Iowa by an almost 2:1 ratio. The Central Valley itself accounted for over $40 billion of that agricultural income.[6] These levels of output alone demonstrate the need for a comprehensive study of PAT adoption within the region. But several other factors underscore that need even further.

The Central Valley grows over two thirds of the nation's fruits and nuts and almost one third of its vegetables.[7] While much is known about PAT adoption for field crops, vegetable, fruit, and tree nut farms are much more capital and labor intensive. Those economic factors and other unique characteristics of fruit, vegetable, and tree nut farms induce variability into the adoption process. Modeling whether, and if so, to what extent that variability affects the relative influences of different factors on adoption is crucial. Our research will examine such differences.

Likewise, state legislation limiting groundwater use could reinforce the need to adopt PAT in the Central Valley. Examining how such legislation influences the perceived economic viability of PAT adoption - and in turn how that PAT adoption process might be fast-tracked under such conditions - would be of significant value to a number of stakeholders. Other drought-prone regions can anticipate similar legislation in the future, making the Central Valley an illustrative test case for examining how sustainability policies influence agricultural decision-making.

There are many audiences for this research. Farmers will be interested to learn about new technologies and available institutional support as well as to hear about adoption practices among their counterparts. Scientists could incorporate the findings in their plans to develop new technologies. Equipment suppliers will consider the findings in their market segmentation and outreach efforts to prospective Central Valley customers. Finally, increasing attention to access and environmental impact suggests that policymakers at the state and national levels would be keenly interested in the findings as well.[8]

[6] California Agricultural Statistics Review, 2019-2020. "California Department of Food and Agriculture." https://www.cdfa.ca.gov/Statistics/PDFs/2020_Ag_Stats_Review.pdf

[7] Paggi, M., J. Noel, F. Yamazaki, S. Hurley, and M. McCullough (2012). "An Analysis of California Agricultural Transportation Origins, Destinations, Modal Competition, and Industry Perspectives – Selected Fresh Fruits and Vegetables." *U.S. Department of Agriculture*. https://www.fresnostate.edu/jcast/ifa/documents/1An%20Analysis%20of%20California%20Agricultural%20Transportation.pdf

[8] Jimenez, C. and C. Bilek (2021, April 3). "Ag Secretary Tom Vilsack says American Rescue Plan addresses cumulative effects of discrimination on farmers of color." *Colorado Public Radio*. https://www.cpr.org/2021/04/03/ag-secretary-tom-vilsack-says-american-rescue-plan-addresses-cumulative-effectsof-discrimination-on-farmers-of-color/

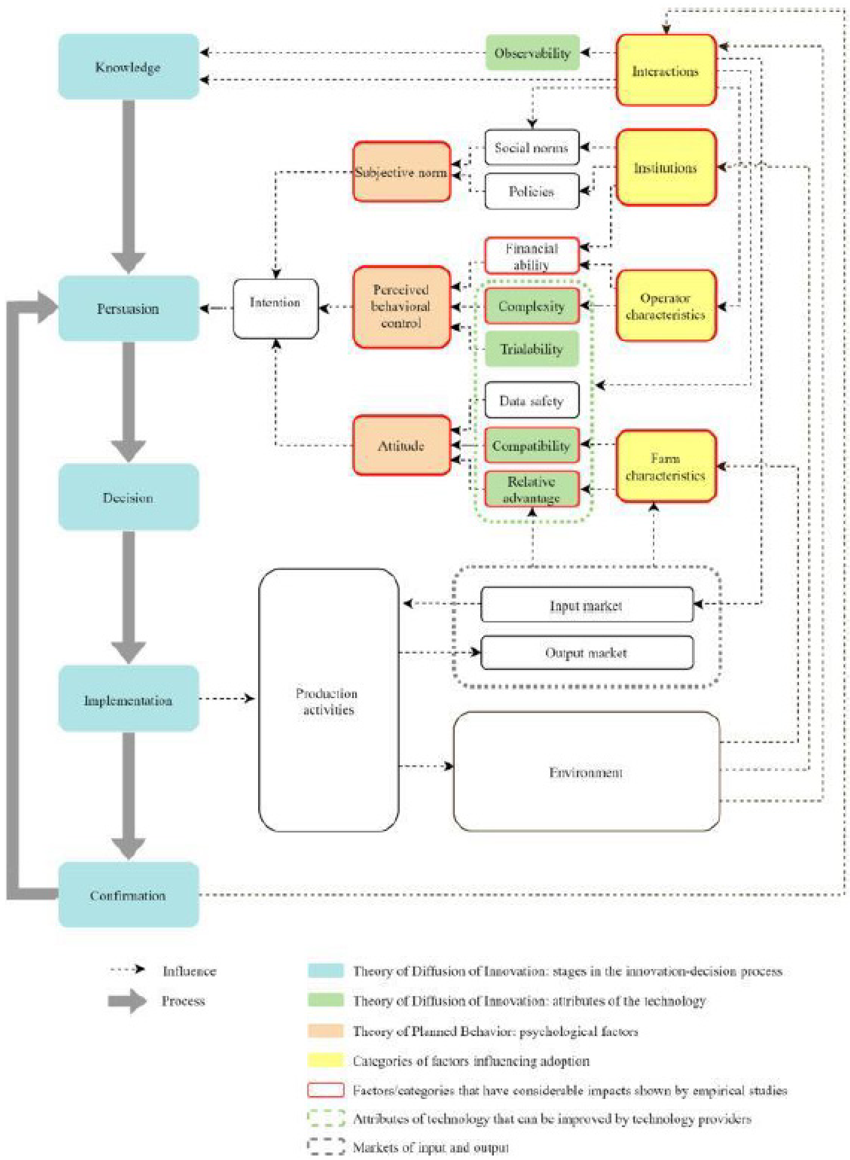


Figure 1. Theoretical framework for PAT adoption process.
Adapted from Shang et al. (2021)

Technical Challenges

As outlined above, PAT encompass a wide range of monitoring and management practices farmers can implement or apply to optimize their production systems, i.e. minimize input production costs and maximize profits, while mitigating potential environmental risks. Overall, such practices stem from the complexity of the soil-plant ecosystems and the inherent spatial and/or temporal variability in plant and soil physicochemical properties. A number of PAT are available to farmers to provide better information for management decisions, ranging from relatively simple soil sampling to very complex satellite images and artificial intelligence. However, adoption of PAT by farmers is complex and related to a number of factors including ease of use, costs and dependability of services provided by companies or consultants, complexity of data management and software, time involvement, and benefits of the technology.

a. Soil-based technologies

Some of the simpler methods to adopt involve measurements of one or several soil properties through soil sampling or soil moisture sensors. Since soil properties are highly variable at the field scale, site-specific soil sampling for example identifies variations in important physical and chemical properties that affect water infiltration, root penetration, and nutrient availability. Common soil properties important in irrigated crop production systems include texture, pH, macronutrient levels, water holding capacity, and infiltration rate. Monitoring and assessment of such properties are important to address field variability and develop informed management practices that take into account or try to remedy this variability. Soil sampling methodologies vary greatly from farmer to farmer, and can range from one or two random sampling locations in a field (unguided GPS) to multiple specific locations that are geo-referenced (grid, guided GPS) with repeated measurements seasonally or annually. When extensive grid sampling is conducted, soil maps can be generated to delineate management zones and determine sitespecific and variable input applications (seeds, fertilizers, amendments).

Soil moisture sensors have been widely adopted by farmers in the Central Valley and are probably the most commonly used irrigation scheduling tools in California.[9] Soil moisture sensors are traditionally installed in one or two locations per field, a practice which can not capture field variability. However, recently, more advanced farmers are integrating grid soil sampling and/or soil mapping to develop irrigation management zones based on soil textural properties, water holding capacity, and infiltration rate. These management zones are then equipped with soil sensors to guide site-specific irrigation scheduling. Over the years, farmers have become very accustomed to integrating soil sensors in their management practices. In addition, with the advancement of technology, many soil sensors are now equipped with telemetry, bluetooth technology and cloud-based data delivery and streaming, which makes data accessibility very convenient for farmers. A challenge that some smaller farmers are facing or may be facing does not actually involve technology but the business model provided by companies that do no longer charge for the equipment but for the service they provide and are limiting hardware accessibility.

[9] Census of Agriculture - 2018 Irrigation and Water Management Survey. USDA-NASS. https://www.nass.usda.gov/Publications/AgCensus/2017/Online_Resources/Farm_and_Ranch_Irrigation_Survey/in dex.php

b. Plant-based technologies

More advanced technologies usually involve measurements of plant parameters, such as yield, reflectance, canopy temperature. Yield monitoring is a very valuable tool to evaluate the temporal and spatial yield distribution within a field and identify areas of high and low production. Yields calculated across a field can be displayed on maps using GIS. When used in combination with soil maps, yield maps can help farmers correlate soil properties with yields and develop site-specific management practices that often result in increased profits. Implementation of yield monitoring and mapping practices have largely focused on row cropping systems, such as cotton, corn, and soybean, in the Midwest. In California, such practices have been applied in grapes for example, but have not extended to the large variety of crops grown in the state.

Other in-field optical sensors can measure crop reflectance to estimate chlorophyll content, Normalized Difference Vegetation Index (NDV) and canopy temperature. Such sensors provide direct indication of plant stress. However, measurements with these sensors remain very variable as they are affected by many factors, including sensor positioning (with respect to light interception), distance from the crop, and influence of climatic parameters such as wind and humidity. Due to the complex methodology for data acquisition and the high data variability, adoption of in-field optical sensors by farmers have been low overall, particularly for site-specific crop management.

When placed on platforms such as satellites, airplanes, and UAV's, such sensors can provide better estimates of crop growth or stress, and encompass field variability. However, the cost of operating these platforms and/or analyzing the data remain prohibitive for many small and average-size farmers who lack the financial resources to effectively benefit from this technology. In addition, the frequency of data collection may not be sufficient for growers to make quick decisions. A simple example relates to irrigation scheduling where remotely sensed data would have to be obtained several times a week to be beneficial, a practice that is not currently feasible not affordable.

c. Survey evaluating factors affecting farmers' adoption of new technologies

Farmers' willingness to adopt new technologies are influenced by dozens of factors, many of which could differ depending on the crop profile of a farm. We will first examine agribusiness patterns and existing reviews of the PAT adoption literature to classify factors according to their regional relevance. This classification process will inform survey design. We will design the survey in consultation with public opinion researchers and agricultural community contacts to ensure the validity and feasibility of the research plan.

d. Farm advisor expert opinion

For some crops, farm advisors' expert opinions are the key source of information for growers' awareness of new technologies, and their advice plays the most important role in farmers' decisions to adopt new techniques; while for other farmers rely more on their own experiences and managers.

Scientific Approach

The overall objective of this project is to analyze the factors influencing adoption of PAT in vegetable, fruit, and tree nut farms in the Central Valley. The achievement of the overall objective requires completion of the tasks described below.

1. Conduct survey to model factors influencing PAT adoption

Survey design will be informed by thorough literature review; focus groups including farmers, farm advisors, and agricultural policy experts; and relevant agribusiness data. Survey implementation will be conceptualized at a later stage in consultation with public opinion experts and agricultural community contacts.

2. Conduct Case Studies with Farmers who have adopted PAT to collect detailed Input Management along with Financial Information under Different Operating Scenarios

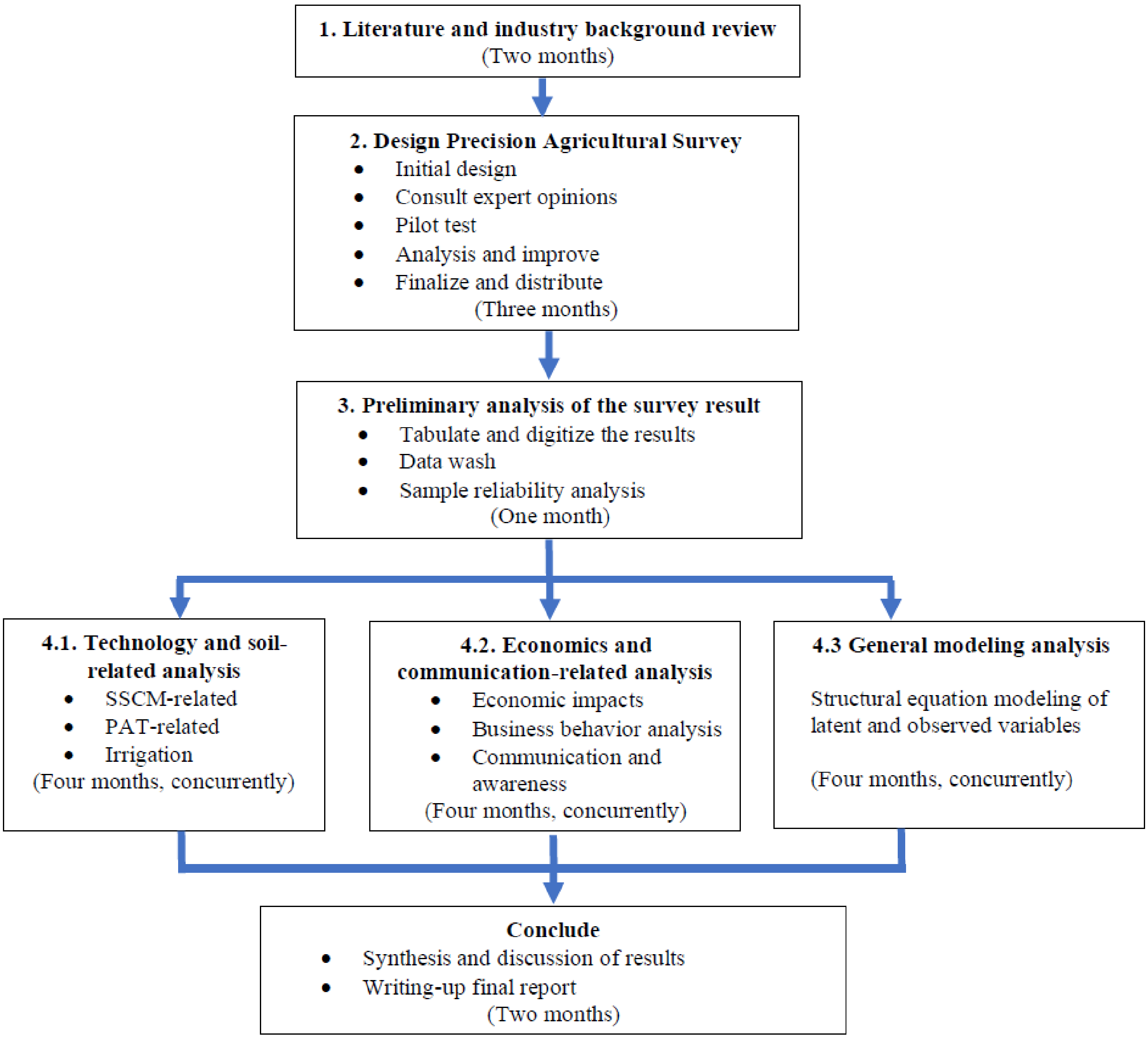
Focus groups will also be used to identify farmers who have adopted PAT and are willing to discuss those decisions with us. We will try to collect the detailed financial data regarding the adoption of PAT, such as the changes of cash flows over time, to quantitatively analyze the benefits, costs, and risks of the new technologies to farmers under different scenarios.

3. Analysis, Reports, and Write-up

All survey data will be analyzed from multiple perspectives. Topline results (e.g., "54% of farmers said that government policies influenced their decision to adopt PAT") will be used to generate variable-based reports for non-academic dissemination. Systems-level models of PAT adoption factors will be developed using multivariate techniques measuring associations between variables.[10] These models will be published in academic journals such as Precision Agriculture. Case study data will be used to inform survey design as well as perform cost-benefit analysis to determine the economic viability of PAT in selected crops.

[10] Bollen, K. (1989). *Structural equations with latent variables*. New York: Wiley.

Schedule


1. Literature and industry background review
(Two months)
2. Design Precision Agricultural Survey
Initial design
Consult expert opinions
Pilot test
Analysis and improve
Finalize and distribute
(Three months)
3. Preliminary analysis of the survey result
Tabulate and digitize the results
Data wash
Sample reliability analysis
(One month)
4.1. Technology and soil-related analysis
SSCM-related
PAT-related
Irrigation
(Four months, concurrently)
4.2. Economics and communication-related analysis
Economic impacts
Business behavior analysis
Communication and awareness
(Four months, concurrently)
4.3 General modeling analysis
Structural equation modeling of latent and observed variables
(Four months, concurrently)
Conclude
Synthesis and discussion of results
Writing-up final report
(Two months)

Deliverables

Precision Agriculture Survey data

1. Topline results compiled into California Water Institute report (see 2018 Valley Water Survey for example)
2. Selected crosstabs shared with relevant stakeholders
3. Agro Economic Community Improvement Policy Makers

Knowledge from Results beneficial to

1. California Department of Food and Agriculture
2. United States Department of Agriculture
3. Central Valley agricultural community
4. Scientists developing PAT
5. Equipment providers
6. Precision agriculture scientific research community
7. Agricultural communication research community

A 2016 roundtable hosted by the USDA-ARS Office of International Research Programs and the International Society of Precision Agriculture identified several keys to ensuring successful PAT (Yost et al., 2018): a. Increase research documentation of PAT outcomes, b. Enhance funding for PAT research, c. Generate more PAT that encompass the goals of sustainable agriculture (economic profitability, environmental health, soil and economic equity), d. Include more stakeholder involvement and retrospective assessments, and e. Enhance research relevance to smallholder farms, especially internationally. It is quite relevant for the project deliverables from this research to address the policies and regulations surrounding sustainable agriculture practices.

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