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Environmental Values, Institutional Trust, and Nitrogen and Irrigation Management Decisions
Among California Farmers

By

ELISE JAE L ZUFALL
DISSERTATION

Submitted in partial satisfaction of the requirements for the degree of

DOCTOR OF PHILOSOPHY

in

Geography

in the

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of the

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ABSTRACT

Agricultural nitrogen and irrigation management in California are salient, controversial, and evolving policy priorities in a state grappling with water quantity and quality challenges. This research uses geospatial data, survey data, and interviews to analyze the impact of university extension and other information sources on learning and adoption of nitrogen and irrigation management practices among California farmers. The first chapter demonstrates the importance of farmer attention to soils in supporting efficient management practice use while noting that advisors should not assume that farmers share their definitions of agronomic and biophysical concepts. The second chapter analyzes the execution and impact of an extension educational intervention. Based on participant self-reports and staff interviews, the program succeeded in furthering learning and plans to adopt best management practices despite being limited in certain ways by farmer institutional trust. The third chapter examines the impact of repeated farm consultations on building receptiveness to new ideas and practices, through the lens of personal trust.

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INTRODUCTION

Nitrogen and irrigation management in California are salient, controversial, and evolving policy priorities in a state grappling with water quantity and quality challenges. Hundreds of wells run dry on an annual basis, and failure to meet nitrate drinking water standards puts the health of nearly a million California residents at risk (DWR 2023; Chappelle et al. 2021). Policy efforts to address overdraft and nitrate loading in groundwater through agricultural regulations have taken many forms in recent years, from introducing reporting requirements (Senate Bill 390), requiring owners of contaminated domestic wells in certain areas to provide safe drinking water to tenants (Drinking water: rental property: domestic well testing, Assembly Bill 2454, Chapter 506, Statutes of 2024), and introducing a bill to set nitrogen limits throughout the state (Water: Nitrogen Pollution Reduction Act, CA AB2447, California Legislature 2025-2026 Regular Session (2026)). In this rapidly evolving policy context, farmers navigate complex, overlapping constraints on their management choices while simultaneously maintaining a substantial degree of autonomy as land managers and businesspersons.

Nitrogen and irrigation management also provide a venue for studying non-regulatory policy levers. University extension advising services and other learning pathways offer opportunities to help farmers maximize efficiency, comply with regulatory requirements, and improve their operation. However, management advice can also be polarizing, because of the risk context and economic implications of management decisions. Beyond improving support for these specific nitrogen- and irrigation-related interventions, understanding the impact of

extension services also illustrates broader ways for non-regulatory educational and relational programs to facilitate voluntary best management practice adoption.

The three chapters of this dissertation collectively demonstrate that 1) valuing on-farm environmental benefits improves management behavior, 2) institutional affiliation and reputation legitimizes programs among participants with favorable views of the institution while delegitimizing them among participants with less favorable views (in this case, farmers who perceive extension to lack staff continuity and on-the-ground expertise), and 3) extension strategies focused on building long-term rapport with individual farms lead to higher perceived client receptiveness. Applied to other policy contexts, these lessons remain: being aware of the benefits certain ecosystem services provide to an operation enables environmental managers to intentionally tailor choices to maximize those services. Consequently, educational interventions have an opportunity to increase their impact by highlighting such benefits and the management strategies that maximize them. Outside of the world of extension, block grant programs and other medium-term policy interventions are still subject to community perception of the program's host institution. By partnering with other organizations with a different trust profile, or by focusing on elements in which the host institution has an especially high level of credibility with the intended audience, a program can multiply its impact. Finally, the question of quality over quantity plagues many intervention choices: do you spread resources across a wide range of participants or invest in key areas or actors who are expected to spark cascading impacts? The evidence from this research indicates that investment over time increases receptiveness, making a case for strategic, quality investments over a diffuse approach.

INTRODUCTION

Chapter One examines soil knowledge among California farmers and investigates the importance of attention to soils on farm management practice use. The results demonstrate an underreporting of loam and overreporting of clayey/heavy clay soils, suggesting that growers may have heightened sensitivity to small fractions of heavy soils on their property. Farmers who recognize soil fertility as a management priority have a higher knowledge of their soil texture and also adopt a higher number of nitrogen and irrigation-related best management practices. Although use of advisors was not definitively linked to greater soil knowledge, advising services have the opportunity to play a role in motivating management practices through the lens of soil health.

Chapter Two analyzes the successes and challenges of an extension program aimed at increasing farmer learning and implementation of effective nitrogen and irrigation management strategies. The program succeeded in promoting learning and adoption, as indicated by participant self-reports and extension staff reports. The program also suffered from low institutional trust among some growers, stemming from a combination of the program's affiliation with the University of California (although this increased trust among other growers), a perception among some farmers that extension advisors have a high turnover, and challenges with hiring and retention within the program. Opportunities to mitigate this barrier could have included a greater emphasis on "train the trainer" initiatives rather than direct interaction with farmers and cultivating stronger partnerships with private sector advisors and other potential collaborators. More broadly, educational interventions and grant programs can benefit from considering their unique advantages and disadvantages within their broader system in terms of

public perception and staff capacity, planning strategic partnerships with this positionality in mind, and strategizing for staff longevity and long-term relationships with program participants.

Chapter Three studies the impact of farm consultations on openness to the ideas, recommendations, and information provided by extension staff, using a novel dataset of post-visit reports prepared by the staff members. Perceived receptiveness is diminished for consultations concerning regulation and is increased for long-term clients, in-person clients, and clients whose primary language is one spoken by the advisor. The results indicate that trusted relationships, as built through repeated, in-person consultations with high-quality communication and site-specific guidance, multiply the impact of extension education and build the reputation of extension professionals among farmers as respected, locally knowledgeable experts.

Taken together, these chapters provide a picture of an effective educational intervention strategy. Connect to values that both benefit the participant and serve the overall goal of the intervention, and work to build common understandings; do not assume that all parties are on the same page. Account for the unique advantages and disadvantages afforded by institutional trust in the intervention design. Last, but not least, cultivate trusted personal relationships.

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CHAPTER 1

DO FARMERS WHO KNOW THEIR GROUND MANAGE IT DIFFERENTLY?

With Mark Lubell, Molly Sears, Jessica Rudnick, Patrick H. Brown, Toby O’Geen, and Sat Darshan S. Khalsa

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ABSTRACT

This study explores the relation of soil and soil knowledge to nitrogen and irrigation best management practice adoption. Soil knowledge was assessed by comparing growers’ self-reported soil type with SSURGO data on those same fields; management practice adoption data was available from a third party known as a water coalition that helps growers with required reporting. The results demonstrate an underreporting of loam and overreporting of clayey/heavy clay soils, suggesting that growers may have heightened sensitivity to small but disproportionately salient fractions of non-loams on their property. Farmers who recognize soil

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fertility as a management priority have a higher knowledge of their soil texture and also adopt a higher number of nitrogen and irrigation-related best management practices. Although there are many factors influencing grower management, soil type is a small but significant predictor, such that sand and sandy loam soils are associated with slightly reduced nitrogen and irrigation management practice adoption, and fields with diverse soils are associated with a slightly higher number of nitrogen and irrigation management practices. This points to a complexity factor, in which more complicated management, such as dealing with multiple soil types, or finer textured soils that are more prone to flooding and drainage challenges, is associated with the use of a greater number of management strategies.

1 INTRODUCTION

Nitrogen management and irrigation management are critical issues in agriculture. Assessing the effects of varying agricultural nitrogen and irrigation management practices is the subject of a large body of literature (e.g. Wang et al. 2025, Zhang et al. 2023, Kamran et al. 2023, Oenema et al. 2012, Chen et al. 2010, Pervanchon et al. 2005, Van Delden et al. 2003, Rejesus and Hornbaker 1999). Agriculture represents 70% of groundwater withdrawals worldwide (World Water Assessment Programme 2009), and agricultural fertilizer inputs and livestock wastes are also among the leading drivers of nitrate pollution in groundwater worldwide (Abascal et al. 2022).

Local knowledge and environmental attitudes may support the use of more efficient management practices and other conservation behaviors. In an agricultural setting, the effect of

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management practices on crop health is moderated by site-specific variables like soil, climate, topography, and local wildlife and disease pressures. These relationships influence the management strategies a grower may want to use. A rich understanding of local factors can inform a grower's management decisions and help maximize efficiency. The relative prevalence of different soil particle sizes, for instance, influences movement of water and nutrients throughout the soil, which can inform ideal irrigation and nutrient application scheduling. Agronomic literature often focuses on how to improve management given particular biophysical constraints, but these recommendations are not always adopted by farmers, as they represent only a portion of the practical constraints farmers face. Human-centered variables, such as local knowledge and connection to information sources, can also influence farm practices. For example, grower knowledge of what soil textures are present on the farm may support the incorporation of irrigation practices that are tailored to suit the local soil texture.

This paper explores the role of both physical soil texture and soil knowledge in shaping agricultural irrigation and nitrogen management decisions, by comparing grower-reported soil texture from Glenn and Colusa Counties in the Central Valley of California with United States Department of Agriculture (USDA) soil survey data, available through the Soil Survey Geographic Database (SSURGO) dataset. Survey responses are synchronized with corresponding spatial data to geolocate the survey responses and compare the grower-reported soil texture with the SSURGO classification on that same parcel. Though scholarship on the role of learning and environmental attitudes on management practice choices is rich, there is relatively little scholarship investigating the role of soil knowledge and attitudes toward soil specifically in

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shaping management. This paper addresses this gap through the combined use of soil survey data, farmer surveys, and farm management practice records, facilitating an analysis combining behavioral data and physical environmental data in a manner rarely observed in agricultural research.

This case provides evidence that growers who are more knowledgeable about their soil—knowledgeability defined here with two components: confidence in one’s knowledge and similarity to SSURGO soil reports—implement a greater number of best management practices. The following section motivates hypotheses related to four research questions: Do farmers have a high level of knowledge of their soil texture? Is this knowledge connected to formal learning pathways and concern for soil fertility? Does soil knowledge translate to an increased use of best management practices? And do farmers manage different soil types differently? The remaining sections discuss the spatial and statistical methods used to process and analyze the data, describe the results, and discuss the evidence for the role of local knowledge in conservation agriculture.

2 BACKGROUND

The hypotheses explored in this paper are linked via the following conceptual model (Figure 1.1). Belief in the importance of soil fertility and use of educational services promote soil knowledge, which leads to increased management practice use, and they also lead directly to the improvement of management use, through increased valuation of those practices. Soil characteristics, such as soil type diversity and texture, are also a key factor expected to influence

the use of management practices. Access to resources, such as formal education level, income, and farm acreage, is a key moderating factor in the system.

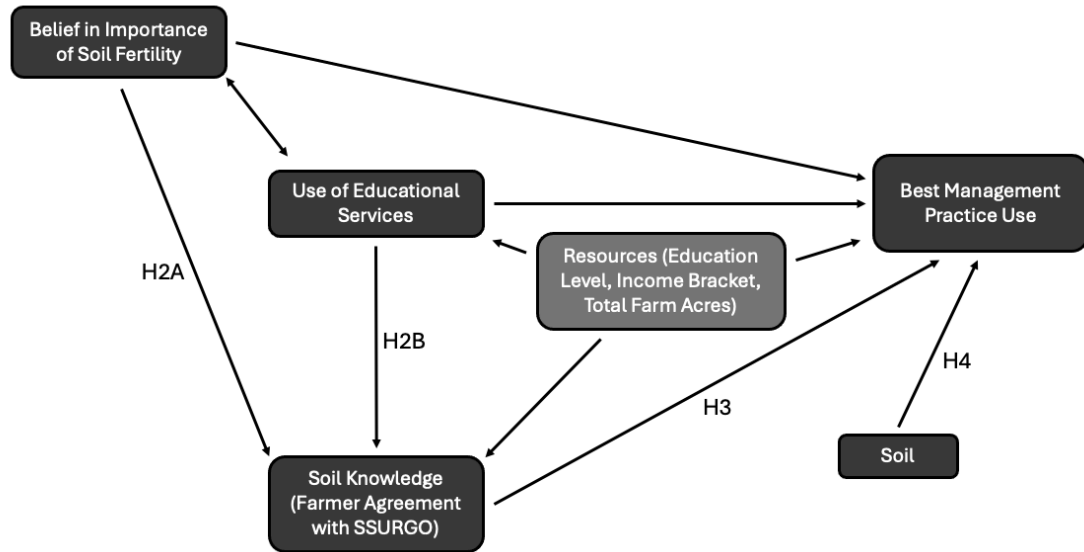


Figure 1.1: Conceptual Model of Linkages Between Soil Knowledge and Behavior

2.1 The Case

The northern portion of the Central Valley of California, known as the Sacramento Valley, is highly industrialized and highly diverse in terms of crop type and farm scale. Colusa County has an estimated annual groundwater overdraft of 68 thousand acre-feet per year (Cole et al. 2023), and the Sacramento River is experiencing land subsidence (DWR 2024). Higher usage of groundwater by agricultural interests in times of drought further strain these drinking water supplies, as evidenced by over 700 dry wells reported from March 2022 to March 2023 (DWR 2023). In return, insufficient water supplies can harm crop growth and threaten the viability of water-intensive cash crops. Nitrate contamination of wells is also a concern in the Sacramento

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Valley, at times exceeding USEPA maximum contaminant level thresholds (Schmitt et al. 2008) (Davids Engineering and West Yost Associates 2018). These resource challenges are exacerbated by phenomena that the region has already experienced and are expected to increase under future climate change scenarios, such as drought and climate whiplash.

2.2 The Role of Soil Knowledge in Nitrogen and Irrigation Management

This paper draws a through-line between management, knowledge, and pathways for change. Assessing how knowledge is related to decision-making enables better-informed management decisions. Understanding what factors support better knowledge can then improve the development of specific interventions. Characterizing the baseline level of knowledge that farmers already have, and whether they are already managing in a way that is optimized for their soil texture, facilitates better assessment of the potential impact of interventions. The research questions in this paper begin by assessing the baseline knowledge of farmers, then ascertain the factors that support this knowledge, how knowledge impacts management, and finally the extent to which farmers currently adopt management practices differently based on their soil texture.

Given the relevance of soil type to water-holding potential and implications for crop health, we expect farmers to have a high level of knowledge, especially for very coarse textures (sand) and very fine textures (clayey/heavy clay). Texture can affect drainage of water, uptake of inputs, and crop health and behavior, which each have implications for farm management. A recent study using interviews from organic farmers in the Sacramento Valley, where the case used in the present analysis is set, indicates a high level of general and applied soil knowledge

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among the population (Klein et al. 2024). Although growers' level of soil texture knowledge was not addressed specifically, the findings of Klein and colleagues indicate that farmer soil knowledge is high in this region. This also aligns with the common folk wisdom among California farmers, that farmers know their ground best.

Hypothesis 1: Farmers' self-report of soil type will largely match professional soil surveys of their region.

We propose two primary factors predicting soil knowledge: use of extension and valuing soil fertility. Although knowledge can be built from independent, experiential learning, it is also known that extension and advising services—and learning networks more generally—can play a key role in farmer education. Recent literature has typically moved away from an extension-only model to recognize that farmers have a number of both formal and informal learning networks that may span private and public actors (Lubell et al. 2014). In California, university extension services such as University of California Cooperative Extension, as well as Pest Control Advisors and Certified Crop Advisors, are part of this education network.

Environmental values can also promote nature-based learning, although literature exploring this phenomenon is scarcer in rural and agricultural contexts (Bhola et al. 2022; Eaton et al. 2019). In the context of farm soil management, research from the US Midwest has found that farmers who possess what Roesch-McNally and colleagues call a soil stewardship ethic

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adopt a higher number of best management practices related to conservation, implying a link between valuing soil and a knowledge of practices that protect it (Roesch-McNally et al. 2018).

We anticipate that access to formal learning pathways, such as public extension services and private advising services, and the desire to protect soil fertility will be associated with greater soil knowledge among farmers. Public and private farm extension and advising services work to help crop growers understand their landscapes, enhance their nitrate and water use efficiency, to help growers save costs, reduce leaching, and comply with state regulations. In California, examples include private pest control advisors (PCAs), certified crop advisors (CCAs), and public extension agents affiliated with university systems such as the University of California.

Hypothesis 2: Concern for soil fertility and use of formal learning pathways will both be associated with higher levels of soil knowledge.

We expect that knowledge will lead to improved management, as evidence from a variety of scholarly fields indicates that environmental knowledge translates to behavior. Existing scholarship supports the idea that local knowledge in general, and soil knowledge specifically, can improve management and conservation decisions. For instance, an identity wrapped up in a place-specific bond can lead to pro-environmental behaviors (Lincoln and Ardoin 2016), and a connection to nature can promote nature-based learning and ecological behavior (Bhola et al. 2022). Local knowledge, supplemented by technical knowledge, can be effective in adjusting

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management behavior (Wyckhuys and Neil 2007). Farmer use of advising services is commonly related to use of sustainable practices, including in California (Johnson et al. 2023; Pascucci and de-Magistris 2011). Additionally, the type and number of information sources from which California farmers learn has previously been shown to be related to the number of practices they eventually adopt (Johnson et al. 2023). Place-embedded organizations more commonly engage in sustainability actions (Rahman et al. 2024), although there have been challenges using typical tools used to study sense of place for applications in working landscapes (Eaton et al. 2019). In the context of soils, a desire to protect soils can motivate practices that increase the resilience and long-term adaptive capacity of agricultural operations (Roesch-McNally et al. 2018).

On-farm management decisions surrounding nutrient and water application strategy, scheduling, and system maintenance influence the efficiency with which resources are used. An understanding of how the soil will respond to the water and nutrients, due to its texture and other characteristics, can assist in the formation of an optimized nitrogen and irrigation plan. Coarse soils like sands or sandy loams drain quickly and do not store as much water compared to finely-textured soils like clays. While it may be acceptable to run long sets of irrigation in coarse soils, as excess can more easily drain and be less likely to damage the crop roots, a fine-textured soil can more easily become saturated. Accordingly, tailoring management decisions based on one's knowledge of the soil has the potential to improve crop outcomes. Thus, we expect to observe an increase in best management practice use among growers with knowledge of their soils.

Within socio-ecological systems literature, the concept of choosing management practices and rules that are best suited to local ecological conditions and challenges is known as

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institutional fit. Though the definition of suitability depends, in part, on the way in which the ecological system and problems are defined (Epstein et al. 2015), certain factors make it easier or more likely to obtain institutional fit: spatial congruence between the geographical extent of the problem and institution; temporal congruence between the rate of change and the rate at which it is possible to respond; and functional fit relating to whether institutions that govern interrelated components of the ecological system are themselves appropriately interwoven (Moss 2012; Galaz et al. 2008; Engle and Lemos 2010; Epstein et al. 2015).

On the farm scale, institutions for managing irrigation are well-matched to the crops affected by those decisions; indicating a high level of spatial fit. Likewise, there is a high temporal fit, as the time scale at which farmers can choose to apply water throughout the season (notwithstanding temporal constraints in water availability) is appropriate for influencing the health of the crops and crop production in that same season. Finally, growers and their staff have a high level of control (though not necessarily complete control) over management decisions relating to many aspects of crop health and productivity: not just irrigation and nutrient management, but also pest control, harvest, and the like. On the whole, this indicates a high potential for institutional fit between farmer management and crop needs. If the farmer is aware of how these decisions relate to their ground and the crop's needs, both the motivation and pragmatic potential to choose appropriate management actions is high. Note that the definition of ecological fit also depends on the way in which the ecological constraints are defined. Although farmers are likely to choose management actions that are broadly suited to the crop needs for the reasons outlined previously, it is possible that these choices diverge from those that optimize

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overall water quality and availability in the basin. However, the management practices used in this research study are chosen because they improve water and nitrogen use efficiency. All else equal, more efficient use of inputs benefits both the individual business and the overall strain on the water system.

Hypothesis 3: Soil knowledge will be associated with a greater rate of adoption of best management practices.

The on-farm benefits farmers can expect to receive and the off-farm benefits to water quality that result from improved efficiency vary by soil type. This is because different soil profiles benefit from different management strategies. Use of nitrogen and irrigation management best practices can minimize runoff and leaching through efficient use of water and fertilizers. Soil texture impacts water retention, water flow, and nitrogen movement throughout the soil profile, as well as the ease with which plants can uptake water and nitrogen (e.g. Tremblay et al. 2012; Gerard et al. 1966). Accounting for the local soil texture is useful for informing fertilizer and water application that minimizes waste of expensive inputs and optimizes crop response (Shahandeh et al. 2015). Soil texture influences the movement of water and nutrients throughout the soil and down to the aquifer and as such is of particular relevance for nitrogen and irrigation decisions.

If farmers are concerned about downstream effects or cost-effective use of inputs, we would expect farmers in sandier soils to adopt more efficient practices, since as, for instance,

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Gaines and Gaines (1994) show, sandy soils have the potential to leach more nitrate in ag contexts. We also expect to see evidence for “limiting factors” – a sandy or clayey streak with more demanding or complicated needs could dictate management protocols for the entire area (Niles et al. 2015). More complicated management needs for a small area would result in the entire area being managed with a larger, more complex set of practices. For instance, a long irrigation set may adequately irrigate a crop on coarse soils but flood a clayey streak and damage the crop. To account for the needs of the most restrictive portion of the field, the entire area may be outfitted with more efficient practices such that the clayey portion is not over-irrigated. Alternatively, since management practices are expected to be tailored to soil needs, an area with more diverse soil needs that uses different practices on each soil texture would end up using a total of a higher number of management practices when aggregated to the overall field level. Evidence of “limiting factors” would include increased management needs for fields with high variability in soil texture. A more tailored management approach would likely be adopted in these areas, since the crop is more likely to respond differently in the different texture zones and need customized treatment, compared to a uniformly textured area.

Hypothesis 4: Farmers in sandier soils and in fields with diverse soil types are expected to adopt a higher number of nitrogen and irrigation best management practices.

3 METHODS AND MATERIALS

First, we describe the models used to answer each research question. We then include details about the source of the data used to create these variables and any transformations or spatial aggregations that were used to generate the metrics used in the models.

3.1 Analysis

For Research Question 1, a series of two-sided Wilcoxon rank sum tests are conducted to determine whether fields in which growers report dominance of a certain soil type (“Reported Soil Type” in Table A1) actually have a higher percentage of that soil type according to SSURGO by surface area. We also present a Sankey diagram of the grower-reported soil type for each field compared with the SSURGO determination of dominant soil type by area to examine trends of over- or under-reporting. Finally, we generate a dose-response curve indicating the likelihood of growers reporting clayey/heavy clay soil types compared to the overall percentage of clay-sized particles in the soil, to examine the possibility of farmers being highly sensitive to a small percentage of clay-sized particles in their soil profile.

For Research Question 2, a binomial logit model is used for level of soil knowledge, where the dependent variable is a binary measure of agreement (Farmer Agreement with SSURGO Regarding Dominant Soil Type). If the grower-reported dominant soil type matches the SSURGO report, this is coded as a 1; otherwise, as a 0. (If the grower reported more than one dominant soil type, at least half of these must match the SSURGO dominant soil type by area).

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The independent variables represent available resources (Income Bracket, Education Level, and Total Farm Acres), Use of Educational Services, and Belief in the Prioritization of Soil Fertility.

A mixed-effect binomial logit model is used to address Research Question 3 regarding the translation of knowledge into management practices, adjusting for the same covariates included in the model for Research Question 2 (except income¹), since available resources and use of educational services have been found in prior literature to impact management outcomes, and since we posit that prioritizing soil fertility would increase the use of best management practices. This is achieved by pivoting the data, such that each observation represents a trial of a particular grower and a particular management practice, with the dependent variable representing whether the grower used that practice (0/1). We also include additional variables relevant for

¹Income was excluded as a predictor of management practices because of the bidirectional link between income and management. Although income can make it easier to purchase equipment and afford the labor necessary to adopt management practices, efficient use of irrigation and nitrogen can influence income by improving yield and minimizing input and energy costs, so it would not be possible to interpret the coefficient for income as the direct effect of income on management practices. Other correlates to income, such as education and farm acreage, are still included in the model to represent access to resources. Income also impeded convergence, due to correlation with other variables, and would have led to the loss of 288 observations.

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management: an indicator representing whether the adopted practice is an irrigation practice or a nitrogen management practice (Practice Category) and random effects for the grower (Survey ID) and category of crop (Crop Group). Finally, we include two parameters relevant to Research Question 4, representing the diversity of soil types on the field (Soil Diversity) and the proportion of the field area that is sand or sandy loam (Sand/Sandy Loam as Proportion of Field Area).

3.2 Data

This analysis incorporates four data sources: grower surveys, farm management data, county assessor shapefiles, and SSURGO spatial and tabular data. The grower survey data was merged with farm management data on nitrogen and irrigation practices using anonymous grower IDs. The structure of each data source and key variables is described below. Full details on variables used from each data source are found in Appendix A.

3.1.1 Grower Survey Data

Grower surveys were distributed by mail to growers in Glenn and Colusa Counties in 2016 and 2017. Each observation in the grower survey data represents a unique survey respondent. A total of 389 respondents at least partially completed the survey. Variables used from the survey data are described in Table A1. To maximize survey participation and gain an understanding of grower priorities and primary trends, the grower survey asked a series of questions about the largest field of the respondent's self-designated "most important crop," rather than requesting this information for every field, of which a single grower may have many.

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The most important crop, as explained by survey respondent write-in reasoning, was typically designated as such because it either was the most profitable, had the largest number of acres, or was the only crop grown. For conciseness, the largest field of the primary crop is referred to in this study as the grower's "most important field." For the analysis that follows, the grower data was filtered to only include the most important field, since these are the fields for which growers reported soil data.

3.1.2 Farm Management Data

Farm management data was obtained through a partnership with the Colusa Glenn Subwatershed Program (CGSP), a grower coalition that helps manage the information growers are required to report regarding nitrogen and irrigation management practices. Each observation in the farm management data corresponds to a single management unit, meaning an area using a particular set of management practices within one APN. Consequently, there can be multiple management units or rows corresponding to different parts of a single APN, but each management unit can never have more than one APN. Details on each variable can be found in Table A2.

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3.1.3 County Assessor Data

Glenn and Colusa County assessor shapefiles were obtained, respectively, from the offices of the Glenn County Assessor for the year 2015² and the Colusa County Assessor for the years 2016 and 2017. In Colusa County, each observation in the dataset represents one Assessor Parcel Number (APN). In Glenn County, each observation in the dataset represents an Object ID, which is typically unique to a single APN, but on rare occasions, there may be more than one Object ID in a single APN. In such rare cases, the management unit is matched with the assessor geometry whose acreage most closely matches its own; if there is no clear match, all assessor geometries with the same APN were merged and assigned to the management unit. See Appendix B for more information on how these cases were handled. See Table A3 for details on each variable.

3.1.4 SSURGO Data

SSURGO soil data is from 2021, downloaded through the interactive Soil Web Survey tool in August of 2022, as shown in Figure 1.2, for Glenn and Colusa counties.³

² Among the available shapefiles from the Glenn County Assessor, 2015 was the closest year available to the time of survey data collection. See Appendix B for more information on data quality.

³ County was used as the Area of Interest to filter the portal results. The files used for this analysis are for Glenn County: soilmu_a_ca021.shp, muaggatt.txt, comp.txt, chorizon.txt, and

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Figure 1.2: A Screenshot from the Northeast Corner of Glenn County. The orange outlines represent borders between map units.

The primary SSURGO tables used for this analysis are the map unit table, component table, and horizon table for each county, as summarized in Figure 1.3 below. Map units are areas of the map that share unique soil properties, such that the same map unit may be found in multiple non-contiguous areas. For instance, “water” is a map unit that denotes the presence of lakes, ponds, and other water bodies. These map units are named and distinguished by their

chtexgrp.txt; and for Colusa County: soilmu_a_ca011.shp, muaggatt.txt, comp.txt, chorizon.txt, and chtexgrp.txt.

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distinctive characteristic components, such as “Tehama clay loam, 0 to 2 percent slopes.” There are 127 map units in Colusa County and 367 in Glenn County. In the map unit table, each observation represents a unique map unit, with corresponding information regarding the series texture of the overall map unit, if applicable. Each map unit is composed of a combination of components, although the spatial distribution of these components within the map unit is unknown. Each row in the component table represents a unique component, including metadata regarding the map unit to which it belongs, whether it qualifies as a “major” component, and the component series texture, if applicable. Each component, in turn, is composed vertically of a number of soil horizons. The horizon table includes each horizon as a unique row, including metadata regarding the thickness of the horizon, its depth from the surface, the component to which it belongs, and texture information including its proportion of sand, clay, and silt particle sizes.

The primary purpose of this data is to generate a soil texture profile of the “most important field” for each farmer for whom survey data is available. This is achieved through a multi-step process:

- 1) First, a metric of “average horizon texture” is calculated for each component. This is not a weighted average based on horizon thickness but is a simple average based on the mean clay, soil, and sand particle percentages for each horizon in the component, excluding horizons that are classified as plant matter. A non-weighted average was chosen because horizon thickness is not always available, particularly for Glenn County soils due to an older method of soil surveying. However, for Colusa County soils, for which horizon

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thickness is available, the non-weighted average was found to closely mirror the

weighted average, and thus was determined an adequate substitute.

- 2) The break-down of soil texture class by percentage was determined for each map unit, based on the average texture of each component as calculated above, times the percentage of the map unit composed of that particular component.
- 3) The break-down of soil texture class was determined at the farmer field level, by taking an area-weighted average of the map units found within the boundaries of the field.

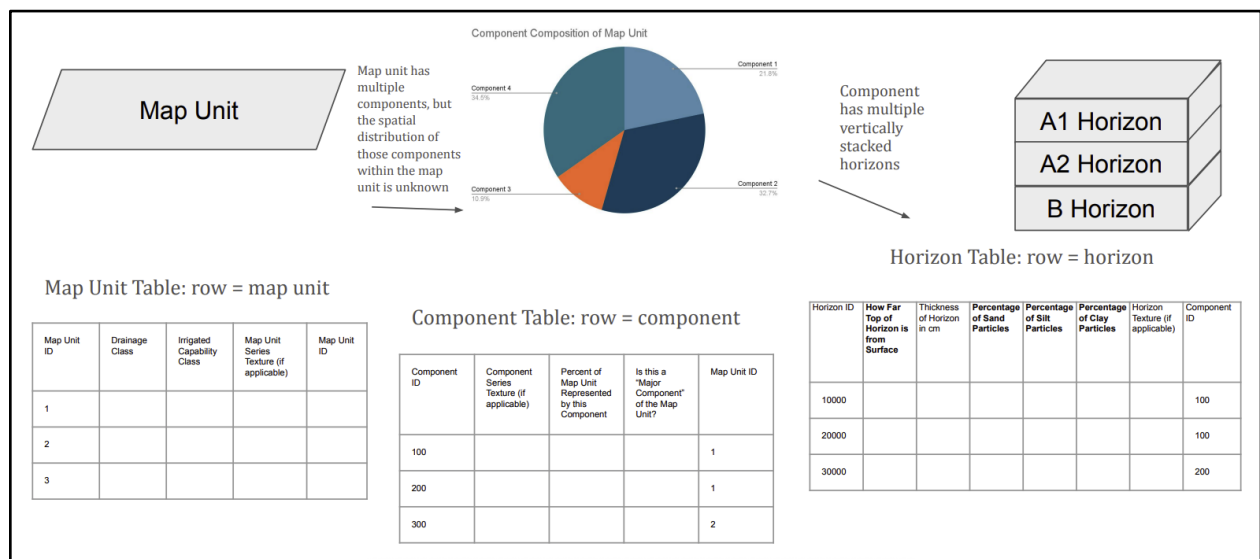


Figure 1.3: Relationship Between SSURGO Tables

3.1.5 Data Merging

More information about edge cases in the APN matching process is available in the Appendix C (Table C1). This subsetting was achieved by matching the crop and acreage of the most important field reported by survey respondents with crop and acreage information from the

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CGSP data to identify the management unit(s) corresponding to each grower's most important field (see Appendix E). In the rare case of finding no management units within a 20% difference in acreage of the reported most important field, or else combinations of up to the grower's largest seven eligible management units that meet this criterion when added together, all of a farmer's fields with the crop type matching that of their most important field were aggregated together. While adding together all management units potentially results in a diluted signal for those plots, there is generally very little variation in soil texture within a single Assessor Parcel Number (APN) (Appendix D), and most of the time, growers' most important field as determined through this process was contained in a single APN. Accordingly, relatively little noise was produced as a result of this processing limitation.

The overall number of survey respondents for which valid spatial data is available is 261, but the 7 observations representing rice fields are removed, as rice involves significantly different irrigation and nitrogen management compared to other California crops, and a sample of 7 was insufficient to properly represent this group. Of the remaining 254 observations, some are excluded from certain regression analyses due to incomplete survey response data for other questions used as control variables in those models. The "Models" section describes the *n* for each regression analysis in which this is the case.

Using Assessor Parcel Numbers (APNs) available from the CGSP data, grower data was merged with county assessor records. Finally, these data were spatially merged with Soil Survey Geographic Database (SSURGO) map unit and horizon soil texture data from 2021, retrieved through the interactive Soil Web Survey tool in August of 2022, using county as the Area of

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Interest. Each row of the county assessor data corresponds to a single object ID, of which there may be one or several within a single APN.

A matching protocol was conducted to merge grower management data with county assessor shapefiles. In many cases, a single management unit corresponds to a single county assessor shapefile, or many management units correspond to a single county assessor object ID, both of which create a straightforward match. In other cases, one management unit corresponds to multiple assessor shapefiles; this occurs in rare circumstances when there is more than one assessor object ID sharing a single APN. In such cases, the management unit is matched with the assessor geometry whose acreage most closely matches its own; if there is no clear match, all assessor geometries with the same APN were merged and assigned to the management unit. Since the level of soil diversity within a single APN is low (see Appendix D), the level of noise arising from these edge cases is minimal.

3.1.6 SSURGO Data Processing

In the grower survey, respondents were asked to report the “dominant soil type” of their most important field.⁴ The survey used soil type categories that mirror the language growers use to talk about their soil: sand, sandy loam, loamy, clayey, and heavy clay. In order to compare

⁴ Respondents were asked to select “one soil type that fits best.” Of the 254 respondents, 245 selected only one, while 9 selected multiple.

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grower reported soil type with USDA SSURGO soil survey data, the following matching scheme was used to match grower-designated soil types with SSURGO-defined texture categories.

For each observation (grower's most important field), the Proportion of Field Area composed by each soil type was calculated. This was a two-step process: SSURGO data is spatially divided into map units, which may have one or more components expressed as an area-weighted percentage of their contribution to the overall map unit. In the first step, the "localphase" soil texture information for each component (see SSURGO documentation) was used to create an area-weighted proportion of the soil textures represented in each SSURGO map unit.⁵ In the second step, these map unit-level soil texture percentages were used to categorize the area-weighted percentage of each grower field made up of each soil texture. These texture designations were then simplified into the basic soil types according to Figure 1.4, to match the options included on the grower survey.⁶ We also create a map-unit level variable describing the texture of the soil series associated with the map unit as a whole.

⁵ Where available, the component soil series texture is used; where this is not possible due to component complexity or otherwise, the texture of the top component horizon that is not "plant material" is used.

⁶ There were four exceptions to the rule visualized in Figure 1.4: fine sand and very fine sand particles are so small that in some ways they can behave more similarly to silt particles.

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Each component is vertically divided into horizons, each of which have a distribution of three different sizes of particles: clay, silt, and sand. This information was used to determine the raw particle percentages of each grower field's soil profile.⁷

Because of this, the four sub-textures with high percentages of fine sand and very fine sand were classified with a bias toward the middle of the soil triangle.

⁷ 183 cm, or 6 ft, was used as the maximum root zone depth to be considered in the particle size analysis. Therefore, any soil horizons beginning more than 183 cm below the surface are not incorporated into the average. The average is not weighted by depth, since horizon thickness is not available for all components in Glenn County, but is a raw average of particle size distribution among all horizons in the component, calculated by summing the particle size percentages and dividing by the number of horizons. The difference between the weighted and non-weighted average for Colusa soils has a mean of only 0.51 percentage points, with a maximum difference of 5.8 percentage points, so the non-weighted metric was deemed suitable for this analysis.

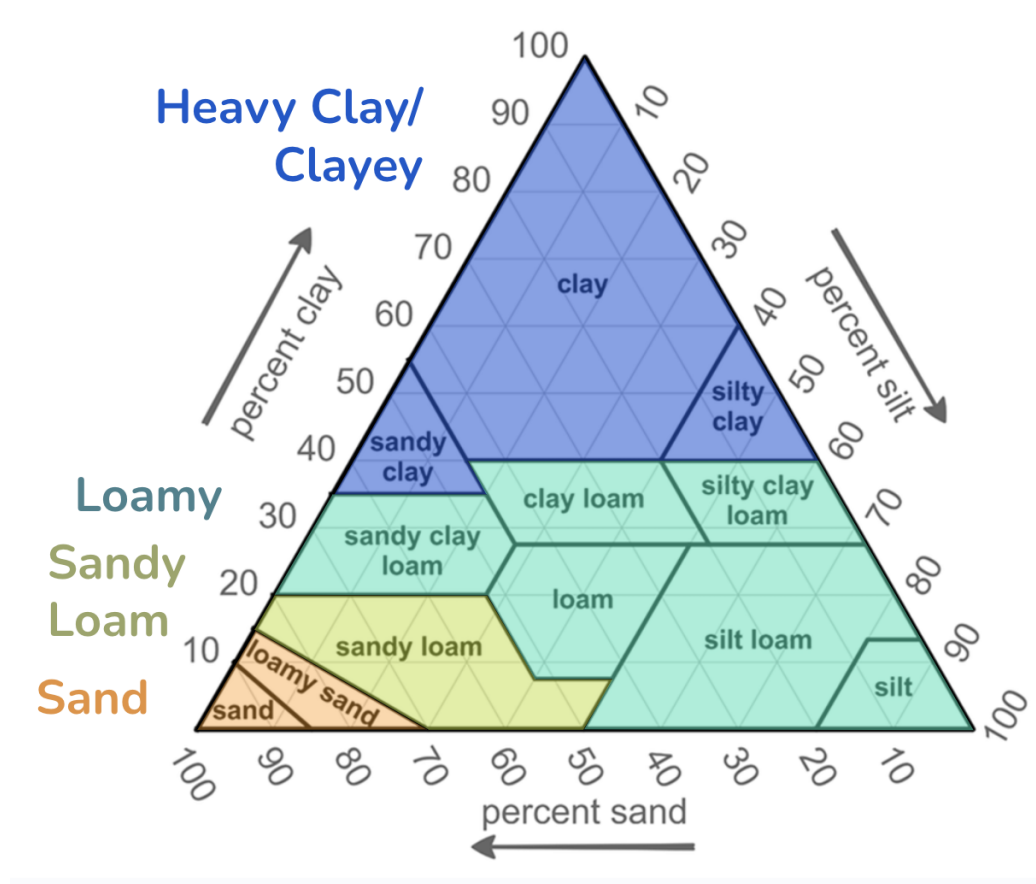


Figure 1.4: Classification Used for Comparison of SSURGO-Defined Textures with Grower Survey Data

3.1.7 Calculating Agreement

We define “agreement” as the extent to which a grower’s report aligns with the “dominant” soil type reported in the USDA SSURGO data. We define the “dominant” soil type as the type that comprises the highest total percentage of the field area, as described above and shown in Figure 1.5. If the grower’s soil type report matches the dominant soil type, then the grower and SSURGO “agree” (coded as 1 in the data) and they “disagree” if they do not match

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(coded as zero).⁸ If the grower left the question blank or selected the answer choice “I don’t know”, the agreement is considered to be zero.

For instance, consider the hypothetical USDA soil map of a farmer’s most important field below (Figure 5), where the dominant soil is loamy, since this is the soil type with the highest percentage (60%). If this farmer reported “loamy” on the survey, they would be classified as “agreeing” with SSURGO, otherwise they would be classified as disagreeing with SSURGO.

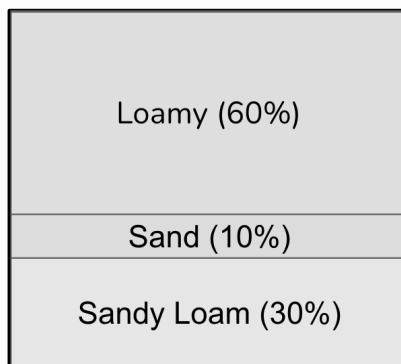


Figure 1.5: Example Breakdown of Soil Types on a Field by Percent of Surface Area

⁸ Out of the 254 growers included in the analysis, 245 report one soil texture, but 9 growers report multiple. In these cases, if at least half of the grower-reported soil types matches the dominant soil type, it is considered a match.

4 RESULTS

4.1 Sacramento Valley Growers Over-Report Clayey/Heavy Clay and Under-Report Loamy Soils

Most growers felt comfortable answering the soil type question: of the 254 survey respondents in the sample, 6 left the soil question blank and 36 answered “I don’t know”. It also does not seem that certain soils are more difficult to identify than others, as there is no relationship between reporting “I don’t know” or leaving the question blank with SSURGO-reported soil texture (Appendix F).

Agreement between growers and SSURGO data was strongest for coarse and fine soil types: sand and clayey/heavy clay. Growers generally agree with USDA that they do not have sand: none of the plots had sand as the dominant soil type according to SSURGO, and only 5 out of the 254 growers reported sand as their dominant soil type. Similarly, although there are only 7 fields in which clayey/heavy clay is the dominant soil type, all 7 of the respective farmers correctly identified their dominant soil type. A two-sided Wilcoxon rank sum test was conducted to estimate whether the percentage of a field composed of clayey/heavy clay according to SSURGO differs between fields in which growers report clayey or heavy clay as their dominant soil type (median 1.02%, mean 11.45%), compared to those in which growers do not report

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having those soil types (median 0%, mean 2.93%).⁹ Fields in which growers report clayey/heavy clay have a slightly higher proportion of clayey/heavy clay soils on their field, compared to fields in which growers do not report this type ($W = 8874$, $p\text{-value} = 0.00019$), indicating grower sensitivity to the presence of clayey/heavy clay soils. However, although the means differ by 8.5%, the estimated difference in location is merely 0.033% due to the heavy skew of the data [95% CI: $2.8e-5$, 1.35].

Conversely, there is little agreement between growers and SSURGO data for medium-textured soils (sandy loam and loamy). The Wilcoxon rank sum test on whether the percentage of a field composed of sandy loam differs between fields in which growers report sandy loam (median = 0%, mean = 13.34%) and those in which growers do not (median = 0.56%, mean = 8.70%) was not significant ($W = 4506.5$, $p\text{-value} = 0.2432$). Likewise, there is no statistically significant difference in loam area percentage ($W = 7106$, $p\text{-value} = 0.67$) between growers who report loam (median = 85.00%, mean = 75.83%) compared to those who do not (median = 85.00%, mean = 75.17%). This pattern is more clearly represented in Figure 1.6. Compared to SSURGO, growers underreport having loam as their dominant soil type, but overreport having sandy loam and clayey soils as their dominant soil type.

⁹ The Wilcoxon rank sum test was selected because percent of the field that is clayey/heavy clay according to SSURGO data is not normally distributed.

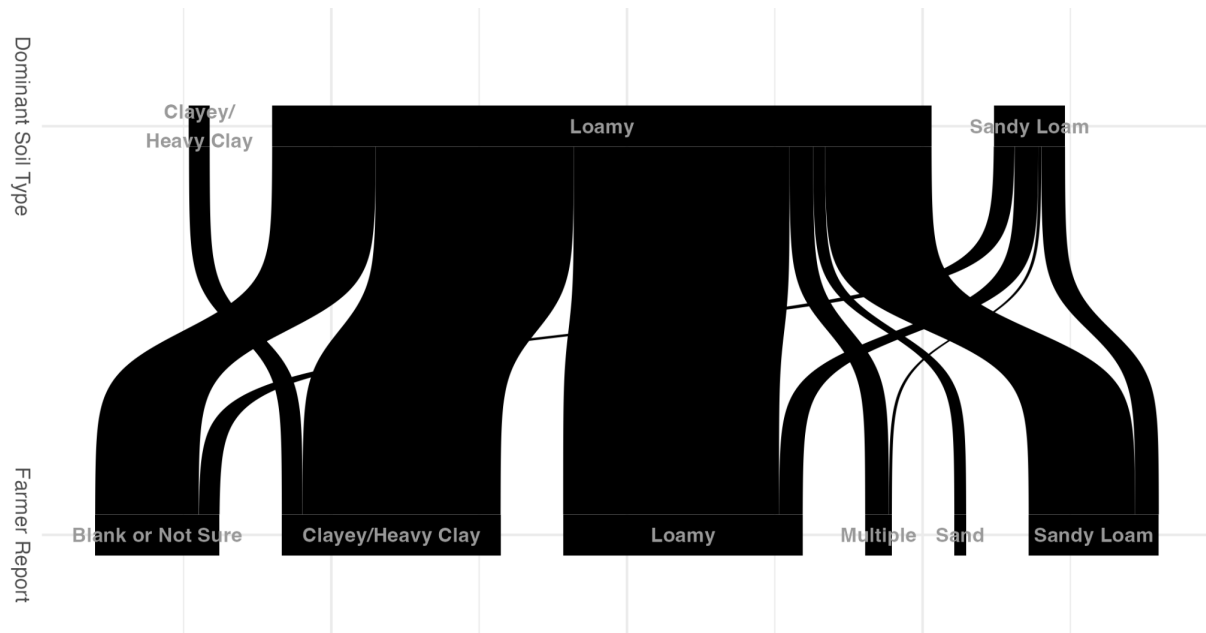


Figure 1.6: Farmer-Reported Soil by Dominant Soil Type (N = 254 farmers)

One possible reason for the over-reporting of clayey/heavy clay and under-reporting of loamy soils is that growers may have a lower threshold of what they consider to be “clayey” soil. This possibility is explored in Figure 1.7, a dose-response curve representing grower reports of clayey/heavy clay on the y-axis as a function of percentage of finely textured particles in the soil. The horizontal line shows the 50% reporting mark, at which growers report clayey soil 50% of the time. The vertical line at $x = 0.35$ represents the lowest clay particle threshold used according to Figure 1.4 for classifying soils as clayey/heavy clay (that is, the boundary between sandy clay loam and sandy clay, when proportion of sand particles is $> 45\%$). We do not observe a threshold effect, as the dose-response curve is linear. This means that there are many growers who report a clayey / heavy clay dominant soil type well before the intersection point. However, the trend line

of predicted probability of a grower reporting clayey/heavy clay passes through the intersection of these two points, indicating that growers become more likely than not to report clayey/heavy clay at SSURGO's threshold for defining a soil as clayey/heavy clay. Therefore, we do not have evidence to support the idea that growers have a lower threshold of what they consider to be "clayey" soil. The average trend is that growers align with SSURGO classifications for finely textured soils, but there is a large amount of variance, and there is no observed step function to indicate a threshold effect.

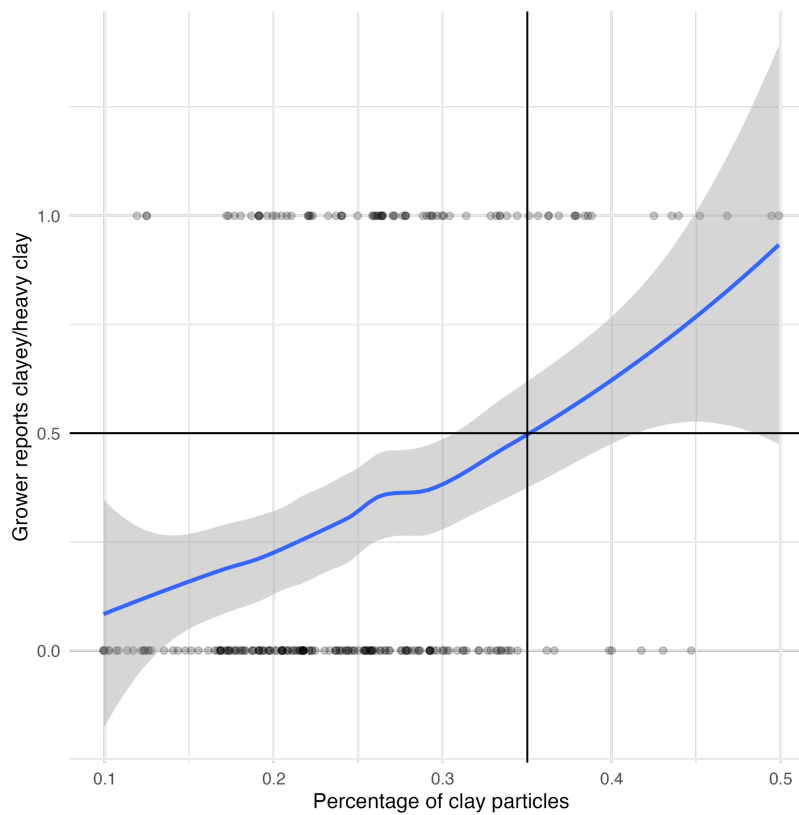


Figure 1.7: Dose-response LOESS curve of likelihood of grower reporting clayey/heavy clay soil type depending on percentage of clay particles.

4.2 Farmers Who Recognize Soil Fertility as a Management Priority Know Their Ground

From the analysis above, it is apparent that some growers know their soil type and others do not. Next, we analyze what determines whether a farmer correctly classifies their soil type as a function of education, farm income, total farm acreage, access to extension services, and focus on soil fertility as a management priority. Figure 1.8 summarizes this analysis: a one-unit increase in belief in the prioritization of soil fertility as a management priority is associated with a 0.49 increase in the log-odds of a farmer correctly assessing their dominant soil type. By contrast, the effect of use of educational services is not significant in the model, indicating that learning to identify one's soil type is not a focus of these services. Full tabular results are included in Appendix G.

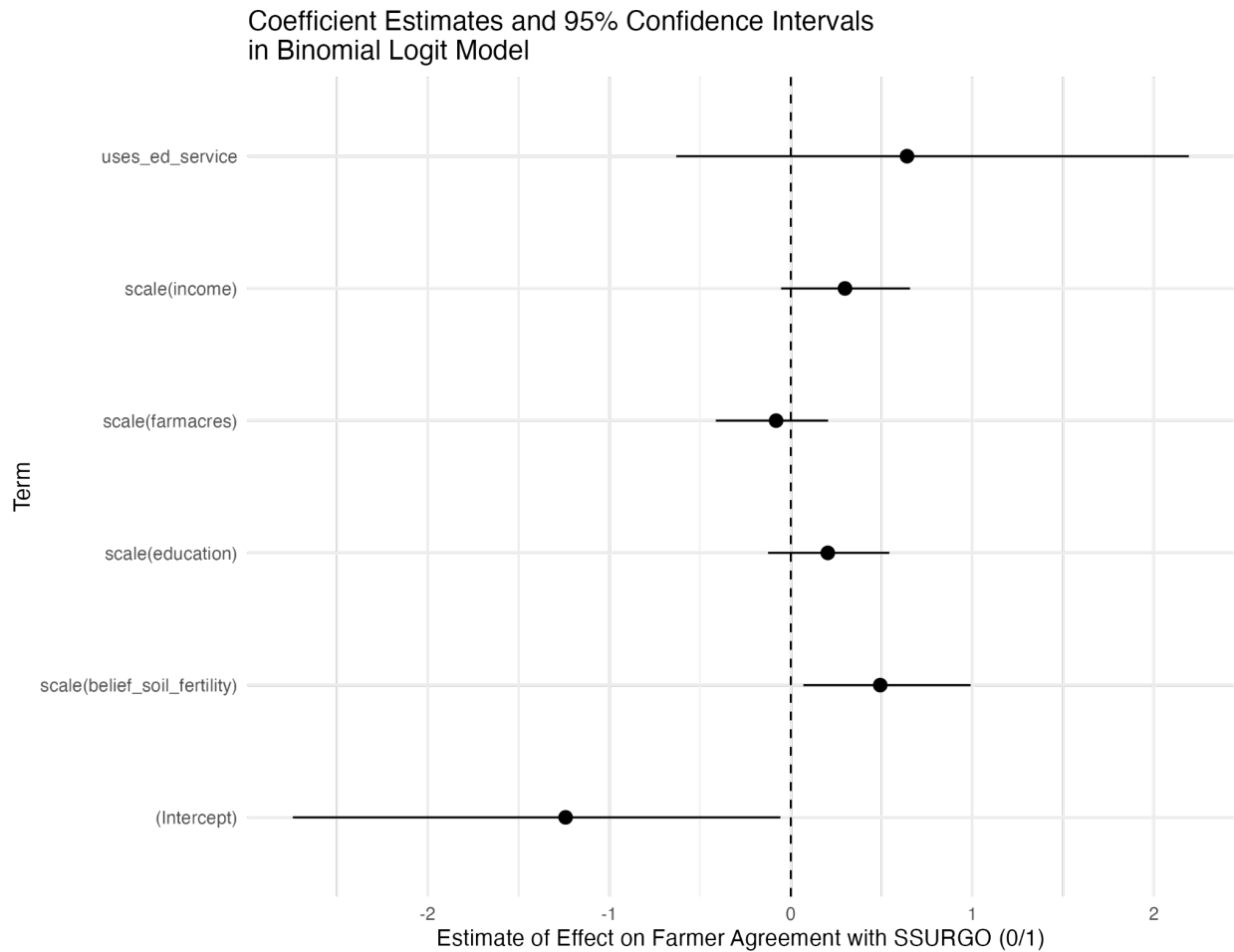


Figure 1.8: Soil Knowledge Model Results

4.3 Soil Knowledge Doesn't Predict Behavior, But Focus on Soil Fertility Does

Although a farmer's focus on soil fertility is a predictor of soil knowledge, soil knowledge itself does not directly predict use of management practices (Figure 1.8). In this model, each observation is one grower's use of one management practice (0 or 1). A random effect is included for the grower, such that there are unique observations for a particular grower's use of each management practice. However, focus on soil fertility is associated with increased

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use of management practices, as is use of extension services and access to resources as indicated by education level and farm acreage, even though those factors did not predict soil knowledge in the previous model. Full tabular results are included in Appendix G.

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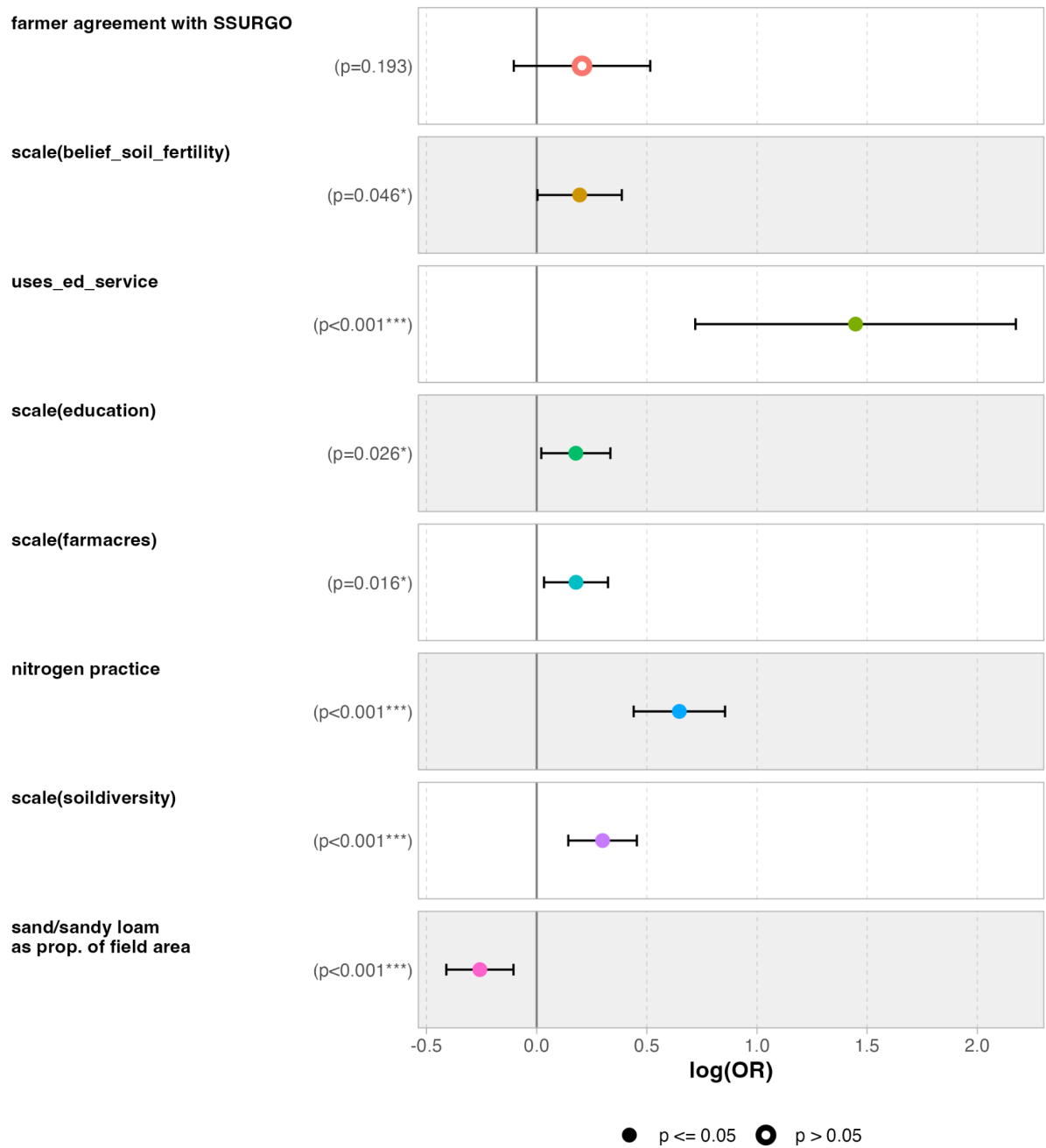


Figure 1.9: Management Practice Model Results, Represented as Log Odds Ratios

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From the results in Figure 1.9, soil texture appears to influence management in two ways. First, plots with higher diversity of soil textures have a higher likelihood of best management practice adoption. This is consistent with the idea that the complexity of field management matches the complexity of the field itself. Since the crop in each area is more likely to respond differently to identical irrigation and nitrogen inputs given unique soil textures, farmers would be expected to have a more complex, efficient system that is appropriate for all texture zones, leading to an overall higher number of practices at the field level. Second, contrary to Hypothesis 4, proportion of field area in sand or sandy loam is tied to a lower likelihood of using best management practices. In other words, the fields with the highest risk of leaching are also those with the lowest adoption of practices that reduce leaching.

5 DISCUSSION

From this analysis, it is not a given that farmers know their soil type; some do, and some do not, particularly for loamy soils, as farmers have a tendency to consider their loamy soils to be “clayey” or “heavy clay”. Although SSURGO data is not absolute truth – it lacks the level of spatial resolution that growers may have of their own property – there was a systematic shift of growers to be more likely to classify their field as predominately clayey/heavy clay and less likely to classify their field as predominately loam, compared to SSURGO categorizations. Clayey or heavy clay soil textures offer unique challenges that may make their presence more salient to growers. Although the low levels of soil diversity in this dataset made it difficult to definitively assess disproportionate sensitivity to small areas of clayey/heavy clay soil, it could

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be that the presence of small clayey patches could color a grower's perception of their entire field, particularly if the needs of those portions dominate management considerations for the entire field. Alternatively, clayey soils could be a catch-all reason that is common to cite for general management challenges. Regardless of the particular explanation, this case illustrates that "clayey / heavy clay" soils may not mean the same thing to a grower as it does to a soil scientist or extension specialist who comes to advise on their farm. Verifying the meaning of shared language could improve outcomes for agricultural consultations.

Second, farmers who recognize soil fertility as a management priority are more likely to know their soil type. It is also possible that increased access to resources, particularly income, helps farmers develop soil knowledge, but the current data does not provide statistically significant evidence to confirm this effect. Although knowing one's soil type does not appear to directly increase management practice use, focus on soil fertility as a management priority does. Meanwhile, these management practices do not appear to be directed towards reducing leaching, as they are less common in sand/sandy loam soils in which leaching is more probable. This suggests that education on the efficiency and environmental effects of different management practices may not be as effective as education designed with the framing of soil fertility. This is consistent with the finding of McNally and colleagues in the U.S. Corn Belt (2018) that a soil stewardship ethic can promote use of conservation practices, indicating generalizability of soil perceptions among farmers in agronomic crop systems of the Midwest to those in diversified specialty crop systems such as that of California. Advising services specifically geared towards building understanding of the role of soil fertility on crop outcomes, and use of nitrogen and

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irrigation management practices not necessarily for their potential to reduce environmental impacts but for their potential to optimize soil fertility could both improve farmer awareness of their soil and its needs and promote adoption of efficient management practices.

Another lens through which to interpret the use of best management practices is the role of complex agricultural environments in influencing management decisions. In loamy, clayey, and heavy clay soils, crops are more easily put at risk by either overwatering and underwatering, compared to in sand and sandy loam soils, in which it is more difficult to overwater the crop due to the ease with which water can drain through coarsely textured soil. Meanwhile, fields with a higher level of soil diversity may require multiple sets of practices to meet the differing needs of the soil types found on the field. Farmers respond to the management complexities of more finely textured soils and fields with greater overall soil diversity with a larger suite of practices. These complexities could also be playing a role in forcing growers to pay more attention to the conditions in the field, enabling them to get into the field and notice conditions on which to tailor their management.

Finally, despite the lack of effect of farmer agreement with SSURGO classifications on management practices, the differentiation of management practices by soil type, after accounting for differences in crop type, indicates that implicit soil knowledge influences management. In other words, even if farmers do not know the formal name of their soil texture, they are managing their fields differently according to their soil texture.

6 CONCLUSION

This study explored the relation of soil and soil knowledge to nitrogen and irrigation best management practice adoption. Soil knowledge was assessed by comparing growers' self-reported soil type with SSURGO data on those same fields; management practice adoption data was available from a third party known as a water coalition that helps growers with required reporting. The results demonstrate an underreporting of loam and overreporting of clayey/heavy clay soils, suggesting that growers may have heightened sensitivity to small but disproportionately salient fractions of non-loams on their property or may attribute other soil problems to a clayey texture. Farmers who recognize soil fertility as a management priority have a higher knowledge of their soil texture and also adopt a higher number of nitrogen and irrigation-related best management practices. Although there are many factors influencing grower management, soil type is a small but significant predictor, such that sand and sandy loam soils are associated with slightly reduced nitrogen and irrigation management practice adoption, and fields with diverse soils are associated with a slightly higher number of nitrogen and irrigation management practices. This points to a complexity factor, in which more complicated management, such as dealing with multiple soil types or finer textured soils that are more prone to flooding and drainage challenges, is associated with a greater number of management strategies.

Although use of advisors was not definitively linked to greater soil knowledge, advising services still have the opportunity to play a role in motivating management practices through the lens of soil health. For farm advisors and consultants, this indicates that nitrogen and irrigation

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practice use is responsive to growers' perceptions of the importance of soil fertility and the role of management practices in supporting healthy soils. This framing is likely to be more effective than is a framing emphasizing the role of best management practices in avoiding adverse environmental impacts, as evidenced by the lower use of best management practices in soils that are more prone to leaching.

The relative uniformity of the soil profile in the counties in this case study, and consequently, the relatively small impact of the resolution limitations of SSURGO data on the validity of the analysis, makes it a valuable proof of concept for the use of assessor parcel numbers to match management data, survey data, and spatial environmental data in a medium-to-large-N analysis. However, because of the relatively uniform environment, there is limited ability with the current data to probe potential specific drivers for farmers to over-report heavily textured soils. Future analysis in more varied environments, potentially enhanced with satellite imagery that can detect dry or wet patches, could shed light on the extent to which overreporting clayey / heavy clay soils is specific to loamy environments or is emblematic of a more general trend, and the extent to which growers exhibit disproportionate sensitivity to small areas with unusually challenging management requirements. Nevertheless, the current study provides evidence for the importance of attention to soils in farm management as a framing that promotes efficient practice use, while offering a warning against taking shared definitions for granted in agricultural advising contexts. More broadly, it demonstrates ways in which a farmer's attention to their specific biophysical environment can influence the agricultural landscape, offering opportunities for advising service providers to identify framings that resonate with farmers.

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CHAPTER 2

**BOOTS ON THE GROUND: EVALUATING AN AGRICULTURAL INNOVATION
SYSTEM INTERVENTION IN CALIFORNIA**

With Mark Lubell, Forrest Owens, and Sat Darshan S. Khalsa

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ABSTRACT

Nitrogen and irrigation management is a state-level priority in California, where overlapping sets of regulations govern agricultural water and nutrient use. This paper analyzes the outcomes of a “boots on the ground” program aimed at increasing outreach and education for growers in the Central Valley and Central Coast. Our analysis links theories of agricultural

innovation systems to program evaluation frameworks. We find that the program improved participants' knowledge, implementation of existing management practices, and adoption of new practices. The program also experienced challenges related to the broader extension landscape such as staff incentives, coordination, and earning trust from growers. These challenges resulted in constraints in terms of outreach relationship longevity and “which boots” were available to participate, limiting effectiveness. This program serves as a case study highlighting the potential capabilities and limitations of short-term programs aimed at improving on-the-ground agricultural decision-making and outcomes.

1 INTRODUCTION

Nitrogen pollution and the nexus with irrigation management have been identified as a critical environmental issue for California and global agriculture over the last two decades ([Abascal et al. 2022](#), [Rudnick et al. 2021](#)). Using a theoretical lens linking Agricultural Innovation Systems (AIS) theory (Klerkx and Leeuwis 2008; Menary et al. 2019) to program theory (Douthwaite et al. 2003; Horton and Mackay 2003), this paper analyzes the effectiveness of an intervention called the “Nitrogen and Irrigation Initiative (NII),” a partnership between the California Department of Food and Agriculture and the University of California Agriculture and Natural Resources extension program designed to support direct grower outreach on these management priorities.

We use the phrase “boots on the ground” (BOTG) to describe programs like NII because they are designed to expand the reach of networks of extension professionals who can translate

knowledge to action for on-the-ground decisions for growers. We argue that BOTG programs can be understood as interventions designed to increase the presence of two structural components of AIS—innovation brokers and their interactions with growers—in order to facilitate the critical innovation system function of knowledge diffusion (Klerkx and Leeuwis 2008). This argument links AIS theory to program evaluation by pinpointing the AIS structures and functions that are targeted by any specific program. However, we also argue that AIS theory alone is not a sufficient basis for program evaluation, because it lacks a theory of change or logic model that links inputs to outputs for a particular program. As a result, we adopt a logic model developed by the United States National Institute of Food and Agriculture as a general approach to program evaluation that is applied to their national portfolio of grants.

Based on the NIFA logic model, we found that the NII program increased participants' knowledge, helped growers improve their existing implementation of management practices, and catalyzed practice uptake. However, program inputs were limited due to program duration and affiliation and staff capacity, constraining learning and uptake. We argue that many of these challenges are rooted in the structural components of the broader innovation system that this specific BOTG program was not designed to address and did not consider from the outset. That is, even though a specific intervention may be narrowly designed to address specific structural weaknesses in an AIS (e.g; presence of innovation brokers and interactions with growers) and a single functional goal in the AIS (in our case, knowledge diffusion), other components of the AIS that shape program inputs influence its effectiveness. Hence, program design should consider how the broader AIS may influence implementation. The next section of this paper

describes how the NII program relates to conceptual models of AIS and the role of program evaluation and program theory in the AIS context. We then organize the rest of the paper based on the USDA NIFA logic model. We describe the case-specific context or “Situation” as defined by the logic model and the “Assumptions” that support the causal relationships in the model and inform our evaluative criteria, data, and methods. We then present the results of the evaluation instruments, classified under the corresponding causal links in the logic model: “Inputs,” “Activities,” “Outputs,” and “Outcomes.” Finally, we end with a discussion of “External Factors” in agricultural innovation systems that can influence the success of such programs.

2 THEORETICAL BACKGROUND

Over twenty years ago, Horton and Mackey (2003) called for the integration of AIS theory and program evaluation. We respond to this call in our evaluation of an extension program in California, using AIS theory to contextualize the role of this project in addressing specific structural limitations to improve system function, and employing program theory as a targeted evaluation tool optimized for learning and collaboration.

2.1 Boots on the Ground Programs: An Intervention in Agricultural Innovation Systems

AIS are composed of networks of actors embedded in a context of organizations and institutional rules that govern behavior and interaction, particularly learning and innovation development and implementation of farm-level decisions (Hall et al. 2003; Klerkx et al. 2012).

We conceptualize BOTG programs as a “systemic instrument” in an AIS: an intervention aimed at improving a functional goal by addressing a structural limitation (Wieczorek and Hekkert 2012; Lamprinopoulou et al. 2014; see Figure 2.1).

AIS theory provides a set of functions (left box in Figure 2.1) that support the overarching goal of identifying and scaling innovations. There are many papers that use variations of these functions to scaffold their analysis of the innovation system (see, for instance, Plummer et al 2024; Menary et al 2019; Lamprinopoulou et al. 2014; Bergek et al. 2008; Hekkert et al. 2007). We adopt the language of Menary et al. 2019: entrepreneurial activities, knowledge development, knowledge diffusion, guidance of the search, market formation, resource mobilization, and creation of legitimacy. Each function is then influenced by structural limitations (center box of Figure 2.1) of an AIS. Again, AIS literature commonly includes variations on these structural limitations (see, for instance, Wieczorek and Hekkert 2012; Borremans et al. 2018; Lamprinopoulou et al. 2014). We once again use the language of Menary et al. 2019: actors, interactions, institutions, and infrastructure. The structural components may then be limited by problems of either quantity or quality, which can compromise the functions associated with those structural elements (Wieczorek and Hekkert 2012). Based on the diagnosis of the problem, specific programs or policy instruments (right box of Figure 2.1) can then be designed as an intervention to target specific structural components and improve function (Wieczorek and Hekkert 2012; Cronin et al. 2022).

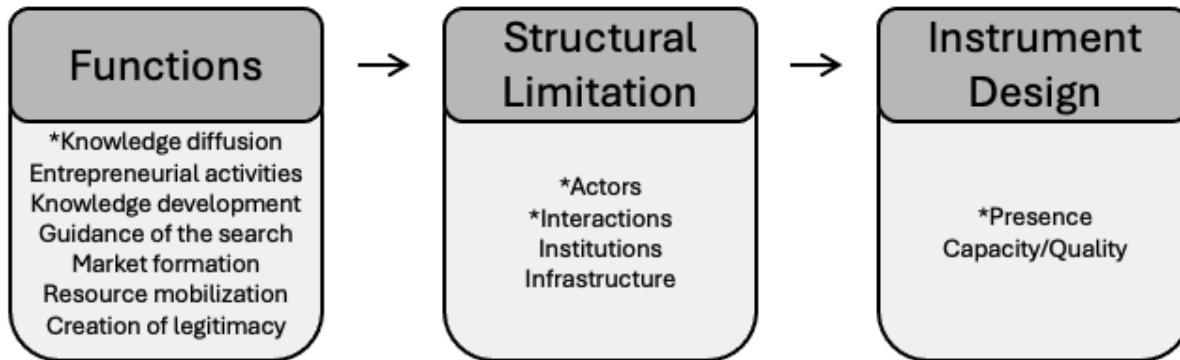


Figure 2.1: A General Agricultural Innovation System Approach to Intervention Instrument Selection. Components targeted by the Boots on the Ground program analyzed in this study are indicated with *.

BOTG programs can thus be conceptualized as programs designed to target specific structures and functions of AIS. Specifically, BOTG programs aim to promote grower adoption of efficient practices by targeting the function of knowledge diffusion – transmission of knowledge throughout the system – in this case, through stakeholder interaction and by helping growers connect to broader knowledge networks (Plummer et al. 2024).

The strategy by which BOTG programs aim to improve this function is by adjusting two key structural components: the number of “innovation brokers” and their interactions with growers (Klerkx and Leeuwis 2008). “Innovation brokers” are key innovation system actors such as agricultural extension, education services, and consultants that bridge the gap between the research and education sector and the agricultural production sector through educational interactions, facilitating information exchange and cooperation among different actors while providing science-based advice to growers about agricultural management (Klerkx et al. 2012; Spielman and Birner 2008; Klerkx and Proctor 2013). In the United States, land grant

universities such as the University of California support strong extension programs centered at the local county level, which are complemented by public extension organizations such as Resource Conservation Districts and private actors such as pest control advisors, certified crop consultants, and producer associations.

BOTG programs are an intervention designed to enhance the effectiveness of these structures by hiring new extension professionals to directly interact with growers at the field level or through grower meetings. BOTG programs are usually funded by state or federal government agencies and represent targeted investments in extension growth to address specific issues, such as the case examined here: nitrogen and irrigation usage.

2.2 Integrating AIS and Program Theory

AIS theory is commonly used to assess either entire systems or components of systems rather than individual programs (Cronin et al. 2022). Although there have been some efforts to develop AIS approaches that enable assessment of small components such as organizations and programs (Lamprinopoulou et al 2014; Cronin et al. 2022), these efforts focus more on creating a general model for understanding common patterns of interdependence between organizations and systems, rather than evaluating the design and effect of a specific systemic instrument with respect to its success in mitigating the unique structural and functional shortcomings it was intended to achieve.

Consequently, some AIS scholars have advocated for the use of evaluation models informed by program theory (e.g. Hall et al. 2014, Klerkx and Begemann 2020, Janssen et al.

2020, Springer-Heinze 2003; Douthwaite et al. 2003; Horton and Mackay 2003). Program theory identifies “the set of beliefs that underlie action” (Mackay and Horton 2003) and the assumed linkages between program design, goals, and impact (Mackay and Horton 2003; Horton and Mackay 2003; McRoberts et al. 2024). For practitioners, program theory is the anchor that guides practice on a pragmatic level (McRoberts et al. 2024).

While AIS provides an analysis of structure and function that can be targeted by an intervention, program theory is a framework to analyze whether the program effectively responds to the system failure it was designed to address. Theory-based evaluation enables productive analysis by demystifying the “black box” between inputs and outputs (Mackay and Horton 2003). Articulating the linkage between inputs, outputs, and outcomes, program theory and logic models can improve the design, interpretation, and utility of evaluations (Mackay and Horton 2003). Evaluation models informed by program theory are valuable for ensuring buy-in from affected parties, promoting effective communication and institutional learning, building program accountability, and bridging the gap between the longer-horizon scholarly knowledge production and the urgency of outcomes needed by the beneficiaries of research results (Thornton 2017).

We respond to this call by linking innovation systems insights with the logic model (Figure 2.2) developed by USDA-NIFA to operationalize the program theory underlying their evaluation of extension programs funded through their grant program (McRoberts et al. 2024). Arrows in the model represent causal relationships in which characteristics of one category influence those of the other. The remainder of this paper uses the terminology of the logic model

to organize the methods and results. The following section on “Situation” introduces the case study. After this, “Assumptions” are addressed, which motivates the evaluative criteria used, as well as the choice of data collection and analysis methods. The remaining portions of the logic model (inputs, activities outputs, and outcomes) will be used to assess the respective aspects of the program intervention. The discussion will argue that many of the challenges of the program derive from external conditions and the way in which the program is nested in the broader AIS.

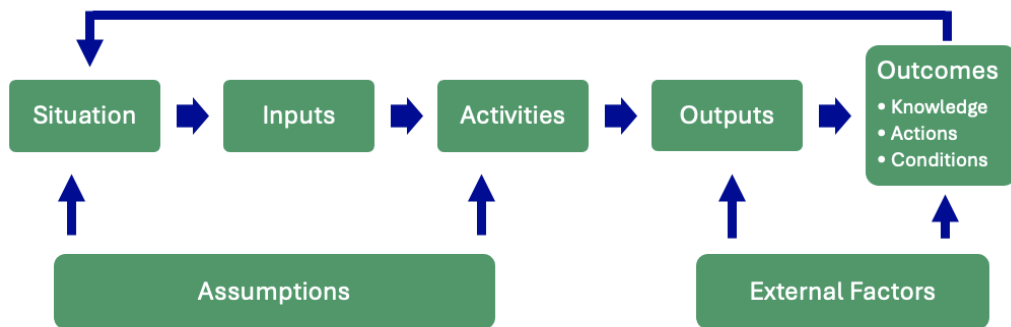


Figure 2.2: The USDA-NIFA Logic Model (adapted from USDA-NIFA 2023)

3 SITUATION: NITROGEN AND IRRIGATION POLICY IN CALIFORNIA

Nitrogen and irrigation practices influence water quality and availability in California. Nitrogen enters water supplies through fertilizer and livestock waste runoff or by leaching into the aquifer. Overirrigation or mismatched timing of fertilizer application with regard to rainfall and irrigation events can exacerbate nitrate pollution. Nitrate pollution in California is widespread and has equity concerns: 250 California water systems, used by 900,000 people, failed to meet safe drinking water standards, and nitrate pollution in one’s local water system is increased for renters and communities with a high Latino population (Chappelle et al. 2021).

Adopting nutrient management practices like variable rate applications, split fertilizer applications throughout the year, and fertigation that integrates nitrogen application into irrigation management can improve the nitrogen use efficiency (Raun et al. 2002, Sanz-Cobena et al. 2017, Wu et al. 2019). Use of efficient practices like these, and minimizing overall inputs, plays a valuable role in minimizing leaching, preventing runoff, and protecting clean drinking water for residents of the Central Coast and Central Valley of California (Balazs et al. 2011, Burton and Wright 2018).

3.1 Nitrogen Management Policy in California

Nutrient management in California is governed primarily by the Irrigated Lands Regulatory Program (IRLP) implemented by the Central Valley and Central Coast Regional Water Quality Control Boards. Initiated by the California Legislature in 1999 (Senate Bill 390), the IRLP has evolved into water coalitions that attempt to achieve nutrient management goals at the watershed level with minimum field-level regulations. Growers are required to submit annual Irrigation and Nitrogen Management Plans and 5-year Farm Evaluations to their coalition, and monitor On-Farm Drinking Wells. The nitrogen management plans detail what practices growers use, including irrigation practices that may influence nutrient pollution, as well as planned nitrogen application rates and anticipated crop irrigation. In theory, these information-based requirements will incentivize growers to improve nutrient management efficiency. But environmental groups have argued that the ILRP should mandate specific field and crop-level

nutrient application rates. For example, the Central Coast program has traditionally been a stricter program and includes quantitative targets for nitrogen applied.

3.2 Case Study: The Nitrogen and Irrigation Initiative

The NII is a partnership between the California Department of Food and Agriculture and University of California Cooperative Extension, with a program evaluation team based at UC Davis. The program's main goal is to improve nitrogen and irrigation management by facilitating the AIS function of knowledge diffusion. To achieve this goal, the program facilitates interactions with innovation brokers through grower meetings and on-farm consultations provided by county-level staff (Staff Research Associates) hired to implement the program. The hired staff complemented the existing University of California extension professionals working in the targeted counties, shown in Table 2.1.

Table 2.1: NII Target Counties

Counties	Funding
Santa Cruz, Monterey	CDFA FREP funding approved by Fertilizer Inspection Advisory Board (FIAB)
Santa Clara, San Benito	CDFA FREP funding approved by Fertilizer Inspection Advisory Board (FIAB) and Federal USDA Specialty Crop Block Grant
San Joaquin, Stanislaus, Merced, Madera, Tulare, Kern	Federal USDA Conservation Innovation Grant and CDFA FREP funding approved by Fertilizer Inspection Advisory Board (FIAB)
Fresno	Federal USDA Conservation Innovation Grant, CDFA FREP funding approved by

	Fertilizer Inspection Advisory Board (FIAB), and Federal USDA Specialty Crop Block Grant
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4 ASSUMPTIONS

The key assumption of the NII is that interactions with innovation brokers will increase knowledge diffusion. The assumption is backed by a range of existing research: Bates and Arbuckle (2017) find that farmers with higher connectivity to agricultural organizations and social networks exhibit greater diversity in nutrient best management practices. Baumgart-Getz et al. (2012) find that extension training increases farmer adoption of best management practices. Lubell et al. (2014) find that innovation brokers are more effective when they are connected to networks embedded in the broader innovation system. Thus, to address the structural limits on knowledge diffusion (starred components in Figure 2.1 based on the process of Wieczorek and Hekkert 2012), BOTG programs seek to increase the number of innovation brokers and interactions between growers and innovation brokers.

4.1 Applying the Logic Model

Table 2.2 summarizes how we apply the logic model to the evaluation of the case study. Each row of Table 2.2 refers to an element of the NIFA logic model for which we have collected empirical data. The goal of the analysis is to evaluate whether the inputs created by the NII program translate into program activities and outputs, and grower-level outcomes.

Table 2.2: Evaluative Criteria for the Nitrogen and Irrigation Initiative and Supporting Data Sources

Logic Model Component	Subtopic	Consultation Case Logs	Grower Meeting Surveys	Qualitative Data
Inputs	Staff Availability			X
	Staff Capacity			X
	Coordination			X
	Available Knowledge			X
Activities	Scope of Activities	X	X	X
Outputs	Participants Reached	X	X	X
Outcomes: Knowledge	Learning Experience	X	X	X
Outcomes: Actions	Behavioral Outcomes	X	X	X
Outcomes: Conditions	Difference of Scale			X
External Factors	Incentives and Compliance			X

5 DATA

The program evaluation data come from three sources: 1) surveys administered at grower meetings, 2) case-logs completed by county-extension professionals for each on-farm consultation; and 3) key informant interviews with UCANR staff and other NII project partners, as well as growers and consultants who attended NII meetings. We include in this analysis all

consultations and grower meetings held until July 31, 2025, corresponding to the original end date of the program.¹⁰

5.1 Grower Meeting Surveys

Grower meetings began in November 2022 and continued throughout the duration of the project. A total of 105 meetings were held, and participant surveys were deployed at 34 of these. Of the grower meetings, 55 involved meetings hosted or co-hosted by the NII, 34 involved NII staff giving invited talks at a meeting hosted by another party, and 13 were other events. The grower meeting-level response rate varied from a minimum of 0% to a maximum of 100%, with a mean of 31% and a median of 27%. Among all 34 meetings at which the survey was deployed¹¹, the overall response rate was 411/1642, or 25%.

To maximize consistent instrument deployment, surveys at non-NII hosted events were distributed at the end of the NII staff member's presentation, while surveys for NII-hosted events were distributed at the end of the meeting. Among the 411 meeting attendees who responded to

¹⁰ One of the three grants received a no-cost extension until Spring 2026, but since the other two funding sources expired in Summer 2025, this was kept as the data collection cut-off for the purposes of this evaluation.

¹¹ An attendance estimate was unavailable for three meetings, which are excluded from the response rate calculation.

the survey were 271 farmers or farm managers, 117 consultants (including 59 who were also farmers), and 33 others.

5.2 Grower Consultation Case Logs

According to case log data, farm advisors and SRAs conducted 382 consultations with clients, 300 of which were held in-person, and 82 of which were held remotely, such as over the phone. Clients included 131 farmers or farm managers, 16 consultants (5 of whom were also farmers), and 25 other individuals, representing a total of 167 individuals at 150 farms. Hence some clients received multiple consultations. Case logs were completed by an NII staff member as soon as possible after each virtual or in-person consultation.

5.3 Key Informant Interviews

The lead researcher conducted a total of 42 interviews with 45 key informants chosen to represent the two main project areas of the NII: the Central Valley and Central Coast (Table 2.3). These included 25 extension staff and project partners, such as water coalition staff, as well as 19 growers and farm company staff who participated in the NII program. These formal interviews were complemented by participation observation at grower meetings, along with ongoing project team meetings involving the authors, NII staff, and NII stakeholders. These data are used primarily in the Inputs results, but key insights are also included for the other results sections. Illustrative quotes and a summary of main results for all logic model sections are included in Appendix I.

Table 2.3: Key Informant Interviews by Region

	Extension Staff	Project Partners	Growers	Grower Staff/Ag Company Staff
Central Valley	11	4	13	2
Central Coast	5	1	3	1
Multi-Region	3	1	0	0

6 METHODS

Results from each grower meeting and each case log were cleaned in R, compiled, and analyzed to assess key trends. Grower meeting responses were additionally merged with spatial and tabular meeting metadata. We include summary tables, maps, and graphs from these sources, as well as statistical tests for certain analyses. Key informant interviews with 45 informants were coded qualitatively and validated; details on this process are available in the Appendix (Table I2).

We include a summarized synthesis of interview data, with illustrative quotes appearing in Appendix I. When quotes are included, we note the type of respondent, but not the participant number or county, as this could jeopardize anonymity for the small group of extension staff and project partners.

7 RESULTS

The following sections summarize the key findings for each element of the logic model, using the statistical methods appropriate for the type of data. Table I3 in the Appendix has a summary of all results.

7.1 *Inputs*

We provide qualitative information about the challenges involved with four main inputs: staff availability, staff capacity, coordination, and available knowledge. The NII faced challenges in staff availability because it was difficult to find and retain the junior staff members (SRAs) hired to implement the project at the county level. This was partly because industry can pay higher wages for people with the appropriate technical knowledge, and also because the longer-term career trajectories of SRAs are unclear. The project timeline and slow start inherent in large, collaborative projects also presented challenges for hiring. This dynamic influenced the efficacy of advisors in the field, as growers are less likely to trust someone they perceive as a revolving door.

The NII faced challenges in matching staff capacity with the specific tasks involved with NII implementation, but this varied for junior versus senior staff. Advisors noted that SRAs were helpful for complementing their existing NII outreach, but the rapid hiring and retention issues prevented the SRAs from developing adequate local expertise and grower relationships. This is especially true for a grant-funded program with a limited lifespan. Building recognition and trust with growers takes years, which limits the influence of even highly skilled assistants.

CHAPTER 2: BOOTS ON THE GROUND

Senior staff had differing skill sets influencing their capabilities. One advisor noted that since they were a subject matter expert, the NII expanded the type of work they already did. However, multiple advisors expressed that the type of irrigation-focused work they were expected to do under the NII was not a strength of their expertise and reduced their availability for other technical advising.

Carrying out a program like the NII requires internal coordination during project design and implementation as well as external coordination with partners. The project was largely designed by a core team based on their experience with growers and other AIS actors. Multiple respondents lamented a lack of early input from the county-level advisor teams, which resulted in a lack of clarity about program expectations and a program design that was not completely congruent with the goals, incentives, and capabilities of program staff. These issues translated into internal coordination challenges in terms of data collection and delivery of a common NII curriculum at grower meetings and consultations.

There were also external coordination challenges, especially with the coalition groups responsible for implementing the ILRP. These coalition groups and their consultants are required to provide outreach and education as part of their programs, informing growers about regulatory program requirements and on-farm nutrient management. While NII advisors did co-hosted events with water coalitions, these were not strategically coordinated at the overall project level.

In terms of available knowledge, advisors provided guidance based on existing agricultural research and the field experience of the advisors. The availability of local expertise is the primary strength of the UC Cooperative Extension and basing the NII program with

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existing county-level staff. However, there is not complete consensus on the efficacy of different irrigation and nutrient management practices for increasing nutrient management efficiency for different types of crops. One advisor remarked that even though there were valuable tools for nitrogen timeline planning for nut crops, the high reliance on accurate yield estimates to determine the appropriate nitrogen application increases the difficulty of long-term planning for growers. There also may be a disconnect between members of the farm staff, since the one who develops the plan is not necessarily the one who implements it, especially on large operations. Irrigators are usually the lowest paid employees on the farm and do not always have training on efficient irrigation management practices.

All of these challenges improved over time, which points to the importance of learning in the evolution and effectiveness of any program. For example, a “Train the Trainer” workshop was held in 2025 to teach extension staff how to instruct others in the use of a digital water management software, and NII staff continued to build internal and external relationships for coordination. In later years of the program, staff members with more nitrogen and irrigation experience hosted skills workshops for staff members in other counties with less experience and trained them on the use of bespoke monitoring equipment. However, we expect these input challenges will be experienced by any BOTG program, so considering them earlier in program planning and design should speed learning and mitigate the costs of the problems.

7.2 Activities

Our analysis of activities includes 411 participant survey responses across 34 grower meetings and 382 post-consultation reports filled out by extension staff. The meeting surveys include questions about learning, participants' experience at the meeting, adoption plans, and demographic information. The consultations cover information about the crop and topic discussed and the advisor's assessment of client responsiveness to their advice. In total, 105 grower meetings fell under the NII umbrella, covering both the Central Valley and the Central Coast (Figure 2.3), with over 4,500 participants.¹² Median meeting attendance was 34, with a mean of 48, maximum of 240, and minimum of 1. Based on self-report in the grower survey, the average meeting participant traveled 29.4 miles to attend. Meeting locations were typically chosen based on convenience and known social gathering places in target counties. However, survey participants were concentrated in the Central Valley, since Central Coast projects were not required to deploy the NII survey for grant reporting purposes.

Grower meeting survey respondents reported discussing a wide range of practices (Figure 2.4), which with the exception of cover crops, were discussed at a similar frequency to the rate at which nitrogen management practices are adopted in the Central Valley (Prakash et al. 2025) and on the Central Coast (Table I1). Nitrogen-related practices (use of a nitrogen budget, testing for

¹² Based on actual or estimated attendance for each event. If the same person attended multiple meetings, they would be counted multiple times, once for each event.

N in irrigation water, soil testing, and leaf sampling), are overrepresented among meeting participants and at program meetings compared to the uptake among growers in general, indicating that meeting participants use these practices more commonly than the typical grower, and that meetings are targeting practices that are not already ubiquitously adopted by the general population.

The consultations were held throughout the Central Valley and Central Coast (Figure 2.5), but more concentrated in the Central Coast. In contrast to the more general growing meeting topics, consultations were often designed to collect monitoring data, help optimize site-specific irrigation equipment and timing, and provide support on CropManage software, which is designed to facilitate irrigation and nitrogen management decisions (Figure 2.6).

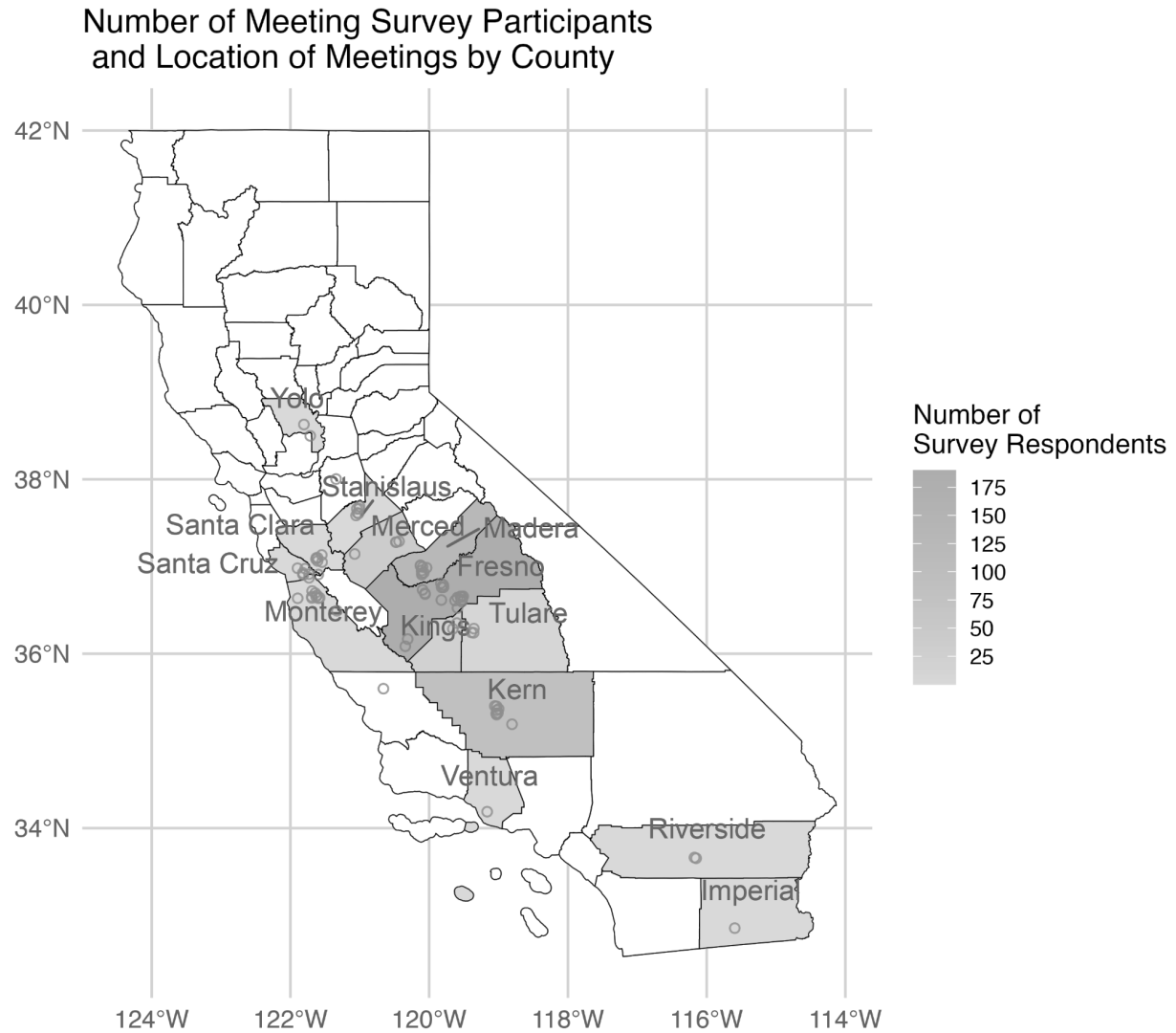


Figure 2.3: Number of Meeting Survey Participants and Location of Meetings by County

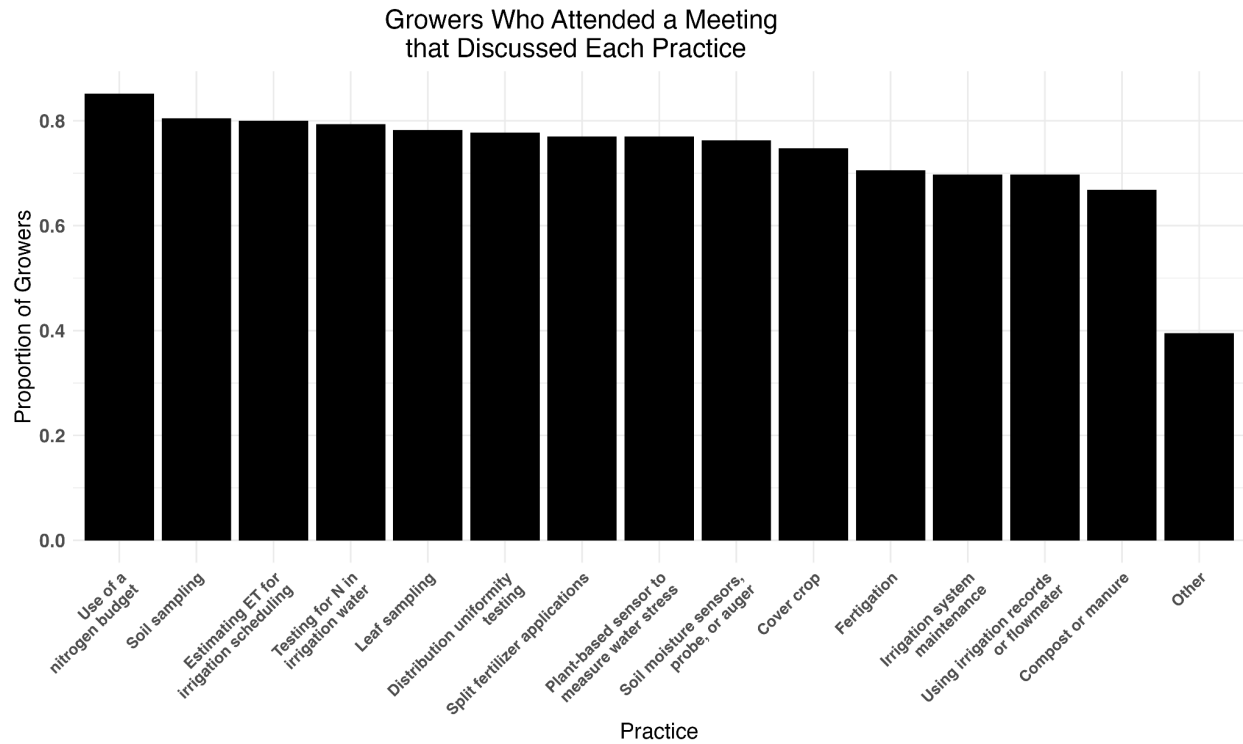


Figure 2.4: Proportion of growers who attended a meeting that discussed each practice, according to grower meeting surveys

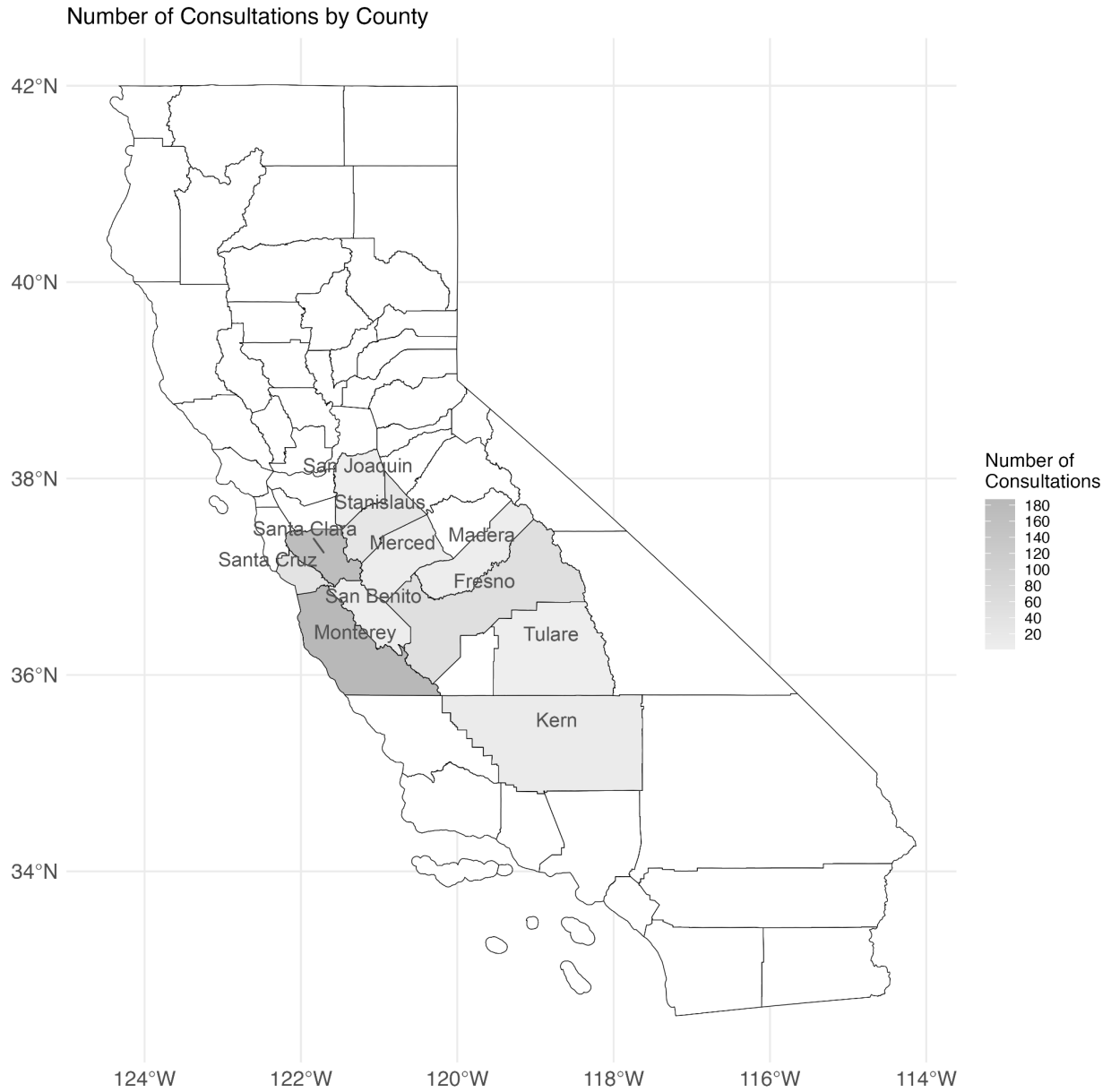


Figure 2.5: Number of Consultations by County

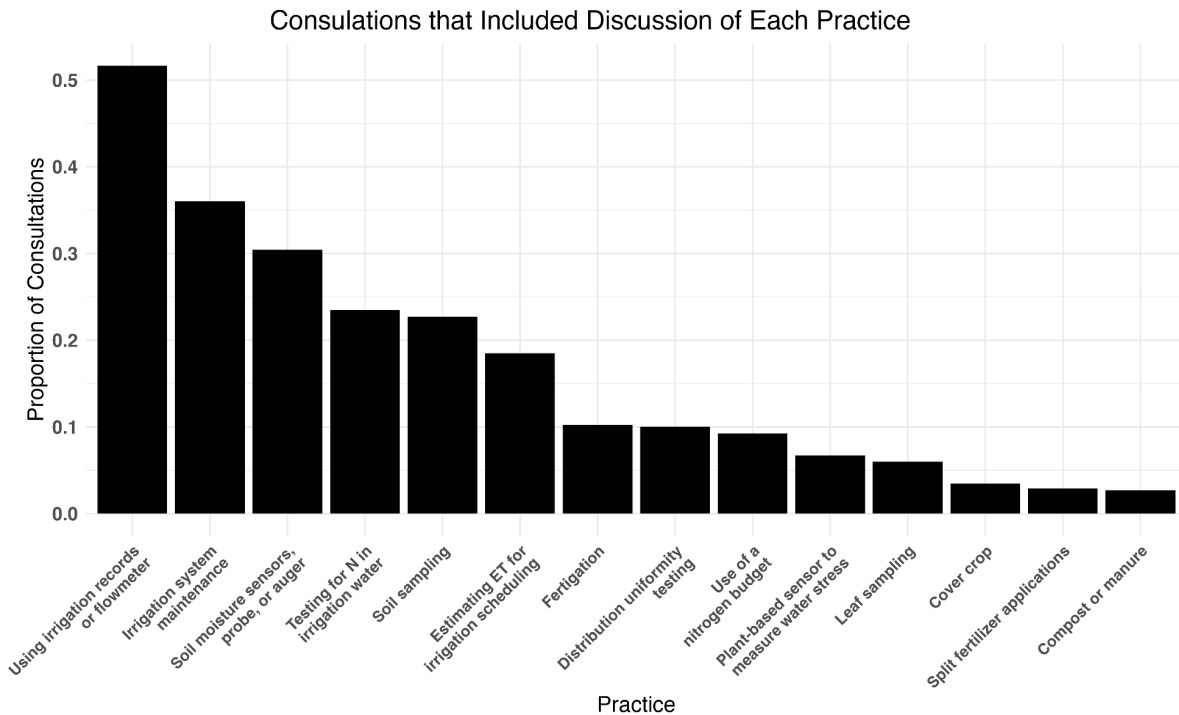


Figure 2.6: Proportion of consultations that discussed each practice, according to case logs

The key informant interviews revealed significant challenges with implementing these activities. It was difficult to design a common curriculum for growers with different experience and interests. Some growers wanted a general overview of nitrogen and irrigation management while others had more specific questions, which might be addressed in a consultation. One advisor described approaching this dilemma by designing their meetings to have something for everyone, but this strategy also risked information overload. Many respondents noted the limits of the lecture style of grower meetings, and recommended “Learn by Doing” strategies such as field days, applied demonstrations, hands-on instruction with a piece of equipment, or incorporation of testimonials from growers who have implemented the practice. However, while

consultations did provide more hands-on instruction, there was not always follow-up to assess whether grower meetings or consultations translated into lasting behavior change.

7.3 Outputs

The USDA-NIFA logic model includes the characteristics of the types of participants reached as an important output. Overall, NII participants were representative of the types of crops and farm systems in each region. Most grower meeting respondents grew perennial crops such as nut trees using drip irrigation (Figure 2.7), and reported a diversity of farm sizes, ranging from less than an acre per crop to over 5000 acres for a single crop (Figure 2.8). The grower meetings participants represent the agronomic diversity of the Central Valley as measured in other statistical analyses such as the USDA Agricultural Census. In contrast, NII consultations were focused more on specialty crops or perennials (Table 2.4). This reflects the high proportion of consultations on the Central Coast, which focuses on specialty annual crops.

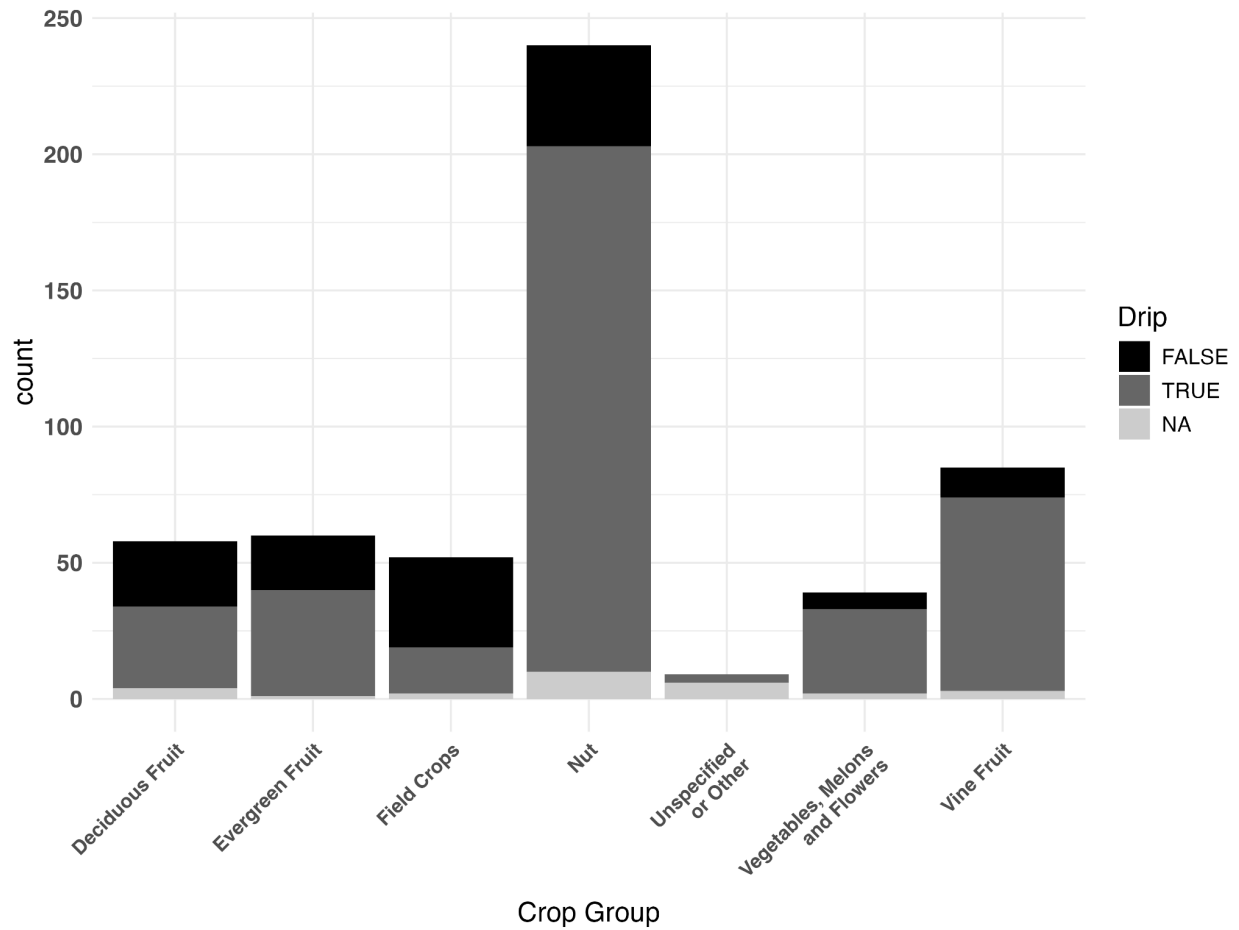


Figure 2.7: Count of growers' top six crops, by crop group, and their associated irrigation practice, according to grower meeting surveys.

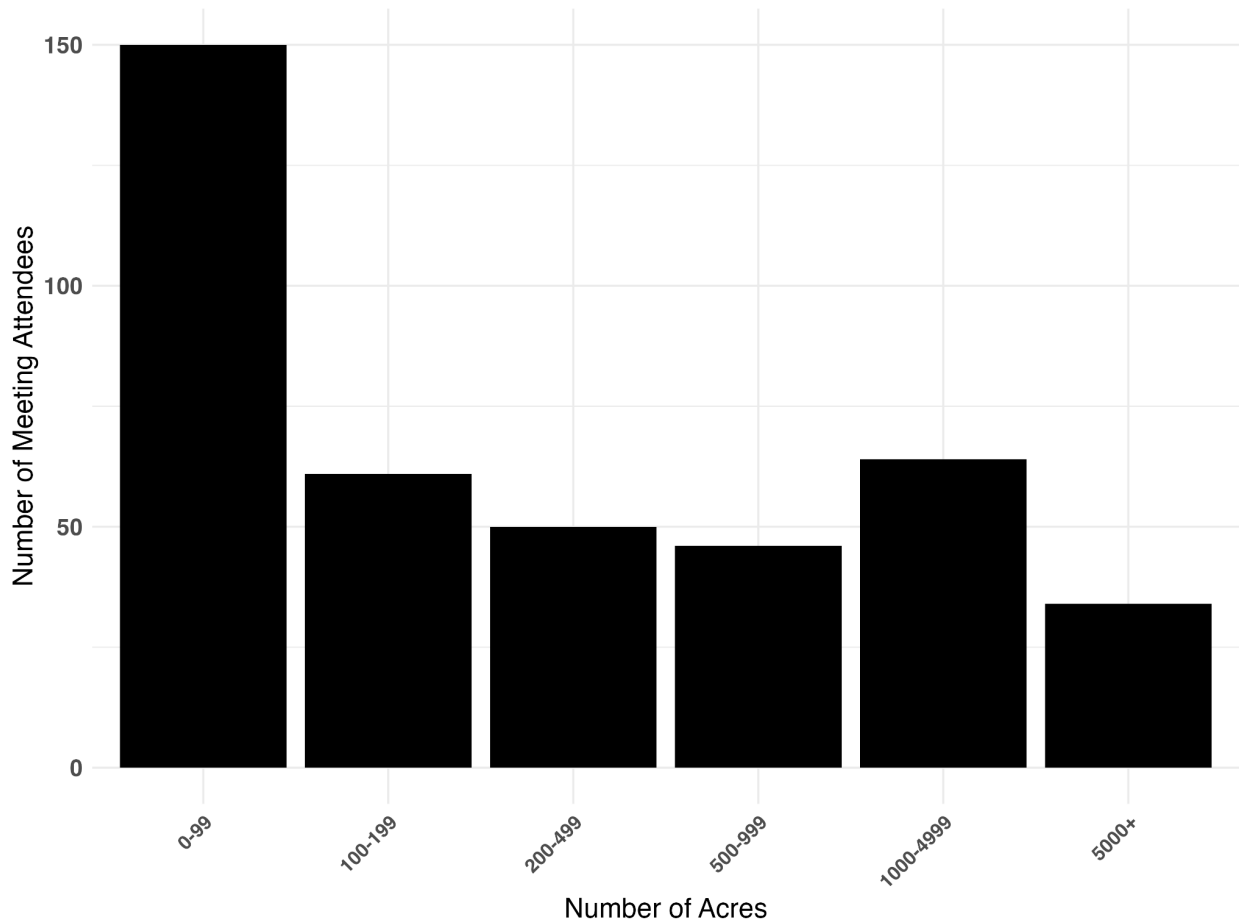


Figure 2.8: Number of acres growers report for each crop, according to grower meeting surveys

Table 2.4: Number of Consultations by Crop Group, according to Case Logs

Crop Group	Number of Consultations
Vegetables, Melons, and Flowers	245
Nut	75
Unspecified or Other	33
Fruit Vines	23
Field Crops	3
Evergreen Fruit	3

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Participation in the NII was influenced by farm scale. One Central Valley informant explained that large growers do not use extension as often because they have their own staff and consultants. However, a Central Coast informant said that services related to the irrigation and nitrogen management software CropManage were more highly adopted by large growers, who need support juggling decisions on many fields. Small, diversified farms also benefitted from NII services because they may not have the capacity to manage the administrative requirements of the IRLP, or may face significant language and cultural barriers. Two staff members explained that they are the only service in the agricultural sector who provides water testing and soil nitrate testing services to non-English speaking growers in their region.

The diversity of crops and farm sizes is a feature of California agriculture that challenges all extension programs. County-level extension professionals are valued for their knowledge of the local agroecological system. It is difficult for new staff hired for the NII to quickly develop local expertise and relationships, and the loss of local staff degrades overall extension capacity. For instance, there was only one NII advisor in the Central Valley specializing in vegetables. Also, despite having an initial goal of focusing program activities on locations or individual growers with high levels of nitrogen application, the NII program reached the typical audience of engaged growers in each county.

7.4 Outcomes

This section presents results for three outcomes that are often of most interest in an evaluation: knowledge, practice adoption behavior, and changes in conditions. In terms of

knowledge, the majority of grower meeting participants reported either learning a little bit or a great deal about irrigation management, nitrogen management, and how nitrogen and irrigation management interact (Figure 2.9). “Strongly Agree” was the modal response to questions about the applicability, clarity, and positive learning environments of the meetings (Figure 2.10). Similarly, case logs show that NII staff perceive their clients to be highly open to the ideas they discussed, and highly valuing the information provided (Figure 2.11).

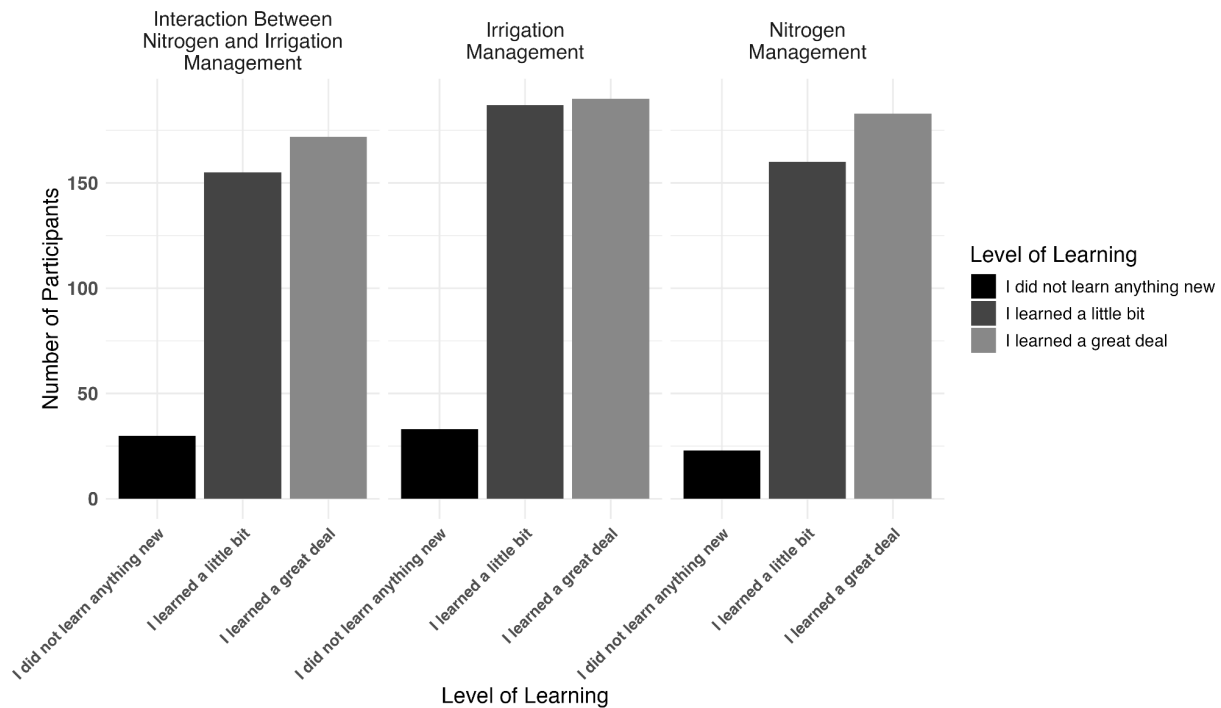


Figure 2.9: Reported Learning among NII Event Survey Participants

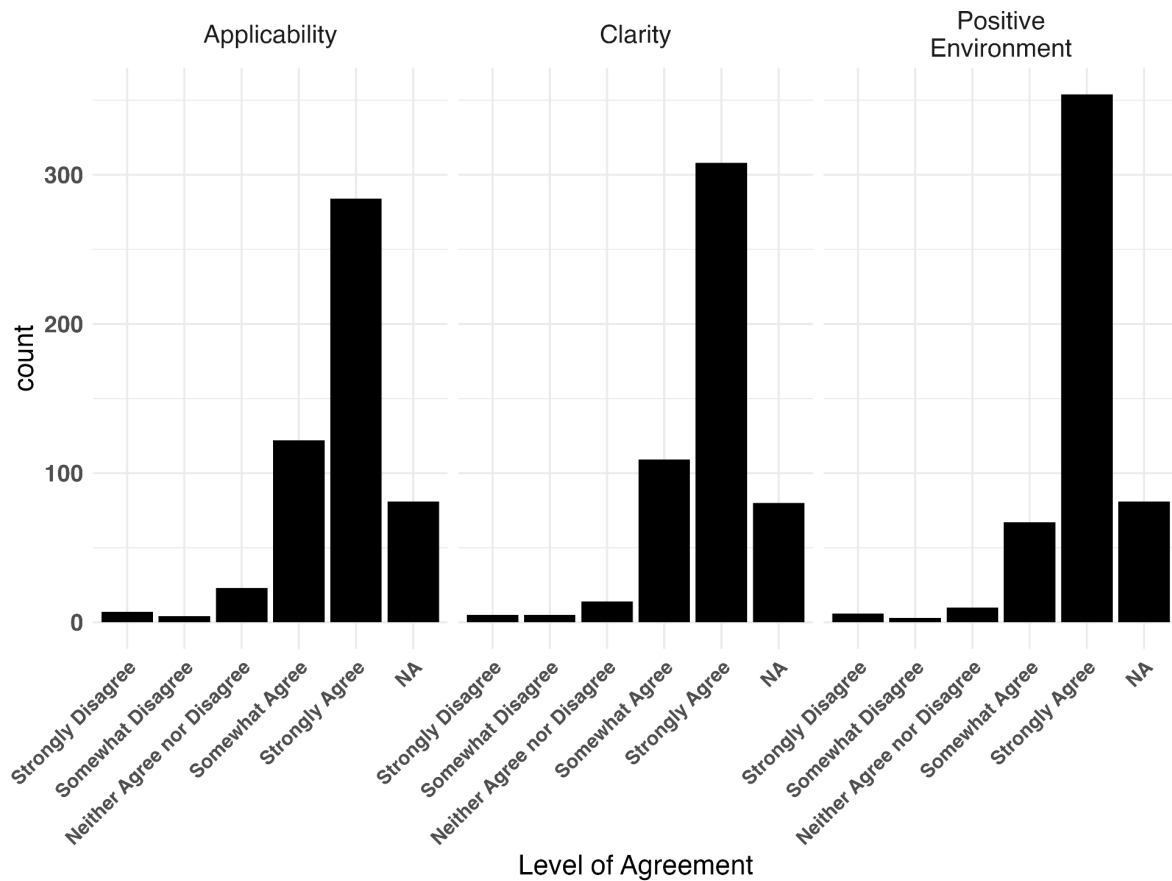


Figure 2.10: Count of grower meeting survey respondents who reported each level of agreement with the following three statements, respectively: 1) Instructions were clear about how to apply the information to my setting. 2) Information and guidance were presented clearly. 3) The cooperative extension staff created a positive learning environment.

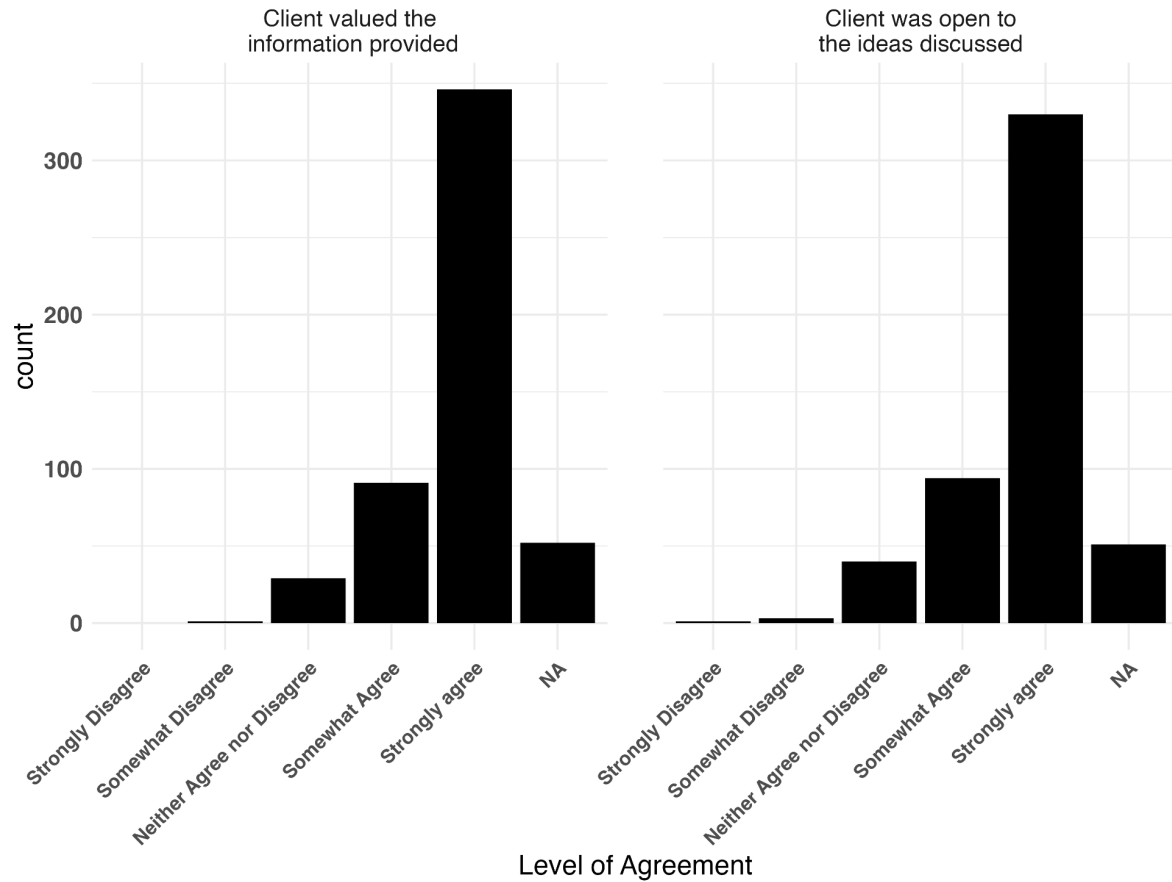


Figure 2.11: Advisors' level of agreement with statements that their client was 1) open to the ideas they discussed, and 2) highly valued the information provided, according to case logs

Interview participants offer a more ambivalent picture, expressing that many growers are not interested in guidance on irrigation and nitrogen management and are confident in their current methods. This means that as with all voluntary extension meetings, there may be selection bias where growers who participate in meetings or ask for consultation, are more open to learning than non-participants. We do not have any information on non-participants that

allows us to assess the extent of any selection bias. Conversely, there were also reports about how much growers appreciate meetings and farm calls. Some participants reported that the guidance of advisors at NII meetings convinced them to reduce their irrigation. Hence, although we cannot statistically estimate the “treatment effects” of any particular meeting, we do have anecdotal evidence that the NII produced changes in knowledge.

In most agricultural research, a key interest is behavioral change and whether the knowledge gained through meetings is translated into lasting on-the-ground practices. The survey design attempted to distinguish between growers who do not use one of the practices discussed in the meetings, versus growers who already use the practices. Figure 2.12 shows that of the growers who do not already use a given practice, many plan to adopt that practice as a consequence of what they learned at the meeting. The “plan to adopt” response follows roughly the same order as practice adoption rates shown in previous studies (Khalsa et al. 2022, Rudnick et al. 2023; Rudnick et al. 2021) from over 60% for irrigation management to around 30% for plant sensors. For the less frequent practices, most growers do not intend to change their behavior, but a fair proportion do want more information.

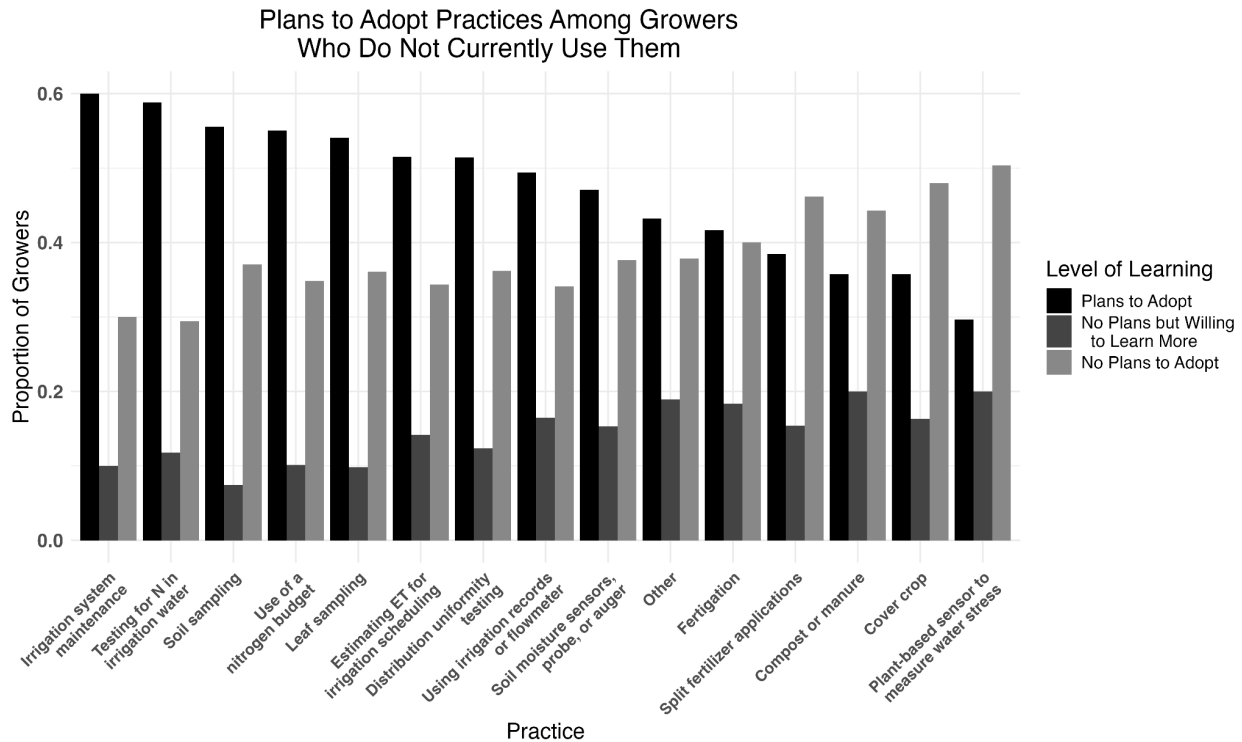


Figure 2.12: Grower meeting survey respondents who plan to adopt each practice, as a proportion of respondents who do not currently use the practice

In contrast, Figure 2.13 suggests there is substantial learning among growers who already implement a particular practice. This is a different type of outcome than typically considered in agricultural decision research, in which the usual question is whether practices are adopted or not. Instead, the NII appears to have improved growers' capacity to effectively implement the practices they have already adopted. An analogy we found useful for explaining this outcome is to think of growers as musicians playing a musical instrument like a guitar—it might be hard to get them to switch instruments, but they are open to improving how they play the guitar.

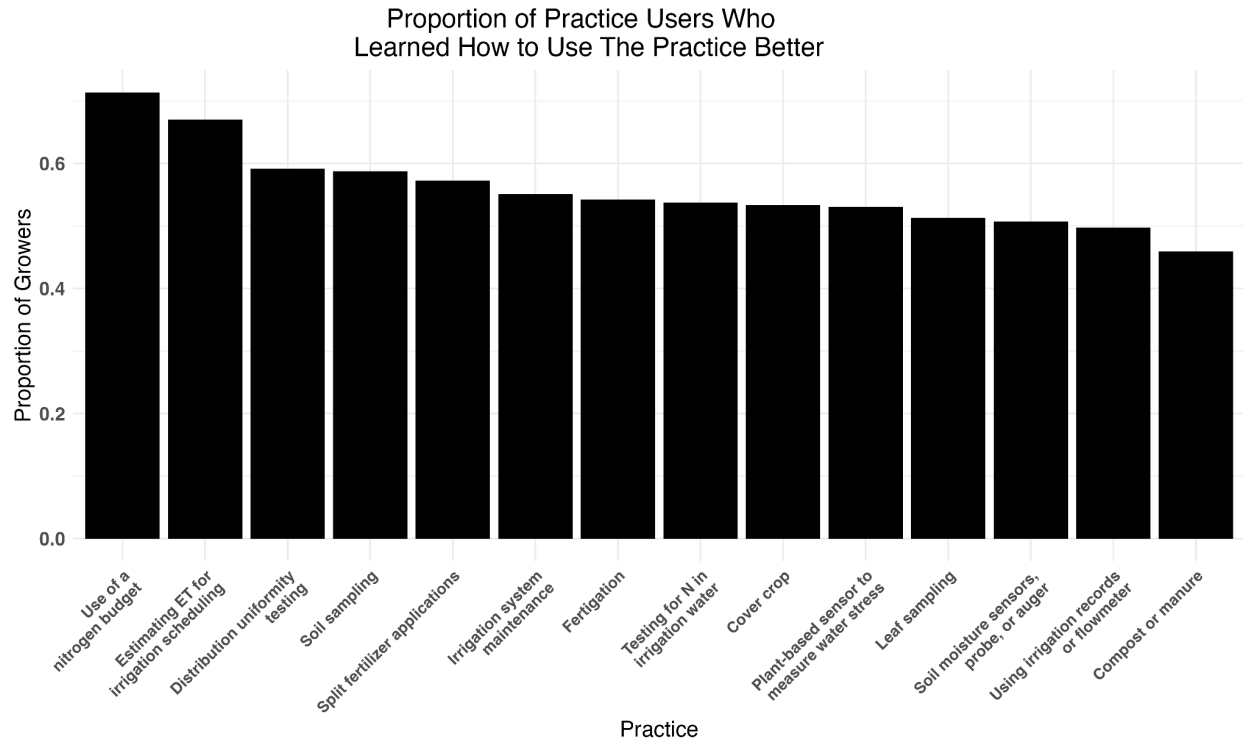


Figure 2.13: Proportion of practice users who learned how to use the practice better, according to grower meeting surveys

The consultation picture is similar – in case logs, advisors reported a high level of agreement that clients were likely to adopt their recommendations (Figure 2.14). However, it is important to remember that growers invited the consultants to visit because they needed help, which means they were open to learning from the outset. Furthermore, the case logs represent the consultant’s perception of the grower’s attitude towards learning, which is vulnerable to an optimistic bias.

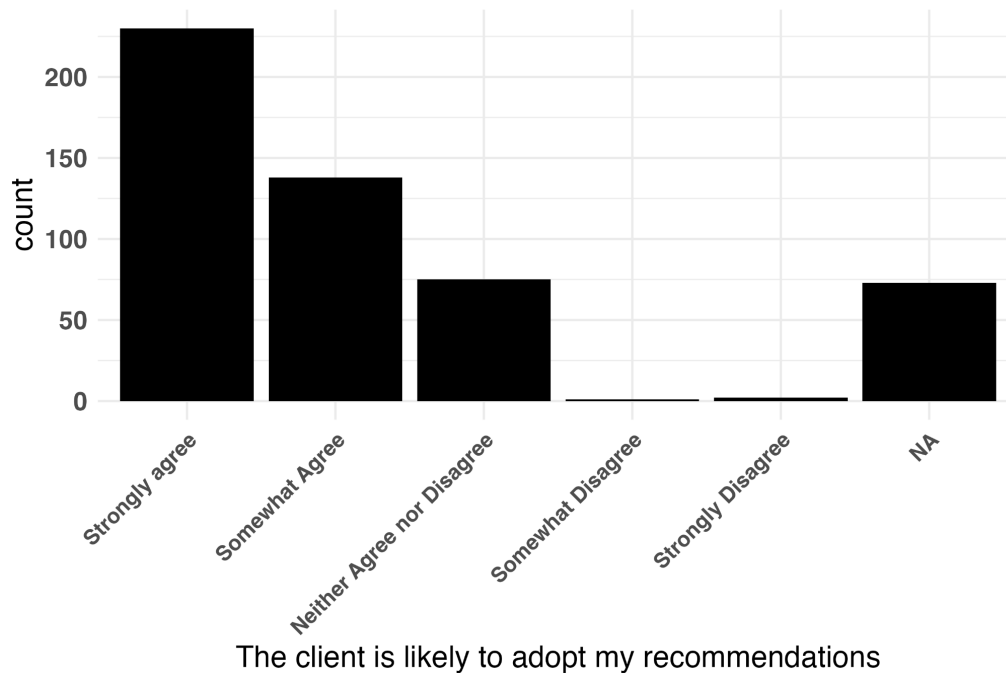


Figure 2.14: Advisors' level of agreement that their client was likely to adopt their recommendations, according to case logs

The final outcome to consider is whether the NII changes the conditions being targeted, which here means reducing overall rates of nitrogen pollution and water use. As is common with many programs, we have no information about outcomes, and it is difficult to attribute societal or ecological impacts to a particular program (Horton and Mackay 2003). The short duration of the NII program may not produce enough changes in grower knowledge and behavior to improve conditions that change over long periods of time. To make a larger impact on broader system conditions, programs like the NII must go beyond considering practice adoption as the end point, and instead think about the complexity of agricultural management across diverse types of farms (Rudnick et al. 2021). For example, interview respondents cited multiple barriers to adoption: the variation of irrigation and nitrogen management decisions across fields, constraints of water

availability, lack of trust in university extension, and concerns about impacts on yields. These barriers change over the long term and require sustained investment in extension capacity.

8 DISCUSSION: IMPLICATIONS FOR INNOVATION SYSTEMS

To integrate AIS with program theory, this paper argues that the NII is an instrument designed to improve a specific structural aspect of an AIS linked to a functional goal (Wieczorek and Hekkert 2012.) In this case, the functional goal is knowledge diffusion and the structural component is the availability of “innovation brokers” and their interactions with growers. However, this framing does not articulate a program theory that links inputs to outputs, and thus we utilize the NIFA logic model to organize our evaluation. Our evaluation indicates that grower meetings and consultations produced positive outcomes in terms of knowledge and practice adoption behavior, but we cannot claim any changes in overall conditions. Changing conditions requires long-term investment and reaching segments of the grower population that may not be as eager to adopt new practices (either in general or in irrigation and nutrient management in particular) or open to participating in extension or learning. Notably, the NIFA logic model recognizes the pragmatic challenges with measuring overall conditions and being able to reliably attribute changes to program effectiveness, so it does not require assessment of impact on system conditions for short- and medium-term projects.

We also found that external factors are also important constraints on effectiveness. In the NIFA logic model, external factors influence overall conditions, and as such ought to inform program input design. This intervention was focused on getting boots on the ground, with little

program-level strategizing at the outset for how external factors influence “which boots” can and ought to be sent out, and onto “which ground.” External factors also link the program back to AIS theory, as the NII intervention is nested in the broader innovation system and cannot be considered in isolation. Although programs embedded within an AIS don’t necessarily need to address every functional and structural component of the system to achieve their intended effect, other structures within the system may influence the success of the intervention. For instance, though promoting innovation broker presence and interaction presence were the main strategies in this case, other structural weaknesses from the menu of Wieczorek and Hekkert (2012) reduced its effectiveness.

Based on the interviews, the key factors that constrained effectiveness are 1) the regulatory environment for nitrogen management in California; 2) mobilization of professional expertise; and 3) trust in extension. Each of these factors are associated with a particular goal and structure of the AIS that was not prioritized in the design of the NII program, as described below:

8.1 Regulatory Environment

In terms of the functional-structural framework of Figure 2.1, the regulatory environment relates to the function of “guidance of the search” and the structural problem of capacity of institutions. In other words, regulations in part serve as forces that incentivize and stimulate innovation and adoption of new practices. In this case, uncertainty regarding the regulatory future and lack of regulatory incentive in the Central Valley limited interest in the NII. Extension staff varied in their perspectives on regulatory incentives. One advisor believed that making

mandatory standards for nitrogen and irrigation management would be ineffective, not necessarily out of willful noncompliance but out of necessity or accidental misuse of practices. Other extension staff favored mandating education and/or nitrogen or irrigation limits, noting that this would also increase use of their services. One advisor noted that although there are existing rules against over-application of nitrogen, these are not well enforced. Multiple participants, including one grower and one advisor, also reported suspicion about false reporting. On the Central Coast, growers and extension staff generally agreed that although the regulatory application targets are achievable now, the limits that would have been required by 2041 and 2051 before they were repealed would have been nearly, if not entirely, impossible for the multi-crop vegetable systems common to the region.

8.2 Mobilization of Professional Expertise

Although the program specialized in getting boots on the ground to educate farmers (building actor presence for knowledge diffusion, in the Figure 2.1 framework), it was not specifically strategized towards improving the function of “resource mobilization;” specifically, enhancing the system’s ability to get the right boots in the room. Improving mobilization of human capital is an entirely different AIS function than knowledge diffusion, which the NII was primarily designed to enhance. So, although part of the NII was hiring new staff, their effectiveness was limited by structural inefficiencies relating to resource mobilization, as the NII funding geared toward hires funded on a short-term grant mismatched the needs and strengths of the extension system. The limited number of nitrogen and irrigation experts within the broader

extension system then impacted the inputs to the program in terms of staff and the resulting service provision.

The AIS is often used to diagnose systemic failures after the fact—such as the resource mobilization problem here—but not as commonly to anticipate failures. However, the logic model provides a mechanism for anticipating failures by applying the linkage between situation and inputs to inform program design. The resource mobilization challenges could have been recognized and mitigated by thinking more critically and collaboratively about the human resources inputs available (“which boots”) and the suitability of the financial inputs to the broader situation. After identifying a potential problem with the program design, one can return to the AIS for prescription of supplementary instruments to enhance the program. In this case, the structural limitations constraining resource mobilization may have been ameliorated through stronger initial collaborations with actors outside of extension, greater initial investment in training for short-term program staff and advisors with little prior nitrogen and irrigation experience, and/or redirection of funds for short-term program staff to support program-level partnerships with external professionals. The expertise of extension staff and other interested parties is valuable here, as they have an experiential understanding of their role and limitations in the agricultural system.

8.3 Trust in Extension

The final challenge also stems from a function beyond the goals of the BOTG instrument: creation of legitimacy. Gaps in the institution of trust (see Cronin et al. 2022) influenced

program success. Part of this is beyond the program's control: staff members have no bearing, for instance, on clients' political preferences and are only a small part of the broader pattern of the client's experience with extension services over time. However, choices in program design can exacerbate or alleviate broader problems with trust. For instance, the connection of program staff to the public university was polarizing—appealing to some growers but repelling others who distrust state institutions and resent state regulation—and high turnover of individuals further harmed institutional trust. Some program staff addressed this challenge by focusing their energy on growers with high buy-in. These are not necessarily the growers with the highest need; however, BOTG programs need to consider “which ground” the available boots are best equipped to service.

8.4 Contextualizing BOTG Programs

The role of external factors in constraining program effectiveness highlights how any program that targets a particular component of an AIS cannot ignore the broader system. This tension between micro-level analysis of a program and macro-level feedback in the system is one factor that makes it difficult to integrate program theory and AIS and evaluate interventions like a BOTG program. Resolving this tension requires three ways of thinking about the link between the micro and macro components of AIS. First, program evaluations must analyze program effectiveness relative to the system-level constraints. Second, program design should consider how to manage system-level factors from the outset, to potentially mitigate barriers to success.

Third, programs should consider system-level interventions across multiple AIS goals and structures.

9 CONCLUSION

Our integration of program theory and AIS to evaluate a BOTG program provides practical and theoretical contributions. Practically speaking, we have evidenced that a BOTG program like the NII is effective in delivering short-term changes in knowledge and behavior for program participants. However, we cannot assess whether the program will change conditions in the long run or reach segments of the grower population that are less engaged with extension or inefficient with nitrogen and irrigation. We also point out important barriers to program effectiveness linked to inputs and external factors. Overcoming these limitations requires a longer-term program and sustained effort to increase extension capacity and adapting program structure to directly address weaknesses.

Theoretically, we demonstrate the utility of linking program theory to AIS by thinking about BOTG as an intervention in a specific structural component of an AIS, which is linked to a functional goal. Decomposing AIS into different structural components and goals thus provides an analytical strategy for program design. Yet at the same time, our analysis reveals the difficulty of targeting only a piece of an AIS without fully considering the broader system. The broader system components and feedback serve as external constraints that limit program effectiveness, and also illustrate the drawbacks of using innovation system theory to prescribe a single instrument design. The evaluation of this instrument from the lens of AIS theory is similarly

challenging: the singular structural and functional goal of the instrument is too narrow, as its effectiveness is influenced by other parts of the system, and yet for short-term projects, it quickly becomes unfeasible to conduct an evaluation of the entire agricultural innovation system. Thus, program theory, such as logic models, offers a complementary lens to facilitate design and evaluation of programs that target specific parts of an AIS on an appropriate scale, while taking into account the relevant aspects of the broader system context.

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CHAPTER 3

**ON-FARM CONSULTATIONS AS A PATHWAY TO LEARNING IN AGRICULTURAL
SYSTEMS: A QUANTITATIVE ANALYSIS OF EXPERT PERCEPTIONS**

With Mark Lubell and Sat Darshan S. Khalsa

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ABSTRACT

Farm consultations provide growers with valuable information, services, and expertise tailored for application on a farmer's own operation. Although they represent a key tool in agricultural extension programs, quantitative evidence of their effectiveness on a large scale is rare. In this study, we collect the post-visit reports of extension specialists from 601 farm consultations in California related to nitrogen and irrigation management, analyzing the specialists' perceptions of client receptiveness to guidance as an indication of the social capital and trust built throughout the consultations. Long-term clients have higher perceived receptiveness, as do in-person clients and clients whose primary language is one spoken by the advisor. Receptiveness is diminished for consultations concerning regulation, potentially due to a shift towards generalized institutional trust governing such interactions rather than personal trust. Perceived likelihood of adoption is lower than perceived openness to ideas, reinforcing scholarly

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evidence of a gap between positive attitude or intention and actual adoption. The results indicate that trusted relationships, as built through repeated, in-person consultations with good communication and site-specific guidance, multiply the impact of extension education and build the reputation of extension professionals among farmers as respected, locally knowledgeable experts.

1 INTRODUCTION

Within agricultural systems, extension services support learning and adoption of new practices and management strategies among farmers and farm staff (Lubell et al. 2014). Farm advisors employed by university extension services are key innovation brokers that translate research findings and knowledge developed in various parts of the agricultural system to farmers and help them adjust their strategies (Klerkx et al 2012). Key extension strategies include grower meetings and on-farm consultations, where extension professionals exchange knowledge and develop relationships with growers. On-farm consultations are considered particularly attractive because of the capacity to build strong personal relationships with individual growers, demonstrate how agricultural practices work in real-world production settings, access populations that may not attend grower meetings, and connect to local innovation networks. These advantages give consultations the potential to strengthen the impact of extension by cultivating grower trust and increasing grower confidence in the credibility of extension professionals and the applicability of their knowledge.

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The goal of this paper is to analyze the extent to which on-farm consultations catalyze receptiveness to incorporating and adopting expert guidance among participating growers. In the process, two primary contributions are made to the literature: first, this case deviates from literature focused on traditional grower meetings to explore individualized, site-specific advising from the lens of relational social capital. Although there is a great deal of research on grower meetings and of farmer perceptions of extension services in general (e.g. Prokopy et al. 2015; Hoffman et al. 2011; Kilelu et al. 2014; Batterink et al. 2010), there is a dearth of research on how on-farm consultations specifically may promote farmer receptiveness to new management ideas. Of the empirical case studies on consultation effectiveness that do exist, many are based on private sector consultations, whereas this case focuses on free consultations by public extension specialists.

Second, this case uses a novel data collection method of advisor perceptions of consultations. Farm advisor perceptions are a potentially valuable source of data as a form of expert judgement, but these perceptions are underutilized in literature about farmer receptiveness to consultation advice. This paper is, to our knowledge, the first academic research that analyzes advisor post-consultation reports. Using a collection of post-visit summary reports for 601 consultations related to nitrogen and irrigation management from April 2, 2022 to April 30, 2026, we model the effect of long-term client relationships and consultation topic on perceived receptiveness. The reports include extension specialists' perceptions of consultation visits and their clients' receptiveness to the ideas presented during the visit. This method showcases the

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utility of consultations, leverages expert opinion, and mitigates traditional data collection challenges associated with farmer surveys.

To guide our analysis, we draw on concepts of personal trust vs. generalized institutional trust (Lubell 2007; Kuehne et al. 2019; Ingram 2008; Fisher 2013; Nettle et al. 2022), particularly cultivation of personal trust over time (Vanneste et al. 2014; Coleman and Stern 2018), face-to-face interactions (Chivers et al. 2023; Rose et al. 2021), salience of government interference (Lubell 2007; Fisher 2013; Sutherland et al. 2013; Kalcic et al. 2014; Hoffman et al. 2011), and the role of shared identity (Moya et al. 2020; Lubell 2007; Matouš et al. 2013; Katungi et al. 2007) in promoting farmer receptiveness. These concepts ground expectations that long-term personal relationships, in-person visits, perceived distance from regulatory institutions, and shared language will be associated with consultation effectiveness. We analyze multiple dimensions of perceived receptiveness: openness to ideas, value of information provided, and likelihood of adoption.

Our evidence indicates that cultivating personal trust through repeated, in-person visits improves consultation effectiveness in all of these dimensions. Client receptiveness to guidance, as perceived by their extension specialists, is found to increase for subsequent visits, decrease for consultations regarding regulatory topics, and increase when the specialist can speak the primary language of the client. In agreement with existing scholarship, we also find that there is a gap between positive attitudes and adoption of the behavior. Extension specialists' assessments of the likelihood of their clients adopting their recommendations trails behind extension specialists' assessment of the openness of their client to the ideas provided in the consultations.

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The remainder of this paper provides background information on the role of extension in supporting client receptiveness to learning, a description of the consultation report data and multinomial models used for this analysis, presentation of the model results, discussion of the relationship between this study and the broader literature, and a summary of the analysis.

2 BACKGROUND: SOCIAL CAPITAL AND THE ROLE OF CONSULTATIONS IN EXTENSION SYSTEMS

Extension services function in agricultural innovation systems by connecting expertise to decision-making. A recent meta-analysis on the impact of extension services found that overall, they have positive impacts on outcomes such as practice adoption, farm productivity, farm income, and knowledge of practices (Ogundari 2022). Farmers commonly report that information sources such as extension impact their management decisions (Nowatzke and Arbuckle 2018). But the role of extension is not merely to transmit information in a formal education setting: experiential and social learning are more effective than formal learning in introducing growers to farm management information (Hoffman et al. 2015). Accordingly, relationality is a large part of what makes extension successful at the individual level. That is why some scholars have argued that building relationships is a primary goal of extension (Hoffman et al. 2015; Hoffman et al. 2011). Extension advisors play a key role in connecting technical expertise to decision-making at the individual level. These experts use a variety of outreach strategies to connect with growers, including public meetings, demonstrations, courses, and individualized private farm visits or consultations.

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The concept of relational social capital helps build expectations for consultation outcomes. Here Putnam's definition of social capital (1993) is used: "features of social organization, such as trust, norms, and networks, that can improve the efficiency of society by facilitating coordinated actions." As Agnitsch and colleagues (2006) explain, social capital encapsulates the phenomenon for well-connected individuals or groups to "mobilize other resources to pursue desired outcomes." In public administration literature, similarly, social capital is explained as a collection of "trust and norms of reciprocity, which helps cement cooperative relationships" (Henry et al. 2010). Often, social capital is examined at the network level or as motifs within a network (e.g. Berardo and Scholz 2010; Hamilton and Lubell 2019; Henry et al. 2011). But the flavor of social capital we mean here is relational, dyadic social capital developed between two parties over time. This is not intended to ignore network level effects, but rather to emphasize the "opportunity to cultivate interpersonal relationships and build reciprocal trust and respect" as itself a network-aware strategy operating at the individual level (Hoffman et al. 2015, p. 121). In a departure from an extension model geared primarily toward lecture-style educational events (Hoffman et al. 2015), long-term farmer relationships as cultivated through on-farm consultations are understood here as an investment in relational social capital to support the joint goals of innovation and learning.

Trust is not a one-size-fits-all component of social capital; people have different levels of trust for different relationships and contexts. Generalized disposition for being trusting, known as "generalized trust," impacts, primarily, infrequent relationships (Lubell 2007). On the other hand, social trust, involving contextual information and judgement about a specific person, is

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likely more important in frequent relationships (Lubell 2007). In an agricultural innovation system, as personal trust increases over time, individual relationships can transcend how actors feel about institutions. Personal relationships are much more likely to be considered “very helpful” sources of information than are organizations, based on a survey of California farmers (Hoffman et al. 2011). Across many contexts and crop systems, trust increases the influence of advisory services on farmer adoption (Cawley et al. 2023; Bard et al. 2019; Kuehne et al. 2019; Ingram 2008; Fisher 2013; Franz et al 2010). Personal trust has been found to impact the effectiveness of one-on-one farm consultation advice (Kuehne et al. 2019), especially for sustainability transitions and among farmers who have low institutional trust in government (Ingram 2008, Fisher 2013). These studies are based on interviews with a small number of farmers—30, 17, and 20, respectively—highlighting the value of quantitative data supporting the role of social capital in farm consultations (Kuehne et al. 2019; Ingram 2008; Fisher 2013).

Under the definition of social capital, trust is a resource that facilitates coordinated actions: trust between two parties makes it easier for them to work together. If trust is a critical prerequisite for these coordinated actions (a necessary condition, but not sufficient), one would expect the openness of farmers to the advice of an extension advisor to be strictly greater than their likelihood of actually acting upon the information provided. Alternatively, if there is no gap between trust and acting upon that trust (trust is both a necessary and sufficient condition for action), one would expect the level of openness to equal the likelihood of action. Finally, if trust is not a critical prerequisite (action can occur through other means besides trust), there may be no gap, or the likelihood of adoption may even exceed the openness to the ideas of the extension

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specialist. Though social capital theory gives us a causal link between trust and action, it does not offer clarity on which of these three scenarios are the case.

To develop expectations as to the gap between openness and adoption, we turn to other behavioral theories, namely the Theory of Planned Behavior and Diffusion of Innovations. Under the Theory of Planned Behavior, attitudes, subjective norms, and perceived behavioral control all jointly influence someone's intention to enact a behavior, and this intention, along with perceived behavioral control, influences whether one actually performs the behavior (Ajzen 1991). That is, a favorable attitude toward the behavior, as well as normative models indicating that the behavior ought to be followed, are a prerequisite for the actual action. Though not explicitly modeled in traditional formulations of the Theory of Planned Behavior, trust in authority figures who support and teach about the behavior can influence all three predictors of intention to adopt: the formation of favorable attitudes, understandings of subjective norms, and perceived ability to perform the behavior (Wollast et al. 2025). However, there is a significant gap between intending to adopt a behavior and actually adopting it; for instance, van Dijk et al. (2016) found that the combination of intention, perceived behavioral control, and an extended variable they called "group facilitation" only accounted for 5% of actual behavior. Thus, one would expect favorable attitudes or openness to adoption to be higher on average than an advisor's prediction of the client actually adopting the behavior.

Likewise, the Diffusion of Innovations recognizes a five-step process to adoption of technology. First, the grower must have knowledge of the innovation. Next, the grower must be persuaded of the benefits of adoption. Third, the grower must cognitively make a decision to

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adopt the technology. Fourth, the grower implements the technology, and finally, the grower receives confirmation of its effectiveness (Rogers 1962). Under this framework, forming a favorable attitude toward the innovation precedes adopting it, implying that openness is necessary for adoption.

Personalized advising is an approach to relational extension that can jump-start nodes of learning and adoption at the individual farmer level. On-farm consultation services are seen as a valuable part of the advising landscape with the potential to improve productivity and field-level management (e.g. Ehsan et al. 2022; Weaver 1996; Choi et al. 2023; Tomer et al. 2014). Farmers in a variety of U.S. agricultural systems report them as a prominent information source (Houser et al. 2018; Varble et al. 2016). Since the learning processes and needs of each farmer are unique and dynamic, individualized advising services can support growers by adapting to their current needs (Kilelu et al. 2014). The customization possible through farm consultations is part of the philosophy of Extension 3.0, in which the role of extension is to provide relevant information “to the right people, at the right time and place” (Lubell et al. 2014).

Though consultations can focus on a variety of topics, they share a few general characteristics. Extension staff offer one-on-one consultation services, or advising with a small group of staff at a single ranch, to discuss the particular set-up and challenges of their operation, offering tailored recommendations. Consultations are often conducted on-farm (“farm calls” or “farm visits”), but may include virtual support as well, such as through emails or phone calls. Consultations commonly start when a grower reaches out to an extension advisor for help with a specific problem; they can also stem from existing relationships with growers, such as when an

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advisor has previously collaborated with a grower on a research study or farm trial and has worked with them over time. Public extension staff offer their time as a free service and sometimes even provide monitoring equipment or testing equipment for free as well, funded by grants. Subsequent consultations may be scheduled by agreement to follow up on the results or data collected and to assess progress.

Extension succeeds by jumpstarting nodes of adoption with certain farmers, but extension professionals do not necessarily directly transmit knowledge to large numbers of farmers; rather, farmers exchange new information amongst themselves (Ramirez 2013; Wood et al. 2014). There is mixed evidence about the link between high connectivity and learning: farmers who are central to peer advice networks have been found to have better learning outcomes (Pratiwi and Suzuki 2017). However, there is converse evidence that socially well-connected farmers may be less receptive to extension (Matouš et al. 2013; Zhang et al. 2020). In any case, it is clear that both farmer-extension relationships and farmer-farmer relationships have a place in supporting social learning (Lubell et al. 2014; Šūmane et al. 2018).

At the collective level, extension systems build social networks that in turn influence practice adoption through information transmission and social learning (Lubell et al. 2014; Klerkx 2020; Beseler et al. 2021; Klerkx and Proctor 2013; Thuo et al. 2013). Farmers with increased access to information and use of social networks generally have higher rates of adoption of best management practices (Prokopy et al. 2008). The network promotes adoption partly through conveyance of information and partly through the influence of subjective norms (Prokopy et al. 2008). Shared norms, trust, and expectations bind the social network together,

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promote collaboration, facilitate the acceptance of ideas, and accelerate innovation (Zheng 2010); without sufficient social capital, dissemination of information can fail to influence agricultural productivity and practice (Vasilaky 2013).

Research on agricultural innovation systems identifies public extension services as key knowledge brokers within a broader, complex network involving public and private actors (Lubell et al. 2014; Klerkx et al 2012). There is rich scholarly evidence about how agricultural advising networks support learning and adoption of innovative practices. Advice networks support knowledge gathering, and farmers with direct access to main information channels, like extension services, use more progressive practices (Pratiwi and Suzuki 2017, Zhang et al. 2020; Bates and Arbuckle 2017; Baumgart-Getz et al. 2012; Carlisle 2016), although the structure of these networks varies depending on the specific context and type of information (Klerkx and Proctor 2013; Nelson et al. 2014; Bastos et al 2018; Albizua et al 2020).

Though existing literature points to the value of consultations, there is a relative lack of empirical data about the effectiveness of farm visits themselves. Evidence from one recent review indicates that consultations and small group learning are the single most effective extension tools in supporting practice adoption (Nettle et al. 2022). However, there is limited research on the role of on-farm consultations in supporting learning, especially consultations with public extension specialists. Qualitative evidence from private-sector farm consultations points to the value of farm visits for increasing farmer receptivity to new information and behavior change. For instance, a case study of on-farm veterinary consultations found that farmers valued accurate information and context-specific applicability (Bard et al. 2019).

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Critically, the presence of a trusting relationship was essential for change (Bard et al. 2019).

These existing case studies indicate that development of relationships is a key factor of the ability of consultations to support receptiveness to learning.

3 HYPOTHESES

The extension, social capital, and behavior literature described above informs hypotheses regarding the impact of four trust-related consultation attributes on client receptiveness and sets the expectation that perceived openness will strictly exceed perceived likelihood of adoption. Attributes associated with high personal trust are expected to increase client receptiveness to the extension specialist's ideas, information, and recommendations. In this dataset there is no direct measurement of trust. However, previous research on California farmers has shown there to be a very strong link between trust-warranting properties, trust itself, and frequency of interaction, so much so that it is appropriate to treat trust and trust-warranting properties as indicators of a single concept (Lubell 2007).

As frequency of interaction was found to be a core element of trust (Lubell 2007), the number of prior consultation visits is assumed to be associated with trust, such that the length of the consultation relationship is expected to play a role in learning and receptiveness. This is because trust in relationships tends to increase over time (Vanneste et al. 2014). Assessment of past performance builds trust in future performance, and positive social experiences can build trust of another's character (Coleman and Stern 2018). Personal relationships are important to growers, and personal trust is key for long-term relationships. Existing case studies concur that

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relationship longevity is more impactful in building trust than institutional affiliation in agricultural advising settings (Nettle et al. 2022).

Not all advisor recommendations necessarily require an equivalent amount of trust to adopt. For instance, consultations may involve helping clients learn about grant opportunities or connect with other financial or informational resources. For a client to follow through on activities like these may not require the same level of trust as it would to change their irrigation program or conduct fundamental shifts in their management practices. Intensive management changes would be expected to require more long-term buy-in. The established relationship between long-term relationships and trust influences our expectation that long-term clients will be more receptive to the guidance of advisors overall, and in particular, more receptive to recommendations geared towards more intensive, long-term management change:

Hypothesis 1: Long-term clients will be more receptive overall, and more receptive to recommendations geared toward management change.

Digital extension methods have seen increasing use in recent years and can successfully deliver information to growers (Rose et al. 2021; Pinzon and Brimm 2025). They can be accepted as effective extension methods if farmers perceive them as free of bias, accessible, and created and delivered by a respected expert (Chivers et al. 2023; Rose et al. 2021). Thus, virtual consultations are assumed to be part of an effective consultation strategy, in that virtual consultations as well as in-person consultations can, over time, build receptiveness to an

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advisor's guidance. However, virtual modes may not be ideal for building relational trust with clients, compared to in-person visits. In-person communication is generally recognized as the most effective method of information exchange with growers (Chivers et al. 2023), and farmers prefer face-to-face advice over virtual advice (Rose et al. 2021). Comparative research between in-person and digital tools in agricultural spaces is limited, but research from other contexts indicates that digital formats can lag behind in-person formats in trust formation. For instance, in-person interaction is associated with higher levels of bonding between friends (Sherman et al. 2013). Meanwhile, digital tools can exacerbate existing social barriers and hinder development of trust and rapport in interviews (Shah 2025). Among leaders and diplomats, though there are opportunities for building trust digitally, physical interactions facilitate stronger bond formation (Holmes and Wheeler 2023).

Hypothesis 2: In-person clients will be more receptive.

It was previously theorized that generalized trust and personal trust operate differently, with personal trust dominating more frequent interactions, and with generalized trust dominating more infrequent interactions. Specifically, generalized trust in government dominates new or unfamiliar relationships with government entities (Lubell 2007). One potential barrier to strong generalized trust of public extension staff among growers is the state affiliation of public servants, as some farmers have low institutional trust in government (Fisher 2013). Trust can be

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compromised if extension staff are perceived as extensions of government (Sutherland et al. 2013), and farmer concerns about government intrusion can reduce adoption (Kalcic et al. 2014).

We expect that for consultations dealing with regulatory topics, the advisor will be positioned as helping the farmer to comply with state requirements, which could increase the perception of connectivity between the advisor and state interests. Additionally, the discussion of state regulation is expected to magnify the salience of a grower's generalized trust in government. As farmers value personal relationships to a greater extent than organizational relationships (Hoffman et al. 2011), generalized trust in government is assumed to be lower on average than personal trust in the advisor. Therefore, receptiveness is expected to be lower for regulatory topics than for other consultation topics.

Hypothesis 3: Receptiveness will be lower for regulatory topics.

Trust is also influenced by shared identity. People are more likely to trust information sources that they perceive as having similar interests, costs, and benefits to themselves (Moya et al. 2020; Lubell 2007). In an agricultural context, this suggests that shared identity between an advisor and client could support trust, and by extension, learning. Indeed, a study in Ethiopia found that when the ethnicity and religion of an extension advisor match that of the farmer, the farmer reports learning more from extension sources (Matouš et al. 2013). Conversely, a study in Uganda showed that ethnic fragmentation reduced participation in agricultural organizations (Katungi et al. 2007). Additionally, language is not only a facet of shared identity, but potentially

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removes a language barrier for growers that could impede understanding. From this evidence, farmer receptiveness would be expected to be higher if the extension specialist speaks the farmer's language.

Hypothesis 4: Receptiveness will be higher if the extension specialist speaks their primary language.

As outlined previously, social capital theory, Theory of Planned Behavior, and Diffusion of Innovations all suggest a gap between openness to new ideas and likelihood of adoption. Particularly, the Theory of Planned Behavior has a famously large gap between predictors of adoption and actual adoption (e.g. van Dijk et al. 2016). The overall theory of change here is that a client must first develop a favorable attitude toward the advisor and their ideas in order to consider adoption, but that a favorable attitude alone is not necessarily enough to spark behavior change. There are a couple of alternatives to this theory: if all three measures of receptiveness are practically identical, measuring a single dimension of receptiveness, one would expect no significant variation between likelihood of adoption and openness to ideas. If, on the other hand, affective openness to new ideas were separate from pragmatic management changes, we would not by default expect a higher overall openness compared to adoption. The expectation of a strictly lower likelihood of adoption compared to openness to ideas tests the distinction between openness to ideas and likelihood of adoption and the idea that favorable attitudes must precede behavior change.

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Hypothesis 5: Advisors will have a higher perception of a grower's openness to their advice compared to a grower's likelihood of adopting their recommendations.

4 THE CASE: NITROGEN AND IRRIGATION MANAGEMENT IN CALIFORNIA

Nitrogen and irrigation management provides a valuable case study for understanding advisor-client interactions in a farm consultation setting. As part of the Nitrogen and Irrigation Initiative (NII), a partnership between the University of California and the California Department of Food and Agriculture, farm advisors and staff research associates employed through the University of California Agriculture and Natural Resources extension service conducted virtual and on-farm consultations with growers to provide individualized support of nitrogen and irrigation management.

The Nitrogen and Irrigation Initiative is part of the effort in California to address nitrate pollution and overextraction of groundwater, two prominent environmental challenges in the state (Abascal et al. 2022, Rudnick et al. 2021; Chappelle et al. 2021; Balazs et al. 2011). It was established as a multi-county, medium-term extension program, starting in 2021. After receiving extensions on the time frame of the project, two final grant reporting milestones were reached in May 2026. Consultations formed a prominent part of the program, as well as traditional grower meetings and other public educational events. County teams consisting of a farm advisor and, typically, a staff research associate hired to support their outreach, operated their own program

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quasi-independently, geared toward their respective strengths and regional contexts, but with a common theme of supporting adoption of best management practices and improving nitrogen and water use efficiency.

The timeframe of the NII corresponded to a period of several significant shifts in agricultural nitrogen and irrigation policy in the state. In 2021, at the start of the program, Ag Order 4.0 went into effect in the Central Coast, limiting nitrogen applications for the first time (Lopez 2021). These limits were struck down by the State Water Board in September 2023 (State Water Resources Control Board 2023). In February 2026, AB 2447 was introduced, which is designed to set nitrogen limits throughout the state (Water: Nitrogen Pollution Reduction Act, CA AB2447, California Legislature 2025-2026 Regular Session (2026)). This rapidly changing regulatory context increased the salience of the program, particularly in the Central Coast, which particularly in early years had stricter policies on nitrogen use. Thus, this case is ideal for demonstrating the value of consultations in extension in a rapidly changing regulatory environment with implications for both agricultural business and environment.

Consultations in the NII varied in topic and scope but were united by the theme of education and/or management support regarding nitrogen and irrigation. Some consultations focused on helping clients understand and apply for grants to fund improvements to their management practices. Others provided help with irrigation equipment maintenance. Some provided regulatory support. Others involved installation, removal, and maintenance of monitoring equipment for longer-term management shifts, or collection and review of data to support management decisions. Others were more explicitly geared towards providing

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management advice and adjusting practices in real time. Due to expertise and regulatory needs, consultations through the NII were concentrated on the Central Coast, but some consultations were conducted in Central Valley counties.

5 DATA

The data for this analysis come from extension staff post-consultation reports for 601 consultations on nitrogen and/or irrigation management, from April 2, 2022 to April 30, 2026. The consultations were conducted as part of the Nitrogen and Irrigation Initiative, involving primarily specialty annual crops like vegetables, melons, and flowers (416 consultations), but also nut crops (84 consultations), perennial fruit crops (55 consultations), and other crops (46 consultations). The project began in 2021 as a partnership between the California Department of Food and Agriculture, University of California Cooperative Extension, University of California Agriculture and Natural Resources, and University of California, Davis. The project was funded by the Fertilizer Inspection Advisory Board, the Federal USDA Specialty Crop Block Grant program, and the Federal USDA Conservation Innovation Grant program. As part of the program evaluation process, a post-consultation reporting protocol was implemented beginning in April 2022, such that the extension staff member providing the consultation services would fill out a short report including the topic discussed and their perceptions of the client's receptiveness to the information provided. The extension staff member providing these consultations was either a farm advisor or a junior staff member who received technical training as a part of the project to assist farm advisors and carry out certain types of farm visits independently. One report was

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submitted per consultation event; a client who received consultation services on multiple occasions would thus have multiple reports. The receptivity of a particular client over time can be traced across multiple reports, using the client ID and the recorded consultation date. The end of the data collection period (May 1, 2026, for consultations occurring on or before April 30, 2026) corresponds to the final grant reporting data collection deadline for the project. Summary statistics for each consultation report are included in Table 3.1. Summary statistics at the client level are included in Table 3.2.

Table 3.1: Consultation Metadata, Including Counts (N = 601)

Aspect	Count of Consultations in Each Category
Type	In Person - 468 Phone / Virtual - 133
Primary Language of Client	Chinese (including Cantonese): 101 English: 190 Spanish: 31 No data: 106 English and another language: -Chinese (including Cantonese): 42 -Spanish: 127 -Other: 4
Can Advisor Speak Client's Primary Language	Yes - 487 No - 114
Consultation Topic	"Intensive management change" (data collection and review or management advice and adjustment) - 387 Regulatory support - 73 Other (includes grant and networking support, work with monitoring equipment, and other irrigation equipment maintenance) - 141

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Table 3.2: Consultation Metadata at the Client Level

Metric	Count
Number of Client Farms	167
Number of Unique Individuals	192
Primary Language of Unique Individuals	Chinese (including Cantonese): 35 English: 89 Spanish: 9 No data: 33 English and another language: -Chinese (including Cantonese): 8 -Spanish: 15 -Other: 3

The map below depicts the spatial distribution of the consultations, aggregated at the county scale. In some cases, such as multi-ranch consultations in which the client farms in multiple counties, the advising spanned multiple counties. In these cases, they are shown on the map as belonging to the county that the staff member listed first in the report.

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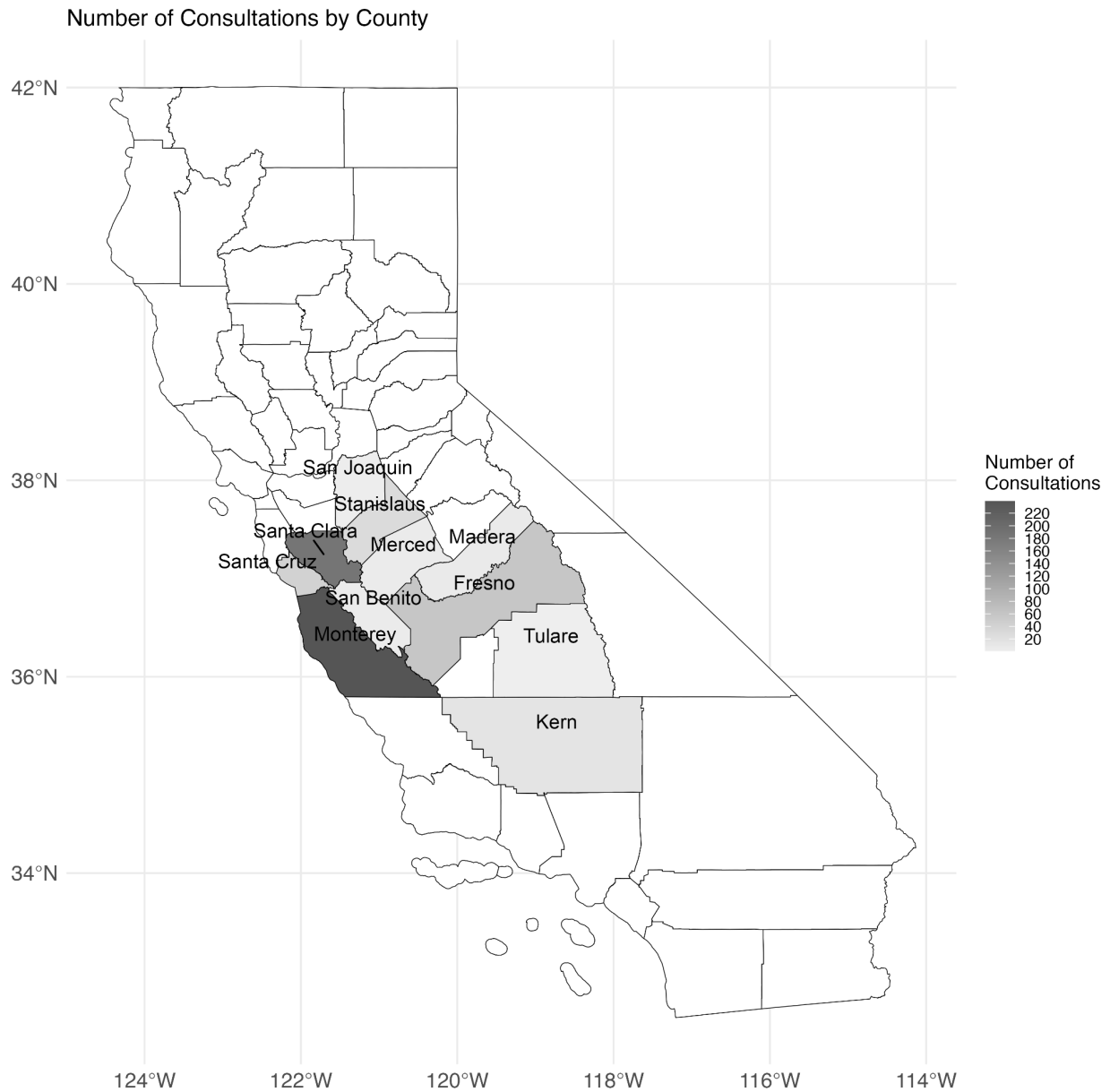


Figure 3.1: Number of Consultations by County

The bulk of the consultations are annual specialty crop growers on the Central Coast, but consultations were also conducted in the Central Valley and with perennial crops. The mean

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consultation length was 89 minutes, with a median of 45 minutes, minimum of 4 minutes, and a maximum of 2400 minutes (for a multi-day testing protocol).¹³

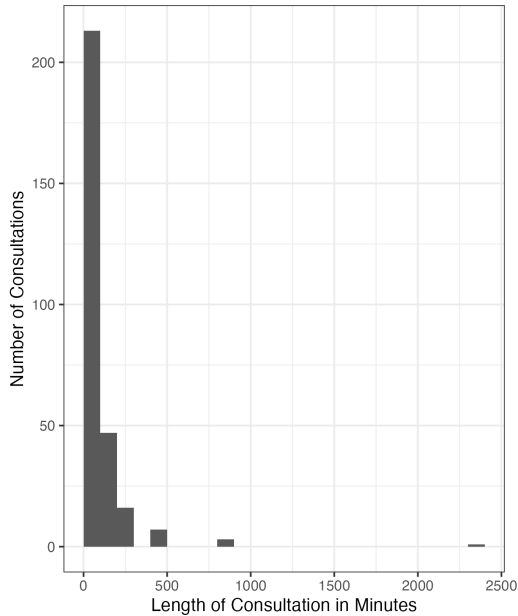


Figure 3.2: Histogram of Length of Consultation

The modal number of consultations per client ranch is one, but 55% of client ranches received more than one, with one ranch operation even receiving over 50 consultations. A sensitivity analysis excluding this most frequent client is included in Appendix J.

¹³ Based on consultations for which length of consultation is available. Collection of this data started part-way through the project; as a result, this data is available for 287 out of the 601 total consultations.

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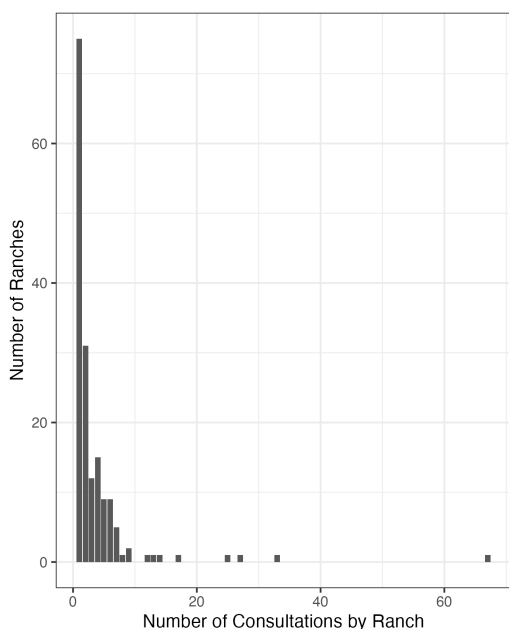


Figure 3.3: Number of Consultations Per Ranch

Two important caveats should be recognized when using this data. The first is that there can be a conflict of interest involved in data reporting. There is an incentive to inflate the report of client receptivity to some extent, especially if this data is used as evidence of program effectiveness and its likely impact on adoption of recommendations. However, there is a limit to the incentive for inflation, since if advisors simply report that all clients will certainly adopt their recommendations, this looks unrealistic to funders and project partners and dishonest, particularly if actual adoption outcomes can be observed, which are assumedly less than 100%. The second caveat is that the current case lacks corresponding data on farmer self-reports regarding their openness to advice, likelihood of adopting the discussed practices, and other

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receptivity metrics, as well as data on actual management changes. Thus, it is assumed, but cannot be quantified, that the advisor perceptions, as career experts familiar with influencing farmer behavior, largely match actual farmer receptivity. Based on evidence from existing literature (Vrain and Lovett 2019), this appears to be a reasonable assumption, although advisors tend to underestimate how much farmers value local, site-specific evidence and knowledge. In this context, such a bias could lead advisors to underreport client receptiveness for site-specific topics such as on-farm data collection and management plan advice, compared to non-site specific, generic topics such as grant and networking opportunities and regulatory support. This study also assumes that farmers and advisors are largely aligned on their respective definitions of successful or helpful advising. That is not an insignificant assumption: actor goals shape the circulation of information within agricultural systems (Coggins et al. 2025). Of particular relevance to virtual consultations and other digital extension methods, the alignment of mental models among members of a virtual team has been identified as key to its effectiveness (Guo et al. 2009). In any case, the present case study utilizes a new data methodology to elicit valuable expert perceptions at scale, although future work involving comparison with farmer perceptions or farm outcomes would further strengthen the literature.

6 METHODS

Our dependent variables are three measures of receptivity from the post-consultation report, based on whether the expert believed the client was open to new ideas, valued the information, and was likely to adopt recommendations. For each report, extension staff members

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were asked to respond on a 5-point Likert scale indicating their level of agreement or disagreement to each of three statements, as summarized in Table 3.3. Due to a small sample size for “Somewhat Disagree” and “Strongly Disagree,” the original Likert scale was collapsed into a three-level categorical variable, which is the dependent variable used in the analysis. The distribution of the resulting DV is shown in Figure 3.4.

Table 3.3: Development of the Dependent Variable “Receptiveness” (Total N = 1627)

Statement in Post-Consultation Report	Dummy Term in Model	Original Likert Scale	DV Used in Model
The client was open to the ideas discussed	Openness (N = 550)	Strongly Agree Somewhat Agree Neither Agree nor Disagree Somewhat Disagree Strongly Disagree	2: Strongly Agree 1: Somewhat Agree 0: Neutral or Disagree (combines “Neither Agree nor Disagree,” “Somewhat Disagree,” and “Strongly Disagree”)
The client valued the information provided	Values Info (N = 549)		
The client is likely to adopt my recommendations	Likely to Adopt (N = 528)		

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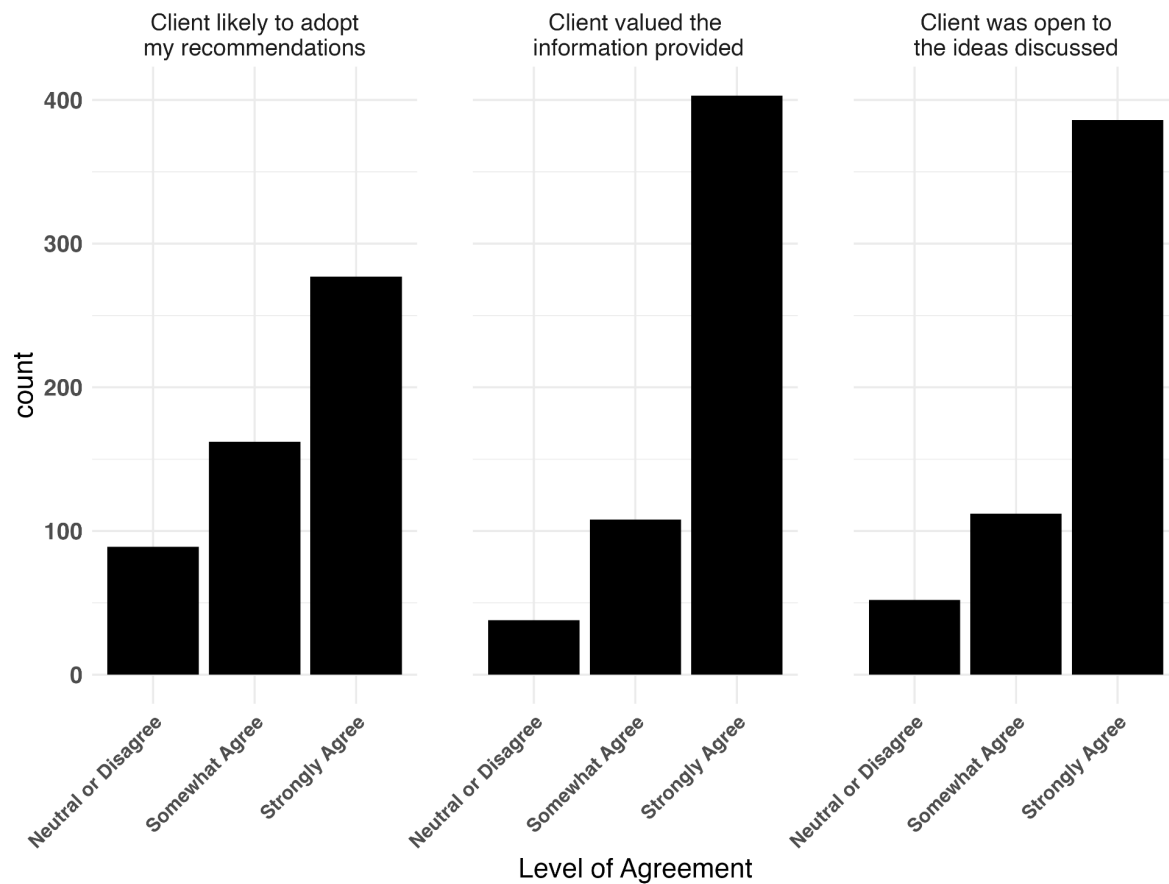


Figure 3.4: Distribution of the Dependent Variable Receptiveness, Stratified by Receptiveness Metric

A multinomial logit model is used to predict advisor perception of client receptivity as a function of several variables expected to influence the development or role of social capital in the consultation relationship, as well as control variables. As a Brant test revealed a violation of the proportional odds assumption, an ordinal model was not considered ideal for this analysis. Instead, the baseline response category is set to the middle level of the DV: “somewhat agree,”

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such that the results represent the logit of observing a response of one of the other two categories with respect to “somewhat agree.” This enables direct comparison of consecutive levels of the response, accounting for the ordered, categorical format of the dependent variable in lieu of an ordered logit model. The unit of analysis is a single response to a single statement; that is, each consultation report is represented by three observations, one for each metric of receptiveness.

The independent variables, summarized in Table 3.4, are designed as tests of the hypotheses, plus a set of controls. The test of Hypothesis 1, that long-term clients will be more receptive overall, and more receptive to recommendations geared toward intensive management change, is captured by an interaction effect between the number of prior consultations the client has had and the topic of the consultation. The natural log of the consultation number (the number of prior consultations plus one) is used to accommodate the skew in the variable and reduce the leverage of the few clients with the highest number of consultations. A sensitivity analysis removing the longest-term client is included to further ensure robustness to removal of high-leverage points, shown in Appendix J. Additionally, a sensitivity analysis using only a binary metric for prior consultations is included in Appendix L. Clients are counted at the operation level, such that consultations with one or more people associated with a particular farm are counted as consultations with the same client. Consultation counts are not separated for individual advisors, partially because advisors often consult in teams, and while the primary consultant is known since they are the one filling out the report, it is not necessarily known which other consultants are present at the meeting.

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The topic of the consultation, one of the seven listed in Table 3.1, is binned into one of two categories: intensive or non-intensive management change. Activities geared toward intensive management change include data collection and review and management advice and adjustment, as these activities reflect a strategy geared toward ongoing data collection and ongoing adjustments to management. Non-intensive activities include maintaining irrigation equipment, grant and networking support, regulatory support, and other miscellaneous activities. These tend to be geared toward individual interventions rather than building a long-term, intensive strategy for management adjustment. An otherwise equivalent model without the interaction term is also included for comparison.

Hypothesis 2 is tested with a two-level categorical variable indicating whether the consultation was conducted in person, as compared to virtually, such as over the phone, email, or video conference. The baseline is virtual consultations, and a coefficient is estimated for in-person visits.

A variable indicating discussion of regulatory topics is included as a test of Hypothesis 3. This variable is mutually exclusive with an intensive management change topic. That is, consultations that were about regulatory issues did not also involve data collection or management advice, and vice versa. The combination of these two factors is analogous to a three-category variable, in which regulatory topic and intensive management change topic are compared against the baseline of “neither,” which includes grant and networking support, maintenance of irrigation equipment, and other miscellaneous tasks.

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A Boolean variable indicating whether the consultant speaks the client's primary language was included as a test of Hypothesis 4. Where data was missing regarding the client's primary language, there was presumed to be no language barrier.

The type of receptivity metric used serves to test Hypothesis 5: that advisors will perceive their clients to have a higher openness to advice compared to their likelihood of adopting recommendations. Openness is used as a baseline, and likelihood of adoption is a comparison. The other receptivity metric, values information, is included as a control, since its focus is on information transfer rather than behavior change.

Finally, a control for the extension specialist was included. This is to account for the subjectivity of the perception and account for variation in an advisor's baseline perception of a client's receptiveness or agreeability. However, region, extension specialist, and crop are all highly linked, since advisors specialize in a particular region and on specific crops. Because of this, the random intercept for advisors also accounts to some extent for variance in client demographics. For instance, of the two regions represented in the consultation data—Central Valley and Central Coast—only two of the ten advisors had consultations in both areas; most advisors exclusively consult in a single region. Likewise, of the two largest crop categories in the dataset—nut crops and annual specialty crops—nine of the ten advisors had consultations from

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only one of these two categories and no consultations in the other category.¹⁴ Because of the large level of overlap between region, crop type, and advisor, advisor was chosen as a fixed effect to account for subjective differences in the advisors' general perceptions of receptiveness, as well as distinctive client features that could vary by region or crop.

Alternatively, an effect for the region could be included rather than an effect for the specialist. Some specialists only conducted a very small number of consultations: 7 and 8, for the two consultants with the fewest consultations. This unevenness in number of consultations per client, combined with the sparsity of data with a "neutral or worse" outcome could impact model fit. Accordingly, a sensitivity analysis was conducted with a fixed effect for region instead of a random effect for advisor (see Appendix K). Because there is a large level of overlap between region, crop type and advisor, the fixed effect for region also accounts to an extent for both variance in client demographics and variance in subjective differences in the advisors' general perceptions of receptiveness.

Because of the skew in the number of consultations conducted with each client, with many clients only receiving one consultation, a sensitivity analysis is also conducted, removing the most frequent client, who had 67 consultations. As points of reference, the second, third, and fourth most frequent clients had 33, 27, and 26 consultations, respectively. Given the similar

¹⁴ An exact breakdown of crop, region, and topic by specialist is not reported, as it would make the identities of the specialists apparent.

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number of consultations for these other frequent clients, these and other less frequent clients were kept in the sensitivity analysis.

Table 3.4: Independent Variables (1627 observations)

Variable	Hypothesis Tested	Variable Type	Possible Values
ln(Consultation Number)	H1 – positive coefficient expected for 1-2 comparison; negative coefficient expected for 1-0 comparison	Numeric	Minimum: 0 Median: 1.1 Mean: 1.4 Maximum: 4.2
Intensive Management Change Topic	H1 – positive interaction effect with Prior Consultations expected for 1-2 comparison; negative interaction effect with Prior Consultations expected for 1-0 comparison.	Boolean - see Table 3.1.	-T if consultation topic is one of: data collection and review or management advice and adjustment -F otherwise
Consultation Format	H1 - positive coefficient expected for 1-2 comparison; negative coefficient expected for 1-0 comparison	Categorical	-Virtual/Phone (baseline) -In-Person
Receptivity Type	H5 – negative coefficient expected for Likely to Adopt for 1-2 comparison; positive coefficient expected for 1-0 comparison.	Categorical - see Table 3.3.	-Openness (baseline) -Values Info -Likely to Adopt (H2)

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	Other categories included as control		
Regulatory Topic	H3 - negative coefficient expected for 1-2 comparison; positive coefficient expected for 1-0 comparison.	Boolean - see Table 3.1.	-T if consultation topic is regulatory support -F otherwise
Language Match	H4 - positive coefficient expected for 1-2 comparison; negative coefficient expected for 1-0 comparison.	Boolean	-T if consultant speaks client's primary language -F otherwise
1 Advisor	Control	Random effect for Advisor	10 Advisors
Region	Control (in Appendix K only)	Categorical	-Central Coast -Central Valley

Client ID could not be included as a predictor in a model designed to assess the impact of repeated visits, as it is highly interconnected with whether a client has repeated visits: a large number of clients have only one consultation or a small number of consultations, and so are not represented in the subset of data from one or more of the prior consultation variable categories. One implication of this limitation is that this study cannot completely distinguish between the effects of long-term relationships and personality characteristics of certain kinds of clients. However, the sensitivity analysis demonstrating overall robustness to removing data points from the most dedicated client strengthens evidence of the impact of long-term relationships.

7 RESULTS

Full results are shown in Table 3.5 for Model 1 without the interaction effect, and in Table 3.6 for Model 2 with the interaction effect. Overall, the two models explain a similar amount of variance in the data, with Model 2 representing a slight reduction in residual variance.

There is support for the first portion of Hypothesis 1: extension specialists perceive a higher receptiveness among long-term clients. In both models, there is a positive, significant relationship between the natural log of a client's number of visits by that date and the advisor's likelihood of responding "strongly agree" compared to "somewhat agree" on receptiveness questions. Reciprocally, there is a negative, significant relationship between the number of prior visits and the advisor's likelihood of responding "neutral or disagree" compared to "somewhat agree." In both cases, an increasing number of consultations shifts responsiveness higher on the Likert scale. The interaction term does not support the second portion of Hypothesis 1. We do not find evidence in Model 2 for long-term clients being more receptive to recommendations geared toward intensive management change.

Hypothesis 2 is supported in both models, only when predicting "Neutral or Disagree" compared against "Somewhat Agree", but not when predicting "Strongly Agree" compared against "Somewhat Agree." This indicates that an in-person visit may tip the scales toward moderate receptiveness for a client who otherwise is likely to not be receptive at all, but has little impact on a client who is already likely to be at least somewhat receptive.

Hypothesis 3 is supported, indicating decreased receptiveness for regulatory topics. In both models, this effect is primarily apparent in the comparison between "Neutral or Disagree"

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and “Somewhat Agree.” This indicates that a regulatory topic can more easily curtail receptiveness among clients who already are less receptive, but has less impact on a client who is otherwise already at least somewhat receptive.

Hypothesis 4, that receptiveness will be higher if the specialist speaks the primary language of the client, was confirmed in both models, only for the comparison between “Strongly Agree” and “Somewhat Agree.” This suggests that while a mismatch in language does not harm receptiveness for a client who is otherwise likely to have a moderate level of receptiveness, a match in language could help that same client become highly receptive.

There is also support for Hypothesis 5, regarding the decreased likelihood of adoption relative to openness to advice. In both models, though there is not a strong effect for the “Neutral or Disagree” response compared to “Somewhat Agree,” there is a large, negative effect for the logit of “Strongly Agree” compared to “Somewhat Agree.” This indicates that the gap between openness and likelihood of adoption is most apparent at the top end of the receptiveness spectrum: it is easier to get to top levels of client openness, but more difficult to get to top levels of likelihood of adoption.

A full discussion of the sensitivity analysis results in relation to the hypotheses and in comparison to the main model results is given in Appendix J, Appendix K, and Appendix L. In summary, the sensitivity analysis models largely resemble the main models and offer similar support for the hypotheses, with the exception that in the sensitivity analysis with an effect for region rather than one for specialist, there is no relationship between in-person visits and receptiveness. Additionally, in the sensitivity analysis with the longest-term client removed,

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there is greater support for the interaction effect in Hypothesis 1. The sensitivity analysis results are discussed in more detail in the Appendices.

Table 3.5: Results of Multinomial Logit Model with No Interaction Term (Model 1)

	“Neutral or Disagree” (vs. “Somewhat Agree”)			“Strongly Agree” (vs. “Somewhat Agree”)		
	Estimate	SE	p.value	Estimate	SE	p.value
Intercept	0.094	0.559	0.866	0.701	0.609	0.249
ln(Consultation Number)	-0.456	0.098	<0.001	0.243	0.062	<0.001
Intensive Management Topic	-1.064	0.273	<0.001	-0.016	0.177	0.929
In Person	-0.569	0.268	0.034	0.169	0.176	0.337
Values Info (Baseline = Openness)	-0.309	0.257	0.230	0.109	0.160	0.493
Likely to Adopt (Baseline = Openness)	0.256	0.220	0.245	-0.833	0.155	<0.001
Regulatory Topic	0.965	0.360	0.007	-0.389	0.272	0.153
Language Match	-0.221	0.351	0.529	0.832	0.259	0.001
Num. Obs.	1627					
AIC	2476.5					

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Table 3.6: Results of Multinomial Logit Model with Interaction Term (Model 2)

	“Neutral or Disagree” (vs. “Somewhat Agree”)			“Strongly Agree” (vs. “Somewhat Agree”)		
	Estimate	SE	p.value	Estimate	SE	p.value
Intercept	0.025	0.573	0.965	0.603	0.619	0.330
ln(Consulta- tion Number)	-0.387	0.156	0.013	0.318	0.102	0.002
Intensive Management Topic	-0.929	0.351	0.008	0.155	0.252	0.538
In Person	-0.575	0.268	0.032	0.157	0.177	0.375
Values Info (Baseline = Openness)	-0.309	0.257	0.231	0.109	0.160	0.493
Likely to Adopt (Baseline = Openness)	0.255	0.220	0.246	-0.834	0.155	<0.001
Regulatory Topic	0.991	0.361	0.006	-0.361	0.274	0.187
Language Match	-0.230	0.352	0.513	0.825	0.260	0.002
ln(Consulta- tion Number) : Intensive Management Topic	-0.100	0.192	0.604	-0.116	0.122	0.343
Num. Obs.	1627					
AIC	2479.7					

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The marginal effect on the log odds of each consultation attribute hypothesized to impact receptiveness is shown in Figure 3.5. The y axis represents the log odds of observing an Openness of “Strongly Agree” or “Neutral or Disagree” compared to “Somewhat Agree”, and the x axis represents variation in a single variable, with all other variables held constant, and using the expected value of 0 for the random effect of specialist. Except when manipulated for their respective plots, values for each attribute are held at the median for the dataset: a consultation number of 3, an intensive management topic, an in-person visit, and a lead specialist who speaks the client’s primary language. Figure 3.6 is constructed in the same manner, but with the y axis representing the log odds of observing Likelihood of Adoption, rather than Openness.

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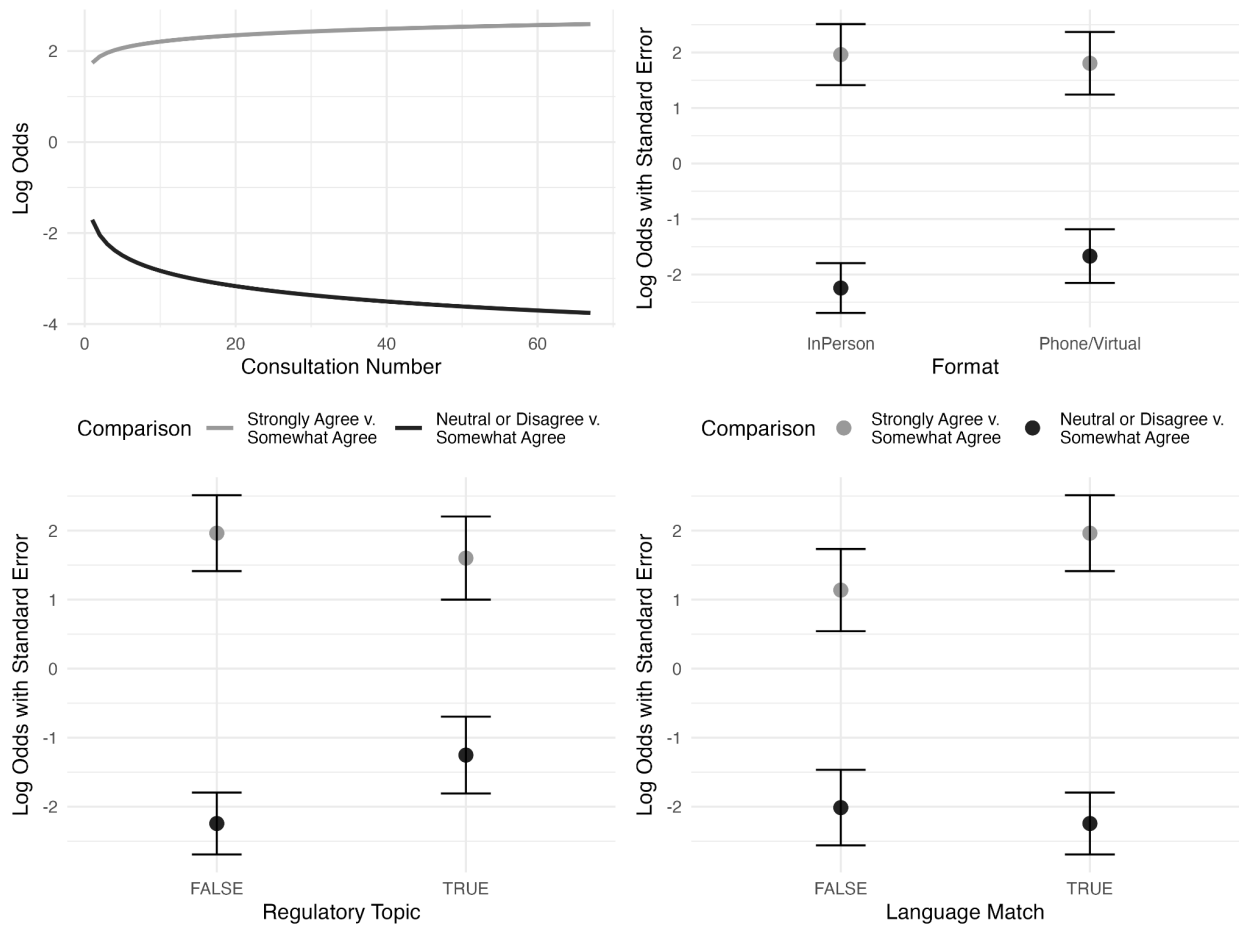


Figure 3.5: Marginal Effects of Predictors on Log Odds of Levels of Openness, with Other Predictors Held at Median

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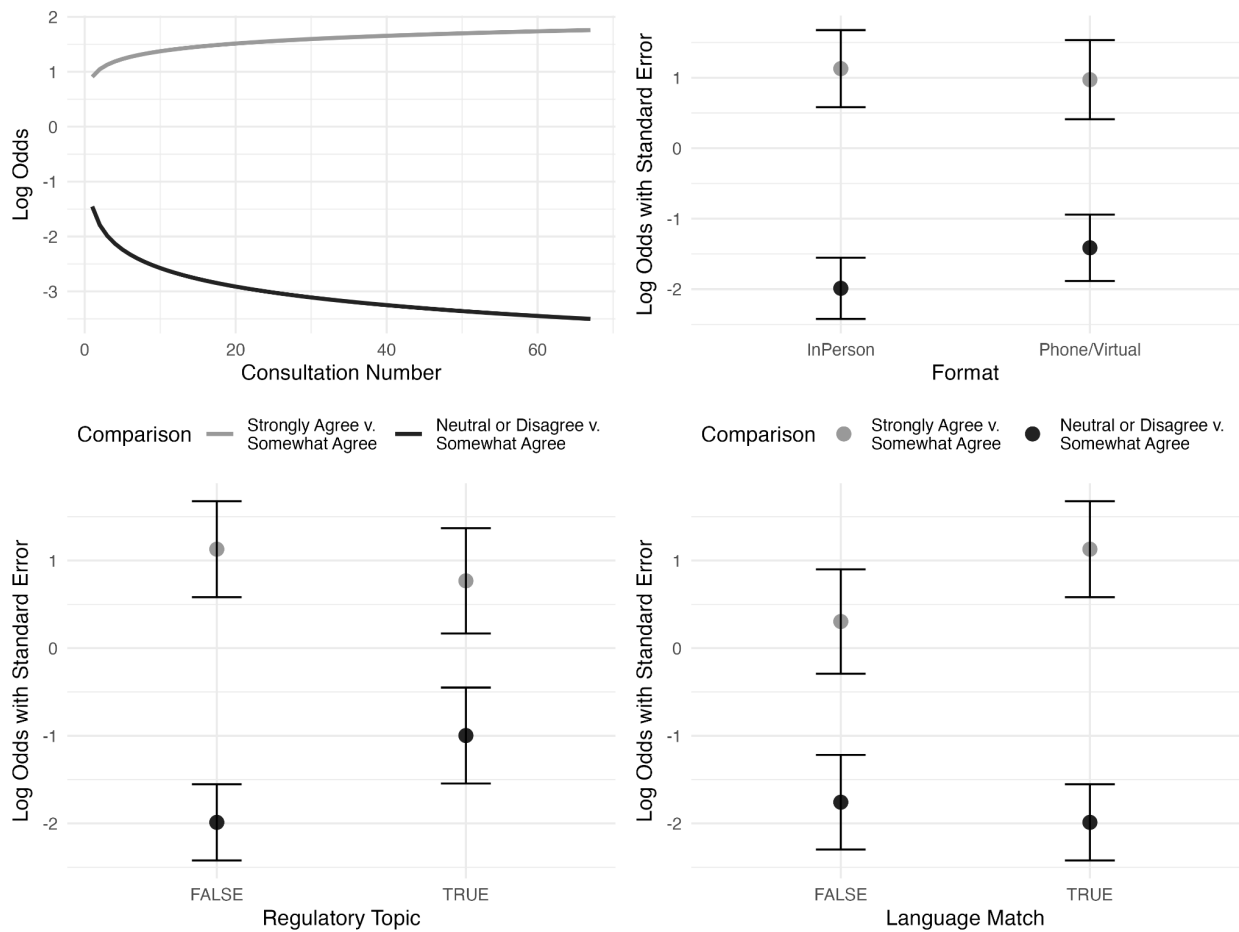


Figure 3.6: Marginal Effects of Predictors on Log Odds of Levels of Likelihood of Adoption, with Other Predictors Held at Median

To demonstrate the difference in predicted receptiveness, consider three hypothetical consultations, simulated for a “typical” advisor; that is, using the expected value of 0 for the random effect of specialist. The predicted probabilities are simulated using the model with the interaction effect (Model 2). Consultation A represents a highly favorable setting: it is the 10th consultation for the client, about a consultation topic related to data review, is conducted in-person, and with a specialist who speaks the client’s primary language. Consultation B represents

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a moderately favorable setting: the 2nd consultation for the client, neither about regulation nor intensive management topics, conducted virtually, and with a specialist who does not speak the client's primary language. Consultation C represents a highly unfavorable setting: it is the 1st consultation for a client, related to regulatory issues, conducted virtually, and with a specialist who does not speak the client's primary language. The plot below illustrates the difference in predicted openness, valuation of information provided, and likelihood of adoption between these three scenarios.

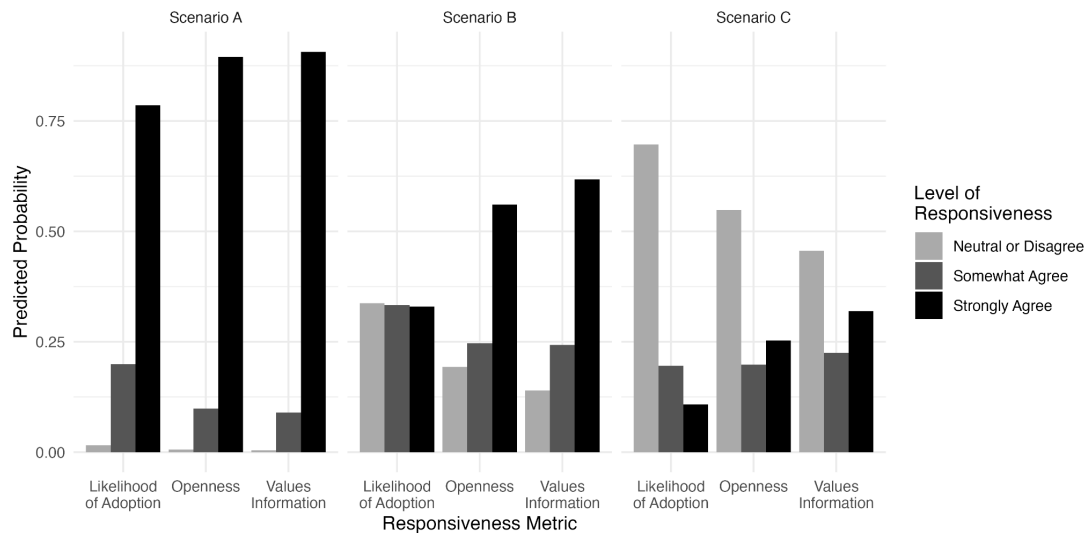


Figure 3.7: Probability of Each Level of Responsiveness Under Three Consultation Scenarios

8 DISCUSSION

The findings demonstrate that extension specialists perceive clients as more receptive to their expertise as the number of prior consultations increases, when the visit is in-person, when the consultation does not concern regulatory issues, and when the specialist speaks their primary language. Additionally, the odds of advisors perceiving their clients to be highly likely to adopt

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their recommendations is reduced compared to their odds of perceiving their clients to be generally open to the ideas they discussed, supporting existing scholarship indicating that the bar for implementation is higher than the bar for a positive attitude toward new ideas.

The implications for extension are that improving management is not just about information delivery. It is also about social capital. Social capital is cultivated through long-term personal relationships and through clear and fluent communication, and it is decreased by perceived proximity to institutions in which institutional trust is low, such as government bodies responsible for imposing regulations. Out of an understanding of the key role of informal advice networks, some prior studies have recommended that extension specialists take a step back and simply facilitate advice network connections, at the risk of losing information accuracy in the process. However, farmers in some agricultural systems may already be more highly connected to one another than they are to extension. The strength of extension comes not from controlling the center of the advice network, but from its catalytic energy. Extension programs that attempt to cast a wide net by maximizing the number of farmers involved rather than the number of touch points over time with each grower may do a disservice by spreading too thin at the expense of supporting specialists in becoming trusted sources of advice to those farmers in their orbit. Instead, connecting individually with growers by providing location-specific guidance can build openness to advisor expertise and support management change. If advisors invest in promising, long-term partnerships with farmers who are open to their ideas, this in time translates into higher perceived likelihood of adopting their management recommendations.

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This emphasis on long-term farmer relationships is a departure from an extension model that is geared primarily towards large-scale lecture-style educational events with the goal of achieving a broad reach. Trust is built at the individual level, and extension organizations do not fully appreciate the extent to which farmers value location-specific guidance. By supporting extension teams' ability to collect site-specific data, provide individualized recommendations, and communicate with linguistically isolated clients, funding agencies could strengthen farmers' image of extension specialists as reliable and knowledgeable, thereby strengthening their influence within the agricultural advice network.

This case is also significant in that many farmers from the dataset are from underrepresented ethnic groups, an understudied population in literature on American agriculture. The lens of social capital and trust is especially beneficial for studying such a dataset, as advisors and researchers can have increased difficulty establishing trust with marginalized groups. Such a dynamic can make it even more challenging to obtain farmer survey data, a gap that is mitigated by the dataset used in this study. Additionally, under-resourced farmers can be at a higher risk of using outdated or inefficient management practices due to upkeep costs and language barriers regarding regulations, posing additional barriers to efficient management. Understanding receptivity to consultations among the population in this case study could be useful more broadly in terms of supporting efficient management.

One expectation was not confirmed in this analysis. Contrary to expectation, the effect of multiple visits was not necessarily more pronounced for consultation topics that concern potentially intensive management change commitments, such as collection and analysis of data

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and management advice. Rather, it appears that receptiveness is increased in general for consultations on intensive management topics, perhaps because in order to agree to a consultation involving the intent to alter management, clients already have buy-in to the idea of taking the specialist's recommendations seriously. There was a small effect in the sensitivity analysis without the longest-running client, which could indicate that repeated visits improve receptiveness for management actions up to a point, but not after a very high number of visits. Alternatively, as this trend was eroded in the sensitivity analysis that had no random effect for specialist, it is possible that there is a more complex relationship between topic, specialist, and client receptiveness, such as clients having more trust of extension staff specializing in specific topics.

9 CONCLUSION

In this study, post-consultation reports completed by extension specialists offered a unique window into the content of these visits as well as farm advisor perceptions of the impacts of consultations. These consultations covered a range of topics, such as providing networking and grant advice to farmers, supporting farmers in complying with and understanding regulations, conducting maintenance, performing tests, and conducting long-term data collection and analysis to inform management choices.

This new source of data supports existing evidence from the literature that farm consultations are impactful tools for learning and adoption. Advisors generally reported that their clients were open to their advice, valued the information provided, and were likely to adopt the

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recommendations they provided. This case provided evidence that four key attributes associated with trust – repeated interactions, in-person visits, higher perceived distance from government regulation, and shared language identity – increase attitudes favorable to adoption.

First, the results demonstrate the consultation model supports agricultural innovation through repeated interactions and personal relationships, as indicated by increased receptiveness after repeated visits. Given that personal relationships tend to carry more weight for farmers than institutional affiliations as trusted sources of advice, investment in key long-term relationships could help public extension specialists be recognized as trustworthy information sources in the agricultural advice network and extend the impact of their work beyond the subset of growers already highly involved in public extension events. Extension education as seen in consultations does not look like large, lecture-style information sessions. Rather, an extension specialist's demonstration of tailored, farm-specific expertise can make clients receptive to transitions they may not have considered at the beginning of their consultation journey. Our analysis suggests that increased client receptiveness to guidance comes after first building trusted relationships with their consultants.

In-person visits were associated with higher receptiveness compared to virtual consultations, particularly in raising the odds of moderate receptiveness compared to being neutral or unreceptive. However, the size of this effect does not rival the overall potential effect of repeated visits, and in-person visits make no difference in tipping a moderately receptive client to strong receptiveness. Though in-person visits are ideal for cultivating trust between

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extension staff and clients, virtual consultations can also contribute to receptiveness and support farmer innovation.

Consultations about regulatory topics were met with lower receptiveness compared to consultations about other topics, indicating that a farmer's generalized trust in government institutions is more salient for decision-making when the topic is directly related to government requirements. This effect could be exacerbated to the extent that advisors are perceived as government representatives, which for public extension staff, may be the case, particularly when regulations are discussed.

Perceived client receptiveness was also increased when the advisor spoke the client's primary language. Translators and multiple extension staff sometimes worked together on consultations, likely mitigating part of the negative impact of a language barrier between the client and the primary advisor. Nevertheless, shared language still increased the odds of an advisor reporting strong receptiveness, highlighting the importance of good communication and the power of shared identity markers to build trust.

Consistent with social capital theory, as well as behavioral theories such as the Theory of Planned Behavior and Diffusion of Innovations, perceived openness to ideas was greater than perceived likelihood of adoption of the recommendations discussed. The path to improving management starts not necessarily with information, but with openness.

Overall, the analysis of post-consultation advisor reports demonstrates the richness and potential of expert perception data and points to the value of extension staff developing trusted personal relationships with farmers. It is these personal relationships, and the personalized

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application of extension specialists' expertise on individual farm operations, that cultivate confidence in expert, evidence-based guidance.

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CHAPTER 3: ON-FARM CONSULTATIONS AS A PATHWAY TO LEARNING

Zhou, Yuan, and Suresh Babu. Knowledge Driven Development: Private Extension and Global Lessons. Academic Press, 2015.

CONCLUSION

This dissertation has examined the impact of extension as an information source on nitrogen and irrigation management decisions in California, particularly in context of attention to soil health (Chapter 1), institutional trust (Chapter 2), and personal trust (Chapter 3). A common thread throughout all three chapters is that use of extension has increased learning, adoption plans, and openness to adoption of nitrogen and irrigation management practices.

The first chapter examined the connection between valuing soil health on management decisions, finding that among surveyed growers in the Sacramento Valley, farmers who recognize soil health as a management priority are more likely to know their textural soil type and to adopt a higher number of best management practices. Combining farmer surveys with field-level management reporting data and location data enabled a systematic comparison between farmer self-reported soil type and spatial soil data from the national Soil Survey Geographic Database. Although use of extension was not directly linked to soil knowledge, there is an opportunity for extension to work to establish shared understanding of field-level soil types and needs and connect with growers to demonstrate the on-farm benefits of soil health. The profile of management practices matched what would be expected from prioritization of on-farm benefits, rather than of downstream environmental benefits. This is not to say that the growers in the sample are not concerned with off-farm benefits! Rather, advising that explains the on-farm benefits of soil fertility, builds awareness of the impacts of different management practices on

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soil health, and contributes to farmer awareness of soils is likely to be an effective strategy, more so than one that emphasizes downstream benefits of those same management practices.

The second chapter analyzed the impact of an education intervention focused on grower meetings and consultations, through the use of surveys, interviews, and post-visit reports. By linking program theory with agricultural innovation system theory, it identified key inputs that posed a challenge to the program – namely, staff structuring, a small number of nitrogen and irrigation experts on the team, and state university affiliation (although this also benefitted the program in other ways) – while documenting a high level of overall learning and adoption plans, based on participant self-report and staff perceptions.

The third chapter focused on on-farm advising services through a unique dataset of extension staff post-consultation reports. Perceptions of client receptiveness increased for in-person clients, with an increasing number of visits with the same farm operation, when the lead staff member could speak the client's primary language, and when the consultation topic was not related to regulations. Each of these aspects represents a phenomenon related to the development of personal trust rather than generalized institutional trust, indicating that consultations succeed in increasing client receptiveness over time by building personal trust.

Each chapter shows a different perspective on a central theme that extension is not simply about conveyance of technical information. It is also an opportunity to build shared language for improved communication (Chapter 1), to build an awareness of how ecosystem health metrics like soil fertility impact farm outcomes and how to manage accordingly (Chapter 1), to build

site-specific knowledge (Chapter 1 and Chapter 3), to connect across the agricultural innovation system to leverage the relative advantages of different actors (Chapter 2), and to support learning and innovation through development of trusted personal relationships (Chapter 3).

In light of this research, two significant questions remain, about advisor perceptions as compared to farmer perceptions and where extension efforts ought to be focused. Mismatched perceptions between advisors and clients feature in all three chapters: in Chapter 1, farmer perceptions of their soil texture were found to differ from official state resources, on which advisors and academics rely. In Chapter 3, advisor perceptions were used as an indicator of client receptiveness, although it was recognized that this may not necessarily match clients' own perceptions of their receptiveness, which can differ still from actual outcomes. In Chapter 2, some farmers stated that they did not perceive extension advisors to have practical in-field knowledge, yet this is exactly what happened in Chapter 3, when advisors provided farm-specific management advice and testing services and worked with growers to tailor their management plans.

Questions of where to focus intervention efforts also feature in multiple ways throughout this research. In Chapter 2, an extension program that was originally intended to target high nitrogen users did have a significant impact on learning among growers overall, but with little documented impact on high nitrogen users specifically. Should management intervention efforts necessarily focus on areas with the greatest environmental, biological, or agronomic need? This was not necessarily the case for the consultations discussed in Chapter 2 and Chapter 3, in which

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client interest is a main factor in clients reaching out for consultations and advisors having the ability to conduct follow-up visits. And yet, the bar for adoption—and thus, potential impact—is even higher than the bar for client openness, as seen in Chapter 3. This lends itself to an argument for focusing voluntary intervention efforts in situations with the highest potential buy-in, rather than directly aiming for those with the most severe management issues. If there is a barrier to openness, first make investments to overcome those barriers. For instance, extension support in multiple languages was important in both Chapter 2 for expanding the reach of extension and in Chapter 3 for building client receptiveness. Chapter 3 made a strong case for a strategy that goes directly to the client, focusing on a few, strong relationships that then catalyze change within a broader practitioner network, rather than a broadcast approach with many practitioners. These findings are relevant not only to extension, but also for planning and budgeting interventions in other information-sharing contexts, particularly those in which practitioners share strong networks (perhaps: fish, game, or forest managers, policymakers / regulators, communities of licensed professionals who undertake continuing education, contractors) and thus can multiply the impact of working with a single client.

The cases explored in this dissertation record successes in recent educational efforts with the goal of improving management and environmental outcomes, using the case of nitrogen and irrigation management in water-strained California. It also illuminates a path forward to increase impact, not only for extension, but for other management interventions as well. Though interventions may be developed at an institutional level, institutional trust alone will not

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necessarily maximize impact on practitioners, particularly for voluntary interventions. Shared language, connection to shared values, accounting for the particular strengths of the institutions leading the initiative, intentional partnerships, and personal relationships are powerful tools for enhancing impact.

APPENDICES

**APPENDIX A: SUMMARY OF VARIABLES USED FROM EACH DATA SOURCE
FOR CHAPTER 1**

Table A1: Variables Used from Grower Survey Data

Measure	Data Type	Interpretation	Submeasures
Use of Educational Services	Boolean, based on responses to a “check all that apply”	“Did you use any of the following information sources to inform your N management decisions on your operation?”	1: if answer includes at least one of -Pesticide Control Advisor -Certified Crop Advisor -UC Cooperative Extension 0: otherwise
Crop	Categorical	“Which crop...do you consider the most important to your farming operation?”	Write-in; condensed for statistical models to one of: Perennial fruit Nut Annual crop
Belief in the Importance of Soil Fertility	Integer 1-5	“How often are the following priorities when adopting nitrogen (N) management practices?”	5: Always 4: Often 3: Sometimes 2: Rarely 1: Never
Acreage of Most Important Field	Numeric	“How many acres is the largest field of your most important crop...?”	Write-in number of acres
Income Bracket	Integer 1-6	“Please estimate your annual gross farm-related income.”	1: Less than \$50K 2: \$50K-\$100K 3: \$100K-\$200K 4: \$200K-\$500K 5: \$500K-\$1 million 6: Greater \$1 million

Education Level	Integer 1-7	“What level of formal education have you completed?”	1: Primary school only 2: Some high school, no diploma ¹⁵ 3: High school degree or equivalent 4: Some college, no degree; or technical school 5: College education, associate’s degree 6: College education, bachelor’s degree 7: Graduate or Professional degree
Number of Years Farming	Numeric	“How many total years have you been working in agriculture?”	Write-in number of years
Reported Soil Type	Categorical	“How would you describe the dominant soil type on this largest field of your most important crop? <i>Select one soil type that fits best.</i> ”	Sand Sandy Loam Loamy Clayey Heavy clay I’m not sure
Grower ID	String	An anonymous numeric ID assigned by the Colusa Glenn Subwatershed Program to facilitate matching grower survey data to farm management data	NA

¹⁵ For four respondents who wrote in “reform school,” this was coded as “some high school, no diploma”

Table A2: Variables Used from Farm Management Data

Measure	Data Type	Interpretation	Submeasures
Nitrogen and Irrigation Best Management Practices Adopted	Integer 0-12, with transform	Number of best management practices used. See list of practices at right. A transform has been applied according to Sharabiani et al. (2023).	-Use of moisture probe / Soil Moisture Neutron Probe -Pressure Bomb -Use of ET in scheduling irrigations -Tailwater return system -Cover Crops -Split Fertilizer Applications -Soil Testing -Tissue / Petiole Testing -Variable Rate Applications using GPS -Foliar N application -Irrigation water N testing -Fertigation
Assessor Parcel Number	String	The Assessor Parcel Number of the management unit, which facilitates matching farm management data with county assessor data on the location and geometry of the field	NA
Crop	Categorical	Crop planted on the management unit	Name of crop; condensed for statistical models to one of: Perennial fruit Nut Annual crop
Irrigation Type	Categorical	Type of irrigation used on the management unit	Flood/furrow Microsprinkler Sprinkler Drip

Acreage of Management Unit	Numeric	Acreage of the management unit	NA
Total Farm Acreage	Numeric	Acreage of entire farm, made by summing acreage of all management units for a given farmer	NA
Grower ID	String	An anonymous numeric ID assigned by the Colusa Glenn Subwatershed Program to facilitate matching grower survey data to farm management data	NA

Table A3: Variables Used from County Assessor Data

Measure	Data Type	Interpretation	Submeasures
Assessor Parcel Number	String	The Assessor Parcel Number of the management unit, which facilitates matching farm management data with county assessor data on the location and geometry of the field	NA
Acres	Numeric	Number of acres of the parcel	NA
Geometry	Spatial	Set of Latitude and Longitude coordinates representing the perimeter of the parcel	NA

APPENDIX B: NOISE IN COUNTY ASSESSOR FILE YEAR

99.7 percent of management units had the same membership in the 2016 Colusa County Assessor file compared to the 2017 Colusa County Assessor file. That is, a given management unit was either present in both Colusa files or absent from both of them nearly 100 percent of the time. As 2016 or 2017 files were not available for Glenn County, the team proceeded with the analysis using Glenn County files from 2015, as the high consistency between assessor file years gave evidence to APN data consistency from one year to the next.

APPENDIX C: NOISE IN APN MATCHING

For the small number of APNs that are present in both Colusa County and Glenn County, county was determined using the grower survey question in which farmers are asked to list the counties they farm; if the grower reported fields in Glenn but not Colusa, or vice versa, this was coded as Glenn or Colusa, respectively. If the grower listed both counties or neither county, that parcel was removed from the dataset. The removed parcels represented only a small percentage of the original parcels. Out of all of the management units, 95.5% were found in at least one of the Glenn or Colusa County Assessor files. The level of overlap was also minimal, as only 5.7% of APNs were found in both Glenn and Colusa Counties.

The table below summarizes the count of the number of management unit combinations (i.e. observations in the farm management data for survey respondents) that match each combination of conditions. The column titles represent whether the APN matches an entry in the county assessor databases, and the row titles represent whether the grower reported farming in a

particular county. The bold values represent observations that were kept based on this matching process; the non-bold values represent observations that were removed from the dataset since they could not be reliably matched. In general, there is a high level of matching between APN county matches and grower self-reports, among those who answered the question: 91% of the management units could be matched to a unique county.

Table C1: Number of APN-Management Unit Combinations in which the APN is Found in the County Assessor Databases (Column headers) and in which the grower reports farming in a particular county.

	APN matches Colusa only	APN matches Glenn only	APN matches both Colusa and Glenn	APN matches neither	APN blank
Farms in Colusa only	629	1	47	21	3
Farms in Glenn only	0	562	38	36	6
Farms in both	156	143	21	21	1
Farms in neither	2	35	1	4	1
Farm location blank ¹⁶	85	76	12	13	2

¹⁶ “Farm location blank” indicates that the grower took the survey but did not answer the question about counties farmed.

APPENDIX D: NUMBER OF SOIL TYPES PER APN

Since there is some uncertainty matching management units to the correct polygon within the APN, we would hope to see that most APNs have only one broad soil textural class, to reduce the error in this analysis. This is the case, both when considering map-unit soil series-level soil textures and component-level soil textures.

Table D1: Summary Statistics of Number of Soil Types Per APN, Among APNs of Growers Included in the Study (Those Who Have an Identifiable “Most Important Field”)

	Number of map-unit level broad textural classes (sand, sandy loam, loamy, clayey/heavy clay, or NA) within the APN	Number of component-level broad textural classes (sand, sandy loam, loamy, clayey/heavy clay, or NA) exceeding 20% of the APN area
Minimum value	1.0	1.0
1st quadrant	1.0	1.0
Median	1.0	1.0
Mean	1.5	1.0
3rd quadrant	2.0	1.0
Maximum value	4.0	3.0

APPENDIX E: APN TO MOST IMPORTANT FIELD MATCHING

Management data was available for every field for growers who completed the survey. A single grower can have multiple fields. Only fields that could reasonably be matched to a grower's reported "most important field" were included in the analysis.

- 990 fields were discarded for not matching the reported crop of a grower's most important field.
- Of the remaining potentially "important fields",
 - 147 fields were a unique match, such that the field with the minimum difference in acreage between coalition reports and grower reports is within 20% of the target acreage.
 - 201 fields were designated as "partial", such that they could be combined with other fields owned by the same grower to create a field with a good match, within 20% of the target acreage.
 - 29 fields were designated as "tied possible," indicating that either there were ties for best acreage match, or that the acreage did not fall within 20% of the target.
 - 26 fields were designated as "large possible", indicating that the field with the minimum difference in acreage between coalition and grower reports is more than 20% larger than grower reports of the acreage of their most important field. In this case, all "large possible" fields from a single grower were added together.

- 56 fields were designated as “candidate”, in which the grower did not fill out the survey question regarding the acreage of their most important field. In this case, all candidate fields for a single grower were added together.
- 196 fields were designated as “in other county.” This designation indicates that a match or combination of matches within 20% acreage could not be identified, and the grower indicated on their survey that they farm in counties other than Glenn and Colusa. These growers were removed from the analysis, as it was assumed that their most important field was in a different county.
- The 118 remaining fields were designated as “no candidate fields.” This designation indicates that no good match or combination of matches within 20% acreage could be identified, but the grower did not indicate that they farm in other counties. These growers were removed from the analysis, since a match could not reliably be made.

APPENDIX F: RELATIONSHIP BETWEEN GROWER SURVEY QUESTION**ATTEMPT AND SSURGO DATA**

There is no significant relationship between the likelihood of growers responding "I don't know" to the survey question about soil texture and the proportion of any particular USDA texture categories present on their property.

Table F1: Pearson's Correlation Tests Between Grower Reporting "I don't know" or Blank and Area-Weighted Soil Texture According to SSURGO

	Correlation Estimate	Confidence Interval
Percent of field area in clayey/heavy clay	-0.083	[-0.20, 0.041]
Percent of field area in loamy	-0.056	[-0.18, 0.067]
Percent of field area in sand/sandy loam	0.099	[-0.025, 0.22]

APPENDIX G: TABULAR RESULTS FOR BINOMIAL LOGIT MODELS

Table G1: Farmer Agreement with SSURGO Regarding Dominant Soil Type (0/1) as a Function of Belief in the Importance of Soil Fertility, Use of Educational Services, and Available Resources (75 observations removed due to missingness¹⁷)

	Estimate	Std. Error	Z value	Pr(> z)
(Intercept)	-1.24	0.66	-1.9	0.061
Belief in the Importance of Soil Fertility (scaled)	0.49	0.23	2.1	0.034 *
Use of Educational Services	0.64	0.70	0.92	0.36
Education Level (scaled)	0.20	0.17	1.2	0.23
Income Bracket (scaled)	0.30	0.18	1.7	0.099
Total Farm Acres (scaled)	-0.081	0.14	-0.56	0.57

¹⁷ We do not conduct multiple imputation in these models, because we have reason to believe that the missing data itself encodes information (Missing Not at Random, in the schematic of Rubin 1976) related to general engagement and/or level of suspicion regarding the survey, that is not necessarily extractable from the other answers on the survey.

Table G2: Binomial Logit Model Predicting Management Practice Use: Fixed Effect Results (n = 2352)

	Estimate	Std. Error	z-value	Pr(> z)
(Intercept)	-2.99	0.51	-5.81	4.3e-9
Farmer Agreement with SSURGO (0/1)	0.21	0.16	1.30	0.19
Belief in the Importance of Soil Fertility (scaled)	0.20	0.098	2.00	0.046
Use of Educational Services (0/1)	1.45	0.37	3.90	9.7e-5
Education Level (scaled)	0.18	0.080	2.22	0.026
Total Farm Acres (scaled)	0.18	0.074	2.41	0.016
Practice Category: Nitrogen (baseline: Irrigation)	0.65	0.11	6.12	9.5e-10
Soil Diversity	0.30	0.079	3.77	1.7e-4
Sand/Sandy Loam as Proportion of Field Area	-0.26	0.078	-3.32	9.1e-4

Table G3: Binomial Logit Model Predicting Management Practice Use: Random Effect Results (n = 2352)

Groups	Variance	Std. Dev.	Num Groups
surveyID	0.59	0.77	196
cropgroup	0.39	0.62	3

APPENDIX H: RELATIONSHIPS BETWEEN NUMERIC VARIABLES IN CHAPTER 1

Figure H1: Correlation Between Numeric Variables

APPENDIX I: SUPPLEMENTARY INFORMATION FOR CHAPTER 2

Table I1: Number of Central Coast ranches using nitrogen and irrigation management practices compared to NII grower meeting participant self-reports of use and inclusion in meeting agenda

Practice	Number of Ranches*	Rank in Reported Usage by Survey Participants	Rank as Discussed in Program Meetings, As Reported by Survey Participants
Irrigation system maintenance	2331	5	13
Split fertilizer applications	2179	6	6
Fertigation	1929	9	11
Use of a nitrogen budget	1741	4	1
Testing for N in irrigation water	1421	3	3
Soil sampling	1353	1	2
Using irrigation records or flowmeter	1324	10	12
Estimating ET for irrigation scheduling	1298	8	4
Leaf sampling	1092	2	5
Soil moisture sensors, probe, or auger	1019	7	9
Cover crop	806	13	10
Compost or manure	761	11	14
Plant-based sensor to measure water stress	551	14	8
Distribution uniformity testing	525	12	7

*Number of ranches is based on data from California Water Boards Central Coast R3 (2024).

Key Informant Interviews were coded using structural coding, in vivo coding, and concept coding to catalog topics that arose in the interviews and values coding to catalog informants' opinions. The lead researcher coded all interviews and conducted thematic analysis

to summarize and convey patterns of ideas that surfaced within the dataset, to group these codes into broader themes. Three research assistants read through a sample of 50 segments from each code as a validation step and Cohen's Kappa was calculated based on two reviewers' initial determination for the segments in the sample.¹⁸ Following this process, the samples were discussed until consensus was reached for each segment, and the results of this discussion were used to inform the final codings. For codes marked with lower Cohen's Kappa values marked with (*), an additional sample of 50, or all remaining codes if less than 50 remained, was used for validation and consensus-building.

Table I2: Qualitative Codes, Cohen's Kappa Based on Sample, and Final Number of Segments

Code	Number of Segments	Cohen's Kappa	Code	Number of Segments	Cohen's Kappa
Crop Type	125	0.82	Learning Outcomes*	70	0.86
Farm Scale	119	1.0	Reach of Extension*	230	0.78
Irrigation Usage	122	0.98	Staff Capacity	67	0.89
Typical Practice Use	321	0.90	Workforce Development	80	0.99
On-Farm Constraints*	209	0.78	Internal Coordination	57	0.93
Actual or Planned Practice Adoption	168	0.91	External Coordination	52	0.91

¹⁸ For codes with fewer than 50 segments, all segments were validated.

Structure of Information Sharing*	153	0.80	Timeline of Extension Actions	16	0.93
Information Supply and Gaps	221	0.84	Timeline of Practices and Environment	21	0.88

Table I3: Summary of Results

Logic Model Component	Topic	Themes	Takeaways	Illustrative Quote or Statistic
Inputs	Staff Availability	Hiring and Retention	Hiring challenges and poor retention	“Usually, by the time you get the money and you hire the person, the money has expired and the person is just starting.” -Extension Staff Member
	Staff Capacity	Match between Staff Capabilities and Project Activities	Junior staff helpful with technical tasks; project made unrealistic assumptions concerning their capabilities. Nitrogen and irrigation management matched some advisor skill sets but not others	“It’s an issue with academia in general that they keep trying to push work onto lower and lower paid employees.” -Extension Staff Member
	Coordination	Project Design	Lack of advisor input during project design	“[The team] probably could have figured out when and how many events were reasonable...but proposals are thrown together really fast...and then you figure it out later.” - Extension Staff Member

		Internal Coordination During Project Implementation	Improvements made, but opportunity for more	“We have a good team right now... We want to set up future incoming generations of UCANR employees, so we’re going to work on... providing tools and materials so that if there is turnover, hopefully it can be smoother and they can learn from our mistakes.” -Extension Staff Member
		External Coordination	Generally positive, but uneven and sometimes rushed	“[Our collaboration] was good. I don’t think it was great. But it was a good starting point.” -Project Partner
	Available Knowledge	Scientific Knowledge	Staff utilize university research; specialization and incomplete scientific information can reduce grower trust	“For the most part, [extension advisors are] just scientists, and the real application sometimes is missing.” -Grower
		On-Farm Knowledge	Yield uncertainty and disconnects between farm staff can influence ability to follow extension recommendations	“The people that are running the show:... irrigators... don’t have a lot of training... So convincing one person in the operation to do something often doesn’t lead to anything [happening].” -Extension Staff Member
	Activities	Number of Activities	Many events throughout project area; many consultations on Central Coast	84 events with 3000+ attendees total; 472 consultations, concentrated in Central Coast counties
		Activity Topic	Consultations focused on monitoring and maintenance; grower meetings favored general principles	A balance of topics is discussed at meetings, particularly nitrogen testing and irrigation monitoring tools (Figure 2.4). Most common practice discussed in consultations is irrigation records and flowmeters (Figure 2.6).

		Meeting Content and Format	Challenging to meet all participant needs without causing information overload; Mixed reports on efficacy of lecture format	“[W]hat happens is, we go to these meetings, there’s so much information, you don’t know what to take home.” -Grower “There was a lot of great information...but it is just not practical in a way where the growers are going to engage...I just think the setting is not the right setting.” -Grower
		Consultation Follow-Up	Uneven follow-through in consultations	“Reviewing the data with your grower...and then making adjustments...that’s how I see a good follow-up report with the grower.” -Extension Staff Member “I never follow up with them [to see if they have adopted my recommendations].” Probably I should. -Extension Staff Member
Outputs	Participants Reached	Crop	Participation shaped by common crops in each area and advisor expertise	“Part of the difference between us and the other members of the NII is that we’re out here on the coast, we’re primarily berries and vegetables, and they’re primarily tree crops, not exclusively.” -Extension Staff Member “The concentration of crops [is] leaning too much on the perennial tree crops...We don’t have grape vines....Where’s alfalfa? Where’s corn? So are they part of the NII?” -Extension Staff Member
		Scale	Participants span a range of farm scales;	“[My clients range] anywhere from 10 acres up to 10,000 acres

			small and large growers benefit from the program	or more.” -Extension Staff Member
		Incentives	Meager financial incentives for growers limit participation	“What if growers want something like financial incentives? They have SWEEP, they have Healthy Soils. Those can offer way more supplies than we ever can.” -Extension Staff Member
Outcomes: Knowledge	Learning Experience	Learning at Meetings	Survey respondents report high learning. Interview participants have mixed reports	“Well, [the advisor] at this last meeting suggested that idea and by God, I guarantee it: this summer, we are going to back off on the water.” -Grower “Well, mostly it’s repeat information...As far as the nitrogen management goes, the only reason we show up is just because they tell us we have to, okay? I am already on drip irrigation...We are already as efficient as even their people think we can possibly be.” -Grower
		Learning in Consultations	Advisors find that their clients value their advice and are open to their ideas	Advisors “strongly agree” that their clients are typically open to their advice and value the information they provide (Figure 2.10).
Outcomes: Action	Behavioral Outcomes	Improvement of Existing Practices	Growers learned how to improve their implementation	Growers commonly learned to improve upon a practice they already implement (Figure 2.13).
		Adoption of New Practices	Growers report plans to adopt new practices	Growers – particularly those who attended NII-hosted events rather than invited talks by an NII staff member – report plans

				to adopt new practices (Figure 2.12).
		Adoption of Consultant Recommendations	Advisors report high likelihood of client adoption of recommendations	Advisors generally “strongly agree” that their client is likely to adopt their recommendations (Figure 2.14).
		Limitations of Approach	Insufficient data to determine efficiency; short-term program limits effectiveness	“My feeling is the weakness of the NII project is that we’re offering a smorgasbord of practices, but we’re not actually measuring how efficient people are... Just because they check all those boxes doesn’t mean they’re efficient.” -Extension Staff Member “Well, essentially, I’ve been around a long time and so some people have just come back to me after five years or six years and say, ‘Well, now we would like to work on this.’ So luckily, I’m still here.” -Extension Staff Member
		Addressing Barriers to Adoption	NII helped growers overcome adoption barriers; affiliation with university is polarizing for grower trust	“I rely a lot on University of California’s opinions because I feel it’s a more unbiased opinion versus getting it from somebody that is trying to sell me a product.” -Grower “Being associated with the university, there’s a suggestion that you’re kind of following their line...the line of this moneyed interest that’s influencing the university.” -Extension Staff Member
Outcomes: Conditions	Difference of Scale	Difficult to Assess Impact	Limited potential for monitoring long-term	“[Groundwater is] a long term thing...[There is] lots of progress that could be made

			impacts of a short-term educational program	[but] because of the legacy impacts...it can be hard to show progress.” -Project Partner
External Factors	Incentives and Compliance	Regulatory Context	Limits interest in program, particularly in Central Valley	“[Even though some people] can tell regulation is coming, you can’t say what that’s going to look like. And so...a lot of growers, they’re not going to want to change their practices to prepare for something that’s as yet undefined.” -Extension Staff Member “If someone reaches out to me for help, they want my help. And I think part of the issue with this nitrogen irrigation project is that it is expecting us to go get people who don’t want help, help.” -Extension Staff Member
		Facilitating Compliance	NII helps increase reporting compliance	“A lot of [small] growers...don’t understand why or how they are submitting these reports and why they are giving us samples. And I think that they did it purely because they trust us and they know that we’re helping them.” -Extension Staff Member

APPENDIX J: SENSITIVITY ANALYSIS REMOVING MOST FREQUENT CLIENT

A table summarizing the results of the sensitivity analysis is included below. For the sensitivity analysis with the longest-standing client removed, Model 2A is a marginal improvement upon Model 1A in terms of variance explained.

Hypothesis 1 is supported, largely mirroring the support of the main models. As in the main models, there is a significant, positive relationship between the log of the consultation number and the odds of the advisor responding “strongly agree” compared to “somewhat agree” on receptiveness questions. For the comparison between “Neutral or Disagree” and “Somewhat Agree”, the p-value for log consultation number in Model 1A is less than 0.001, while the p-value in Model 2A is between 0.05 and 0.1, with coefficients in both models matching the expected direction.

The interaction term in Model 2A supports the second portion of Hypothesis 1, as opposed to Model 2, which did not clearly support the hypothesis. In Model 2A, long-term clients appear more receptive to recommendations geared toward intensive management change, only at the comparison between “Neutral or Worse” and “Somewhat Agree.” Long-term clients who work on intensive management topics are relatively unlikely to have a perceived receptiveness of “neutral or disagree” and are more likely to be at least somewhat receptive, compared to other clients.

As in the main models, Hypothesis 2 is supported in both Model 1A and Model 2A, only when predicting “Neutral or Disagree” compared against “Somewhat Agree”. This indicates that an in-person visit may promote moderate receptiveness for a client who otherwise is likely to not

be receptive at all, but have little impact on a client who is already likely to be at least somewhat receptive.

Hypothesis 3 is strongly supported, as in the main models. The coefficient for regulatory topics is positive and significant at the 0.05 level for the “neutral or disagree” outcome compared to “somewhat agree”, both for Model A1 with no interaction and for Model A2 with the interaction. The coefficients for the “Strongly Agree” vs “Somewhat Agree” are in the hypothesized direction, but the p-values are greater than 0.2.

Hypothesis 4, anticipating that receptiveness will be higher if the specialist speaks the primary language of the client, was confirmed at the “strongly agree” versus “somewhat agree” comparison, as in the main models. There is no statistically significant effect for either model at the “somewhat agree” level compared to the “neutral or disagree” category.

As in the main models, there is some support for Hypothesis 5, regarding the decreased likelihood of adoption relative to openness to advice. In both models, the logit of advisors responding “strongly agree” relative to “somewhat agree” is significantly decreased for the “likely to adopt” question compared to the “open to the ideas discussed” question, supporting the hypothesis. For the “somewhat agree” level compared to “neutral or disagree,” the logit is increased for the “likely to adopt” question in the hypothesized direction, with a p-value between 0.1 and 0.05.

Table J1: Sensitivity Analysis Removing Most Frequent Client: Model 1A with No Interaction Term (N = 1427)

	“Neutral or Disagree” (vs. “Somewhat Agree”)			“Strongly Agree” (vs. “Somewhat Agree”)		
	Estimate	SE	p.value	Estimate	SE	p.value
Intercept	0.282	0.592	0.635	0.596	0.608	0.327
ln(Consultation Number)	-0.641	0.121	<0.001	0.303	0.079	<0.001
Intensive Management Topic	-1.252	0.294	<0.001	0.128	0.193	0.506
In Person	-0.672	0.285	0.019	0.097	0.190	0.609
Values Info (Baseline = Openness)	-0.344	0.269	0.202	0.079	0.167	0.636
Likely to Adopt (Baseline = Openness)	0.393	0.232	0.091	-0.710	0.166	<0.001
Regulatory Topic	0.992	0.363	0.006	-0.325	0.273	0.234
Language Match	-0.253	0.356	0.478	0.804	0.259	0.002
Num. Obs.	1427					
AIC	2201.9					

Table J2: Sensitivity Analysis Removing Most Frequent Client: Model 2A with Interaction Term (N = 1427)

	“Neutral or Disagree” (vs. “Somewhat Agree”)			“Strongly Agree” (vs. “Somewhat Agree”)		
	Estimate	SE	p.value	Estimate	SE	p.value
Intercept	-0.001	0.603	0.999	0.608	0.620	0.327
ln(Consultation Number)	-0.351	0.185	0.058	0.300	0.133	0.024
Intensive Management Topic	-0.799	0.367	0.029	0.101	0.264	0.703
In Person	-0.650	0.284	0.022	0.100	0.190	0.599
Values Info (Baseline = Openness)	-0.346	0.270	0.199	0.079	0.167	0.635
Likely to Adopt (Baseline = Openness)	0.398	0.233	0.087	-0.709	0.166	<0.001
Regulatory Topic	1.031	0.365	0.005	-0.320	0.274	0.242
Language Match	-0.238	0.355	0.502	0.801	0.260	0.002
ln(Consultation Number) : Intensive Management Topic	-0.508	0.238	0.033	0.018	0.158	0.911
Num. Obs.	1427					
AIC	2200.4					

APPENDIX K: SENSITIVITY ANALYSIS WITH REGION EFFECT IN PLACE OF SPECIALIST EFFECT

The results of the sensitivity analysis are included in the table below. For the sensitivity analysis with region instead of specialist, Model 2B and Model 1B are very similar in terms of variance explained.

The support for Hypothesis 1 largely mirrors that of the main models. As in the main models and in the Appendix J sensitivity analysis, there is a positive relationship between the log of the client's number of visits at that time and the odds of the advisor responding "somewhat agree" compared to a neutral or negative response on receptiveness questions. Likewise, as hypothesized, there is a negative relationship between number of client visits and the odds of a "neutral or disagree" response compared to "somewhat agree."

There is no support for the second portion of Hypothesis 1 regarding the interaction effect between number of consultations and topic. In the model with the interaction term, the absolute value of the coefficient for the interaction term in the comparison between "Strongly Agree" and "Somewhat Agree" is lower than it is in the main Model 2, with a p-value between 0.1 and 0.05. A clue for this behavior comes in the difference in the estimate for the intensive management topic effect, particularly for the "strongly agree" response logit, compared to the main model estimates. Since each advisor has a different breakdown of consultation topic areas based on their strengths and specialization, the lack of accounting for specific advisors could be impacting the apparent effect of consultation topic on receptiveness. Although an effort has been made in the main models to account for the effect of working with a particular individual specialist (or an

alternative explanation, the advisors’ differing baseline interpretations of “receptiveness”), it is possible that there is a more complex effect on receptiveness involving a combination of topic and advisor, such as working with an advisor on one of their best specialties.

The models in Appendix K do not support Hypothesis 2. There is no clear effect between the impact of in-person visits and receptiveness.

Support for Hypothesis 3 and Hypothesis 5 matches that of the other models. The effect of regulatory topics is apparent in the “neutral or disagree” vs “somewhat agree” comparison, and the effect of “likely to adopt” is significant in the “strongly agree” vs “somewhat agree” comparison

Support for Hypothesis 4 as seen in the comparison between “Strongly Agree” and “Somewhat Agree” is not as clear as in the other models. The effect is still in the hypothesized direction, but the coefficients for language match are smaller here, and the p-values for language match in Models 1B and 2B are now between 0.05 and 0.1, and between 0.1 and 0.2, respectively.

Table K1: Sensitivity Analysis With Region Effect in Place of Specialist Effect: Model 1B with No Interaction Term (N = 1627)

	“Neutral or Disagree” (vs. “Somewhat Agree”)			“Strongly Agree” (vs. “Somewhat Agree”)		
	Estimate	SE	p.value	Estimate	SE	p.value
Intercept	0.026	0.419	0.950	1.398	0.292	<0.001
ln(Consultation Number)	-0.306	0.094	0.001	0.122	0.056	0.029

Intensive Management Topic	-0.523	0.230	0.023	-0.655	0.148	<0.001
In Person	-0.105	0.236	0.655	-0.189	0.158	0.233
Values Info (Baseline = Openness)	-0.287	0.255	0.260	0.081	0.154	0.599
Likely to Adopt (Baseline = Openness)	0.202	0.217	0.351	-0.721	0.148	<0.001
Regulatory Topic	0.625	0.318	0.049	0.282	0.244	0.249
Language Match	-0.003	0.294	0.991	0.403	0.220	0.066
Central Coast	-0.232	0.255	0.363	-0.216	0.173	0.213
Num. Obs.	1627					
AIC	2692.3					

Table K2: Sensitivity Analysis With Region Effect in Place of Specialist Effect: Model 2B with Interaction Term (N = 1627)

	“Neutral or Disagree” (vs. “Somewhat Agree”)			“Strongly Agree” (vs. “Somewhat Agree”)		
	Estimate	SE	p.value	Estimate	SE	p.value
Intercept	-0.013	0.436	0.977	1.204	0.307	<0.001
ln(Consultation Number)	-0.285	0.148	0.055	0.266	0.095	0.005

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Intensive Management Topic	-0.459	0.313	0.142	-0.317	0.224	0.157
In Person	-0.112	0.236	0.637	-0.189	0.158	0.232
Values Info (Baseline = Openness)	-0.288	0.255	0.259	0.082	0.154	0.595
Likely to Adopt (Baseline = Openness)	0.202	0.217	0.351	-0.723	0.148	<0.001
Regulatory Topic	0.649	0.318	0.041	0.340	0.245	0.166
Language Match	-0.031	0.249	0.917	0.346	0.221	0.116
Central Coast	-0.228	0.256	0.374	-0.174	0.174	0.318
ln(Consultation Number) : Intensive Management Topic	-0.001	0.186	0.995	-0.222	0.114	0.051
Num. Obs.	1627					
AIC	2691.5					

APPENDIX L: SENSITIVITY ANALYSIS WITH BINARY PRIOR CONSULTATION EFFECT

Appendix L investigates the impact of at least one prior consultation compared to no prior consultations. This is included as a sensitivity analysis, to reduce the leverage of points in the dataset for which the number of prior consultations is very high. The results for the model using the binary metric for prior consultations here in Models 1C and 2C largely match the main models. In general, the level of support for Hypothesis 1 regarding the impact of repeated consultations in these models as seen through the coefficient for “Has Prior Consultations” is comparable to that of the main models. One exception is in Model 2C with the interaction effect, the effect of prior consultations is eroded. One possible interpretation is that a larger number of consultations, rather than simply at least 2, is what brings clients to the highest level of receptiveness.

Table L1: Sensitivity Analysis with Binary Effect for Prior Consultations: Model 1C with No Interaction Term (N = 1627)

	“Neutral or Disagree” (vs. “Somewhat Agree”)			“Strongly Agree” (vs. “Somewhat Agree”)		
	Estimate	SE	p.value	Estimate	SE	p.value
Intercept	0.292	0.552	0.596	0.736	0.618	0.234
Has Prior Consultations	-0.857	0.208	<0.001	0.326	0.158	0.039
Intensive Management Topic	-1.000	0.270	<0.001	-0.082	0.176	0.642

In Person	-0.647	0.268	0.016	0.201	0.178	0.258
Values Info (Baseline = Openness)	-0.309	0.258	0.231	0.106	0.159	0.504
Likely to Adopt (Baseline = Openness)	0.242	0.220	0.271	-0.820	0.155	<0.001
Regulatory Topic	0.974	0.358	0.007	-0.422	0.272	0.122
Language Match	-0.252	0.350	0.471	0.849	0.260	0.001
Num. Obs.	1627					
AIC	2502.9					

Table L2: Sensitivity Analysis with Binary Effect for Prior Consultations: Model 2C with Interaction Term (N = 1627)

	“Neutral or Disagree” (vs. “Somewhat Agree”)			“Strongly Agree” (vs. “Somewhat Agree”)		
	Estimate	SE	p.value	Estimate	SE	p.value
Intercept	0.064	0.582	0.913	0.847	0.631	0.179
Has Prior Consultations	-0.581	0.297	0.050	0.195	0.233	0.402
Intensive Management Topic	-0.633	0.376	0.092	-0.300	0.290	0.301
In Person	-0.635	0.268	0.018	0.208	0.178	0.242

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Values Info (Baseline = Openness)	-0.310	0.258	0.230	0.107	0.159	0.503
Likely to Adopt (Baseline = Openness)	0.247	0.220	0.261	-0.820	0.155	<0.001
Regulatory Topic	1.019	0.361	0.005	-0.430	0.273	0.115
Language Match	-0.228	0.350	0.516	0.845	0.260	0.001
Has Prior Consultations : Intensive Management Topic	-0.642	0.404	0.112	0.282	0.306	0.357
Num. Obs.	1627					
AIC	2501.0					