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Linking Agronomic and Knowledge Barriers to Adoption of Conservation Practices for Nitrogen Management

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Agricultural nitrogen (N) use is a major contributor to environmental problems arising from nitrous oxide emissions and N loading to groundwater. Advances in the adoption of conservation practices requires a better understanding of the agronomic context for cropping systems. This paper tests hypotheses about how agronomic and knowledge barriers influence the adoption of conservation practices for N management in orchard agroecosystems. Agronomic barriers are characterized by farm size, irrigation systems and access to water resources, and knowledge barriers are influenced by the availability of information and use of information sources. Our study focuses on the California's San Joaquin Valley where we collected 879 in-person surveys from fruit and nut growers focused on ten different conservation practices related to fertilizer use, irrigation and soil health. We used logistic regression models to identify parameters influencing adoption and differences in adoption between fruit and nut growers. Our results indicate that overall growers report higher adoption for practices for fertilizer use compared to irrigation and soil health. Growers with larger parcels, microirrigation and more water security had a higher probability of practice adoption. Nut crops are more agronomically intense than fruit crops requiring higher rates of N fertilizer and water use. Nut growers adopted significantly more practices than fruit growers, and also utilized significantly more information sources and experienced significantly fewer practice challenges. Our results collectively support our hypotheses that agronomic and knowledge barriers differ between fruit and nut growers, and help to explain the variance in adoption of conversation practices in orchard agroecosystems. Furthermore, the significance of our work offers a case study for other regions and agroecosystems to address the need for linking agronomic and knowledge barriers to adoption in an effort to promote global climate-smart and regenerative agriculture initiatives.

Keywords: fertilizer use, soil health, irrigation, marginal effects, fruits and nuts

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INTRODUCTION

This paper analyzes how agronomic and knowledge barriers differ between fruit and nut growers and how these barriers influence the propensity for adoption of conservation practice for nitrogen (N) management. Agricultural N use is a major contributor to environmental problems arising from nitrous oxide emissions (Reay et al., 2012; Kuang et al., 2021) and N loading to groundwater (Rosenstock et al., 2014). In California, many farming regions grapple with groundwater supplies with nitrate (NO_3^-)concentrations above the maximum contaminant level of 10 mg NO_3^--N L^{-1} for drinking water (Tomich, 2016). The low cost of N fertilizer relative to the high value of fruit and nut crops creates reluctance among growers to implement lower N rates (Pannell, 2017). To address this water quality issue, California became one of the first states in the U.S. to implement a regulatory program for agricultural nonpoint source pollution (Dowd et al., 2008), where adoption of conservation practices to improve N use efficiency (NUE) is required to reduce N loading to groundwater (Khalsa and Brown, 2019).

The effectiveness of regulatory programs depends on understanding the drivers of farmer practice adoption behavior, which has been extensively researched since the 1930s (Ryan and Gross, 1943; Rogers, 1961; Lynne et al., 1988; Padel, 2001). The literature has demonstrated some consistent predictors of behavior such as farm size (Daberkow and McBride, 2003; Prokopy et al., 2008), information sources (Padel, 2001; Lubell and Fulton, 2007; Kassie et al., 2015; Houser et al., 2019), and positive attitudes toward conservation and farmer income and level of education (Prokopy et al., 2019). However, a major knowledge gap in the adoption literature is the extent to which drivers of adoption vary across agroecosystems and agronomic contexts, for example between different cropping systems (Knowler and Bradshaw, 2007; Prokopy et al., 2019). In our qualitative field research, farmers often expressed the sentiment that a certain practice "just doesn't work on my farm" for a variety of reasons. Hence, we require additional insights to understand why certain practices are more prevalent among certain cropping systems and how agronomic and knowledge barriers vary across agroecosystems (Giller et al., 2015).

Comparing fruit and nut crops in California provides an excellent opportunity to examine how barriers to adoption vary across agroecosystems. In the San Joaquin Valley, fruits and nuts are planted on over 600,000 hectares with an annual production value of over US$15 billion (USDA, 2018). Our analysis compares growers of fruits and nuts in terms of agronomic differences in their cropping systems, as well as their levels of knowledge and perceived challenges. This comparison is grounded in the fact that nut crops have higher N and water demand due to greater N contents (15 – 70 kg N mt^{-1}) and higher net primary productivity (Khalsa et al., 2020) compared to fruit crops (1 – 10 kg N mt^{-1}) (Smart et al., 2011). Thus, gains in NUE for nut crops have a greater potential to reduce N loading to groundwater compared to an equal gain in NUE for fruit crops. As a result of high N and water use California nut crops have been the focus of significant research and extension efforts (Khalsa and Brown, 2019) with fewer resources devoted to a wide variety of fruit crops.

Existing research suggests understanding local variables in agroecosystems like climate, slope, soil type and crop type is necessary to further explain adoption behavior (Reimer et al., 2014). In China for example, climate impacted soil conservation practices where only regions with lower precipitation and higher temperature significantly improved grain yield under no-tillage (Zheng *et al.*, 2014). In Spain, farm slope played an essential role in the adoption of soil conservation practices in olive groves (Rodríguez-Entrena and Arriaza, 2013). In Italy, soil type affected the adoption of no-tillage where farmers on fine-textured soil were more likely to adopt compared to farmers on more sandy soil. (Pagliacci et al., 2020). In California's water limited climate, greater water demand in nut crops encourages conversion to microirrigation, which paves the way for the adoption of suites of conservation practices. (Lopus et al., 2010; Taylor and Zilberman, 2017; Rudnick et al., 2021). To that end, we expect growers who use more N and water inputs to have more awareness and incentives to adopt conservation practices.

California fruit and nut growers also differ in terms of the amount of education and outreach effort they have received, and thus the extent to which they experience knowledge barriers (Tucker and Napier, 2002; Lubell and Fulton, 2007; Houser et al., 2019). Within nutrient management, the 4R framework is adaptable to different cropping systems and describes how to utilize the right rate, time, placement and source of N fertilizers (Bryla, 2020; Fixen, 2020). In almond cropping systems, researchers worked to establish the right rate and timing of N fertilizer (Muhammad et al., 2015; Muhammad et al., 2018; Muhammad et al., 2020); improved the utility leaf sampling (Saa et al., 2014); and demonstrated proper placement of N fertilizer sources (Schellenberg et al., 2012; Alsina et al., 2013; Wolff et al., 2017), results of which have also extended to inform other nut crop management like walnut and pistachio (Muhammad et al., 2019). Advances in conservation practices for fruit crops have also been beneficial for citrus (Martínez-Alcántara et al., 2012; Quaggio et al., 2014), peach (Rufat and DeJong, 2001; El-Jendoubi et al., 2013), table grapes (Williams, 2017) and winegrapes (Lambert et al., 2008). However, unlike nuts, there is a limited transferability of knowledge due to the higher diversity in fruit species, and a greater focus on improving fruit quality (Tagliavini and Marangoni, 2002). Thus, knowledge barriers hamper further extending research and education to fruit growers leading to an incomplete knowledge base to foster conservation practice adoption.

This paper addresses the agronomic and knowledge barriers to adoption of conservation practices for N management using different cropping systems of fruits and nuts in the San Joaquin Valley, California as a case study. We consider two different hypotheses to explain differences in adoption: H1*) agronomic barriers*, characterized by farm size, irrigation systems and access to water resources, as well as differences in N and water use, explain differences in adoption of conservation practices between fruits and nuts; and H2) *knowledge barriers*, influenced by the availability of information for fruits and nuts, and availability of information sources by growers, explain differences in adoption of conservation practices between fruits and nuts. We focus on ten conservation practices including split fertilizer N application, soil sampling for residual NO_3^-, leaf N sampling for crop N status, use of an N budget, measuring of irrigation distribution uniformity, irrigation scheduling by evapotranspiration (ET), deployment of soil sensors, measuring water stress with a pressure chamber, use of cover crops, and use of organic matter amendments, each of which results in potential improvements in NUE. This research aims to understand adoption of conversation practices related to fertilizer use, irrigation and soil health with a focus on agronomic and knowledge barriers.

MATERIALS AND METHODS

Research Context and Sampling Approach

The focus of this study was related to water quality issues of nitrate in groundwater. The study region is the San Joaquin Valley, an area of California's Central Valley that lies south of the Sacramento-San Joaquin River Delta. The region is dominated by livestock operations and irrigated agriculture, with fruits and nuts planted on over 600,000 ha with an annual production value of over US$15 billion in 2017 (**Table 1**). Many rural areas in the regions have groundwater resources above the maximum contaminant level of 10 mg NO_3^--N L^{-1}. In response to nitrate pollution in groundwater, the California State Water Quality Control Board instituted the Irrigated Lands Regulatory Program (ILRP) where local groups known as "Water Quality Coalitions" implement mandatory reporting elements and participation in education events focused on best management or conservation practices for its grower members (Central Valley Regional Water Quality Control Board, 2020). The governance structure of the ILRP includes state-mandated data collection of irrigation, N use and conservation practice adoption from all grower management units, that is collected and collated at the local water quality coalition level. This unique approach to addressing non-point source pollution stands in contrast to programs relying principally on voluntary participation (Hillis et al., 2018; Reimer et al., 2018). The reliance of the ILRP on grower adoption of conservation practices motivated this study to understand how adoption and barriers vary across agroecosystems.

Survey data collection was conducted in-person at annual grower meetings hosted by the San Joaquin Delta and County Water Quality Coalition and East San Joaquin Water Quality Coalition in the North San Joaquin Valley, whose memberships includes over 7,900 grower members, and the Southern San Joaquin Valley Management Practice Evaluation Program representing Water Quality Coalitions in the Southern San Joaquin Valley, whose memberships is made up of over 10,700 grower members. A total of 16 in-person meetings were attended from January to April in 2017 and 2018 (**Figure 1**). The meeting

TABLE 1 | Fruits and nut crops with nitrogen (N) intensity reported as N in the harvested crop, total crop area in hectares (ha), crop production in metric tons (mt) and crop value in $US millions from 2017 for the San Joaquin Valley, California U.S.A.

Crop and N Intensity			Area	Production	Value
Fruit and Nuts	**N in harvested crop[1]**		***ha*[3]**	***mt*[3]**	***$US million*[3]**
Apples	0.54	kg/mt fruit	1,640	43,932	24
Apricots	2.78	kg/mt fruit	2,944	67,652	71
Cherries	2.21	kg/mt fruit	14,344	69,776	265
Figs	1.27	kg/mt fruit	2,264	8,423	22
Grapefruit	1.48	kg/mt fruit	1,061	27,984	27
Grapes - Raisin	5.05	kg/mt fruit dried	53,553	1,299,749	434
Grapes - Table	1.13	kg/mt fruit	50,113	1,177,835	2,287
Grapes - Wine	1.80	kg/mt fruit	108,107	2,255,932	1,041
Lemons	1.29	kg/mt fruit	5,548	170,109	233
Nectarines	1.82	kg/mt fruit	8,301	177,602	259
Olives	3.14	kg/mt fruit	5,996	52,714	55
Oranges	1.48	kg/mt fruit	65,064	2,296,494	1,413
Peaches	1.13	kg/mt fruit	16,380	498,490	458
Pears	0.65	kg/mt fruit	661	27,577	37
Plums	1.42	kg/mt fruit	8,586	176,435	277
Pomegranate	7.60	kg/mt fruit	2,768	45,815	22
Prunes	5.60	kg/mt fruit dried	2,606	31,239	57
Tangerines	1.27	kg/mt fruit	25,032	642,160	883
		Fruits Total	374,969	9,069,916	7,866
Nuts					
Almonds	68.0	kg/mt kernel	403,770	1,008,264	5,269
Pistachios	28.1	kg/mt CPC[2] yield	132,141	461,971	1,805
Walnuts	16.0	kg/mt in-shell	71,607	310,874	664
		Nuts total	607,518	1,781,109	7,737

[1]*Data reported by Geisseler (2016).*
[2]*California Pistachio Commission yield adjusted for blanks and cull nuts.*
[3]*Data reported by USDA (2018).*

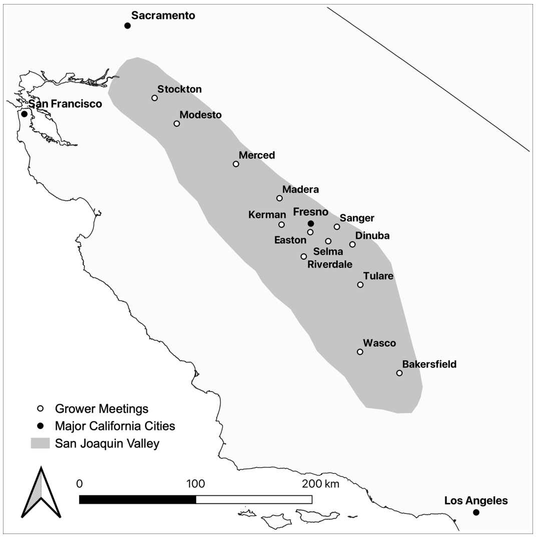

FIGURE 1 | Map display of in-person grower meetings locations where surveys were conducted in 2017 and 2018 within the San Joaquin Valley relative to major California cities.

format consisted of presentations by coalition directors on the status of program progress, pending changes in the regulatory climate, and what to expect from correspondence with water quality coalition staff. At fourteen meetings, paper surveys were distributed to attendees to fill out during the meeting and collected when attendees left the meeting. At two smaller grower meetings, clicker software (Turning Technologies, Youngstown, OH) was used to allow growers to electronically complete the survey by clicking in their answers to each question. We attended seven meetings in 2017 and nine meetings in 2018. Care was taken to survey different geographical locations each year, so as not to survey the same grower populations twice. The mandatory nature of these meetings reduced the potential for selection bias. In total, we received 1,096 survey responses, of which 950 were completed of which 879 growers focused their response on a fruit or nut crop. The meetings were attended by over 3,100 growers during both years, allowing us to estimate a survey response rate of 35%.

Survey Tool

Many San Joaquin Valley growers manage more than one parcel, and parcels can be noncontiguous management units. For this reason, the survey tool asked growers to consider their largest, most-important parcel. In the first section of the survey, growers were asked to report characteristic information about the parcel including crop type, parcel size, ownership, irrigation system and water source. Crop categories for fruits were stone fruits, table grapes, wine grapes, raisin grapes and citrus, and for nuts included almonds, walnuts and pistachios. Parcel characteristics included options for size at 1-20, 21-40, 41-100 and greater than 101 hectares. Options for ownership of the parcel included leasing or owning. Irrigation system options for the parcel were sprinkler or drip microirrigation, flood or furrow irrigation or both systems. Water source for the parcel was either surface water including riparian rights or irrigation district water, groundwater or both sources.

In the second part of the survey, growers were asked about adoption of conservation practices on the parcel during the last growing season. Practices include split fertilizer N application, soil sampling for residual NO_3^-, leaf N sampling for crop N status, use of an N budget, measuring of irrigation distribution uniformity, irrigation scheduling by evapotranspiration (ET), deployment of soil sensors, measuring water stress with a pressure chamber, use of cover crops, and use of organic matter amendments. For each individual practice, we asked about challenges associated with adopting the practice including: cost of the practice, labor requirements, need for supplies, requirement for technical expertise, lack of practice efficacy, and overall uncertainty. Finally, growers were asked to identify information sources they use for conservation practices, which included the county agricultural commissioner, University of California cooperative extension, certified crop advisors, pest control advisors, water quality coalitions, resource conservation districts (RCD), industry associations and grower peers.

Data Analysis and Statistics

For each practice, survey data was coded with 0 for non-adoption and 1 for adoption. Farm size and ownership were categorized with 0 for parcels less than or equal to 20 hectares and 1 for parcel greater than 20 hectares, and 0 for leased and 1 for owned. Irrigation system and water source included three categories with 0 for flood or furrow irrigation, 1 for sprinkler or drip microirrigation, and 2 for both systems equipped on the parcel, and 0 for groundwater only, 1 for surface water only and 2 for the parcel having access to both water sources. All practice challenges were coded as 0 for negative and 1 for positive identification of a challenge for each practice. Lastly, information sources were coded as 0 for non-use and 1 for use of the specific information source. Challenges were listed for each individual practice, and information sources were listed for general use without association with specific practices. Growers were given the option to select all that apply for challenges and information sources.

We tested our hypotheses regarding differences in agronomic and knowledge barriers as principal driving factors when contrasting fruit and nut growers. In general, the N contents of harvested parts for fruits range from approximately 1 to 10 kg N mt^{-1}, while nuts possess far higher N contents ranging from 15 to 70 kg N mt^{-1} (**Table 1**). The denominator of metric ton (mt) is mass of the harvested crop. Kruskill-Wallis t tests to measure differences in proportions of binary measurements were carried out for conservation practice adoption, challenges and information sources between fruits and nuts.

Ten individual logistic regression models were developed, one model for each practice with adoption as the dependent variable, and parcel characteristics (i.e. size, ownership, irrigation and water source), challenges and information sources as independent variables (i):

$$p = \beta_0 + \sum_{i=1}^{m} \beta_i x_i$$

Where p is the probability that Y = 1, Y is the practice, and 1 indicates adoption; β_0 is the log-odds of Y = 1 when $\beta_i = 0$ and $x_i = 0$; m is the number of independent variables (i) used to predict adoption; β_i is the log-odds for each independent variable; and x_i is predictor variable of 0 or 1.

Marginal effects were calculated from the log-odds from each independent variable and are reported herein. Marginal effects inform how adoption changes when an independent variable changes by one unit, while all other independent variables are held at their mean value.

Multiple iterations of the ten individual models were tested. A general model was used to examine marginal effects of all independent variables by pooling fruit and nut growers (**Tables S1-3**). Independent variables such as farm ownership and the information sources of county agricultural commissioner, water quality coalition, and industry association showed no significant ($p < 0.05$) affect for all ten practices, and were eliminated from subsequent models. Next, we included an interaction term between fruits and nuts to test our hypotheses related to how barriers differ between cropping systems. The first iteration of an interaction model assessed the remaining variables from the general model in combination with an interaction term for fruit and nut growers for each of the six practice challenges (**Table S4**). From this first iteration of an interaction model, only the challenge of practice efficacy resulted in a significant ($p < 0.05$) affect for more than two practices. A final interaction model was run with all variables from the first iteration, but only an interaction term retained for practice efficacy. All other challenges did not include an interaction. The marginal effects from this final interaction model for practice efficacy by fruit and nut growers is reported herein. All statistical analyses and model rendering were carried out in STATA 15.1 (StataCorp LLC). Map construction was carried out in QGIS 3.16 (QGIS Project) and figures were made in Sigma Plot 14.0 (Systat Software Inc).

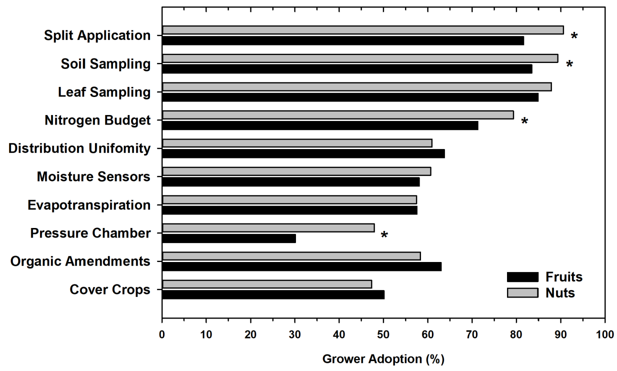

FIGURE 2 | Adoption percentage (%) of conservation practices for nitrogen (N) management by by fruit and nut growers. Differences at $p < 0.05$ reported by an asterisk (*) signify the effect is significant between fruit and nut growers using a Kruskill-Wallis t test.

RESULTS

Adoption Differs by Practice, Crop Type and Farm Characteristics

Our results show that all growers adopt fertilizer use practices at higher rates than irrigation and soil health practices (**Figure 2**). Practice adoption also varies by crop type, with nut growers adopting fertilizer use practices at a significantly higher rate than fruit growers. Furthermore, growers reported lower adoption of irrigation and soil health conservation practices with only one significant difference between fruits and nuts, namely use of a pressure chamber to quantify tree water status (**Figure 2**). These results support our agronomic barriers hypothesis where greater N contents and demand of N inputs like fertilizer for nut crops (15 – 70 kg N mt^{-1}) compared to fruit crops (1 – 10 kg N mt^{-1}) increases the need for conservation practices while leading to higher adoption. Many soil health practices including use of organic amendments and cover crops in no-till orchards soils necessitates alternative management practices that are under investigated. As a result, the limited knowledge base of soil health practices leads to knowledge barriers, and potentially explains low adoption by both fruit and nut growers.

Our results show parcel sizes greater than 20 hectares consistently increase the probability of adoption of all conservation practices for fruit and nut growers combined (**Figure 3**). There was 3 to 10% increase in the probability of larger parcels adopting all three fertilizer practices as well as cover crops, as compared to smaller parcels. Additionally, probability of adoption of irrigation practices and organic amendments increased from 10 to 20% for large parcels over small parcels. For all growers, our results show that use of microirrigation increases the probability of adoption for the majority of conservation practices. Greater water security, where parcels have access to both surface and groundwater as opposed to groundwater only, increases the probability of adoption for all conservation practices. Parcels with microirrigation systems show an increased probability of split application for fertilizer use, as well as for moisture sensors and scheduling irrigation by ET, as compared to flood or furrow irrigated systems. At the same time, use of microirrigation had a negative effect on adoption of cover crops, perhaps due to restricted water distribution for seed establishment during dry winters. Overall, these results show that farm infrastructure like irrigation systems and access to water resources have a large and significant effect on adoption of conservation practices.

Fruit Growers Use Fewer Information Sources and Experience More Challenges

Our grower survey identified many different information sources utilized by growers in California for conservation practices. Local information sources with an on farm presence like pesticide control advisors (PCA), grower peers and the University of California cooperative extension dominate grower engagement (**Figure 4**). Significantly more nut growers identified using these top information sources compared to fruit growers. In addition to information sources, growers identified the challenges they experience in adoption of each practice including operational

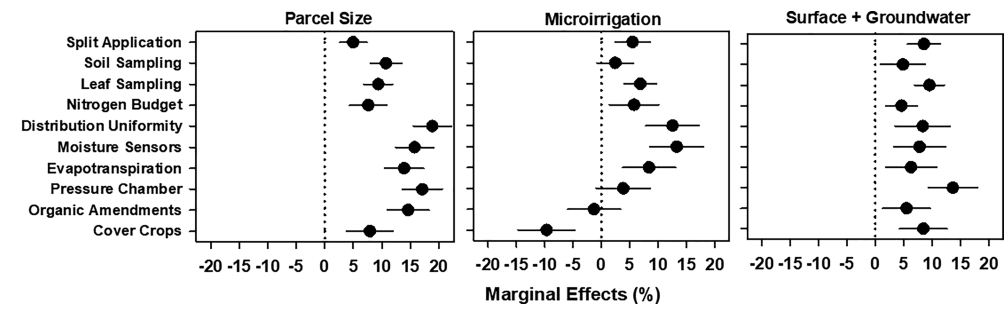

FIGURE 3 | Marginal effects for conservation practices for nitrogen (N) management with standard errors from regression models are shown for variables of parcel size, irrigation system and water source. Effects are parcel sizes >20 ha relative to baseline parcel sizes ≤20 ha; use of microirrigation relative to a baseline of surface irrigation; and access to surface and groundwater sources relative to groundwater only.

challenges like cost, supplies and labor, and technical challenges like uncertainty, expertise and practice efficacy. Fruit growers report greater technical challenges on average across all conservation practices than nut growers (**Table 2**). For fertilizer use practices with higher overall adoption rates, fruit growers report significantly greater uncertainty as compared to nut growers. Furthermore, fruit growers report significantly more technical challenges for use of an N budget. These results further support our knowledge barriers hypothesis where fruit growers experience more challenges than nut growers. The knowledge barriers for fruit crops hamper further extending coordinated research and education to fruit growers, and constrains advancing adoption of conservation practices for a diverse segment of California agriculture.

Nut Growers Are Less Likely to Adopt When Practice Efficacy Is a Challenge

A key finding from our study resulted from our interaction model examining the differences between practice challenges for fruit and nut growers (**Table S4**). Perceived practice efficacy proved to be a particularly important challenge, with markedly different patterns emerging between fruit and nut growers. Both nut and fruit growers adopt all surveyed practices. However, nut growers adopt more practices, use more information sources and identify fewer challenges, but for half of the conservation practices when they identify practice efficacy as a challenge are significantly less likely to adopt the practice as compared to fruit growers (**Figure 5**). While fruit growers report more practice efficacy

TABLE 2 | Percentage (%) grower response for operational and technical challenges associated with conservation practices for nitrogen (N) management. Differences at $p < 0.05$ signify the effect is significant between fruit and nut growers using a Kruskill-Wallis t test.

Conservation Practice	**Cost (%)**			**Labor (%)**			**Supplies (%)**		
	Fruits	**Nuts**	***p***	**Fruits**	**Nuts**	***p***	**Fruits**	**Nuts**	***p***
Split Application	12.9	9.09	0.11	13.9	7.83	*0.01*	2.37	1.77	0.58
Soil Sampling	26.1	18.7	*0.02*	6.93	4.98	0.28	2.64	1.24	0.17
Leaf Sampling	22.6	13.4	0.16	7.41	2.99	0.73	3.37	1.24	0.06
Nitrogen Budget	17.1	15.2	0.49	8.22	6.17	0.30	3.09	2.31	0.53
Distribution Uniformity	16.8	12.8	0.15	14.7	14.7	0.99	2.46	1.09	0.18
Moisture Sensors	25.7	25.7	0.98	7.25	8.64	0.52	6.52	3.94	0.13
Evapotranspiration	12.8	13.2	0.88	6.92	7.30	0.85	3.46	3.50	0.98
Pressure Chamber	25.4	16.8	*0.01*	12.2	15.7	0.21	7.35	4.59	0.14
Organic Amendments	28.9	21.5	*0.03*	11.5	7.26	0.07	6.67	6.45	0.91
Cover Crops	21.0	14.8	*0.04*	15.2	14.5	0.79	6.88	3.83	0.08
	Uncertainty (%)			Expertise (%)			Practice Efficacy (%)		
	Fruits	Nuts	*p*	Fruits	Nuts	*p*	Fruits	Nuts	*p*
Split Application	12.5	6.06	*<0.01*	8.81	5.56	0.10	6.44	1.52	*<0.01*
Soil Sampling	15.8	11.0	0.06	10.2	10.2	0.99	6.27	3.98	0.17
Leaf Sampling	13.5	8.46	*0.03*	11.5	10.7	0.75	3.37	2.24	0.36
Nitrogen Budget	24.0	17.2	*0.03*	21.9	14.4	*0.01*	14.0	6.94	*<0.01*
Distribution Uniformity	16.8	20.4	0.25	16.5	11.2	*0.05*	4.56	4.09	0.77
Moisture Sensors	20.7	17.0	0.24	13.8	12.8	0.73	8.70	7.59	0.61
Evapotranspiration	21.5	20.5	0.76	24.2	20.8	0.29	11.8	7.28	*0.05*
Pressure Chamber	29.8	24.6	0.14	26.5	19.5	*0.04*	14.3	5.68	*<0.01*
Organic Amendments	27.4	26.1	0.71	4.81	5.11	0.87	17.4	12.9	0.11
Cover Crops	35.0	31.0	0.11	5.07	4.10	0.56	25.0	17.5	*0.02*

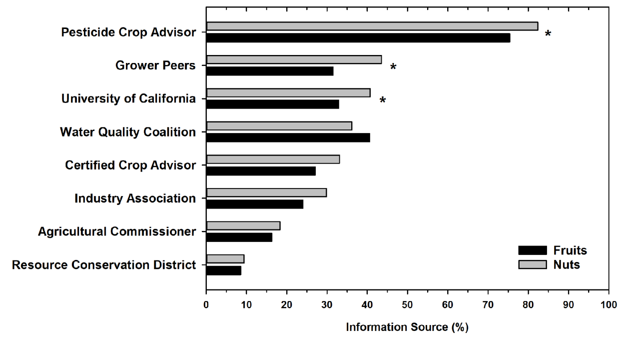

FIGURE 4 | Percentage (%) use of information sources for nitrogen (N) management by fruit and nut growers. Differences at $p < 0.05$ reported by an asterisk (*) signify the effect is significant between fruit and nut growers using a Kruskill-Wallis t test.

challenges overall (**Table 2**), identification of practice efficacy as a challenge did not reduce the probability of adoption, but surprisingly increased adoption for multiple practices (**Figure 5**). These results demonstrate separate patterns of adoption and information use patterns for specific conservation practices, groups of growers and different agroecosystems.

DISCUSSION

Crop Resource Use and Grower Knowledge Drive Adoption

Greater agronomic intensity driven by higher N and water demand by nut crops increases the adoption of conservation practices. As a result of intensive commodity board and public agency investment in research and extension funding, almond has become the model crop for improved NUE from 70 to 90% (Khalsa and Brown, 2019; Khalsa et al., 2020), values that exceed other commodities in the U.S. and globally (Zhang et al., 2015). In many cropping systems, including orchards, fertilizer use practices such as split application, leaf sampling, soil sampling and use of an N budget are conservation practices with widespread scientific evidence and extension support (Weber and McCann, 2015; Srivastava and Malhotra, 2017; Heinemann and Schmidhalter, 2021). Muhammad and colleagues established the right fertilizer N rate and timing for almonds forming the basis for use of an N budget (Muhammad et al., 2015; Muhammad et al., 2018; Muhammad et al., 2020). Saa et al. (2014) increased the value of early-season leaf sampling to aid grower decision making. Numerous researchers demonstrated the efficiency of split application of N fertilizer sources (Schellenberg et al., 2012; Alsina et al., 2013; Decock et al., 2017; Wolff et al., 2017) and the value of soil sampling and monitoring for nitrate movement (Baram et al., 2016a; Baram et al., 2016b) in almond systems, and extended empirical results to other nut crops like walnut and pistachio (Muhammad et al., 2019). To this end, the agronomic intensity of nut crops coupled with research in fertilizer use practices has resulted in significantly higher adoption with resultant improvements in NUE and reductions in N pollution.

Growers of both crop types reported overall lower adoption of irrigation and soil health conservation practices than fertilizer use practices. Fertilizer practices are direct manipulation of N, rather than indirect through soil or irrigation. Advances in microirrigation technology have resulted in equipment and strategies to deliver crop nutrients and water through the irrigation system (Bar-Yosef, 1999). In California, a reliance on microirrigation has made fertigation widespread resulting in a coupling of N and water management approaches (Lopus et al., 2010; Taylor and Zilberman, 2017). While irrigation systems are now widely used to deliver fertilizers there is only a limited understanding of how to co-optimize both practices. Irrigation specialists often focus on water demand and uniformity with limited consideration of biological crop N use. At the same time, crop advisors responsible for nutrient management have little-to-no responsibility for the management of irrigation systems. Limited integration between irrigation and nutrient management specialties leads to information gaps for all growers, likely contributing to lower adoption of irrigation-specific N conservation practices. Yet this knowledge disconnect also varies across cropping systems. Nut growers reported significantly greater adoption of pressure chambers, which has been shown to reliably quantify tree water stress and guide irrigation decision-making for both fruits and nuts (Shackel et al., 1997). As almonds and pistachios use 43-59% more water per unit area compared to other fruit trees and vines (Johnson and Cody, 2015) water demand likely drives higher use of the pressure chamber. Research from Alberta supports our observation where higher adoption of conservation practices occurred in water-intensive specialty crops (Bjornlund et al., 2009). Thus, our results demonstrate greater agronomic intensity for water use increases the adoption of irrigation conservation practices.

Soil health practices can also lead to multiple benefits for nutrient and water management in fruit and nut cropping systems (Sanchez et al., 2003; Lepsch et al., 2019; Andrews et al., 2021; Villa et al., 2021). Many soil health practices

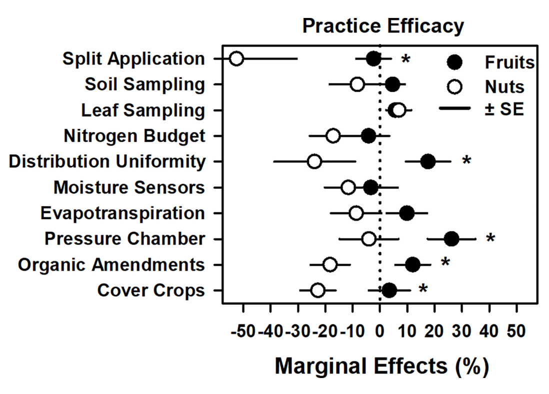

FIGURE 5 | Marginal effects plus and minus standard errors for practice efficacy as a challenge to adoption of conservation practices for nitrogen (N) management by fruit and nut growers. Differences at $p < 0.05$ reported by asterisk (*) signify the effect is significant using an interaction term between fruit and nut growers within the logistic regression.

including use of organic amendments and cover crops can take many years to realize benefits. Increases in soil organic matter can both supply nutrients leading to a decreased reliance on fertilizers as well as retain nutrients during periods of potential loss (Khalsa and Brown, 2017). The no-till nature of many orchards soils however, necessitates surface application that limits nutrient availability and other benefits from both organic amendments (Khalsa et al., 2022) and cover crops (DeVincentis et al., 2020) when compared to cropping systems where tillage is more common (Jackson et al., 2003). In general, the limited knowledge base of soil health practices specific to no-till soils (Eghball and Power, 1999; Jin et al., 2008) leads to knowledge barriers and lower adoption.

Farm Size and Water Resources Matter to Adoption

Multiple adoption studies over decades across regions and cropping systems have demonstrated higher adoption of conservation practices on larger farms (Prokopy et al., 2008; Prokopy et al., 2019). Larger farms have more financial capital and economics of scale, which reduces barriers to practice adoption associated with cost, time to return on investment, and risk (Kipling et al., 2019; Rudnick et al., 2021). Risk allocation across larger farming operations with many management units facilitates grower testing of new practices and technologies that cannot easily be achieved in smaller operations (Ghadim et al., 2005; Miller et al., 2019). Additionally, drought conditions in California drive high water costs and the dominance of irrigation for fruit and nut crops creates a paradigm where water conservation and security are paramount to economic viability. Use of microirrigation facilitates greater adoption of other conservation practices that are easier to implement through pressurized irrigation systems than in flood-irrigated systems (Rudnick et al., 2021). Historically, the promotion of drip or microirrigation has been shown to play an important role in conservation (Taylor and Zilberman, 2017). We also show a strong effect on adoption with growers how have access to both surface and groundwater adopting more practices over all. Since water access is the basis for irrigated lands growers that secure water for irrigation likely have the time and resources to focus on other areas of conservation. Bjornlund et al. (2009) reported higher adoption of conservation practices in an irrigation district with greater availability of irrigation water. These results also support a limiting factors hypothesis where growers perceive and response to resource issues based on their experiences and limiting factors with their systems (Niles et al., 2015).

Nut Crop Adoption Supported by Research and Extension

Advances in knowledge for nut crops enables key information sources to promote applied outcomes on the farm (Khalsa and Brown, 2019). While not as prominent, advances in knowledge for fruit crops like stone fruits, citrus and grapes are ongoing and have proven beneficial (Rufat and DeJong, 2001; Martínez-Alcántara et al., 2012; El-Jendoubi et al., 2013; Quaggio et al., 2014; Williams, 2017). Knowledge transfer among fruit crops is however, hampered by the great diversity of fruit crops and a critical focus on fruit quality (Tagliavini and Marangoni, 2002; Khalsa et al., 2019). Increasing knowledge of these practices and trust among growers requires greater tailoring of practice recommendations to the specific agroecosystems (Stuart et al., 2014; Osmond et al., 2015). Our results and existing research demonstrate that on farm information sources have the greatest potential for influence and adoption (Boland et al., 2006; Eanes et al., 2019). Our results showing how knowledge barriers impact practice adoption is consistent with studies from other farming regions in California, the Midwest U.S., Europe and Africa, (Padel, 2001; Lubell and Fulton, 2007; Kassie et al., 2015; Houser et al., 2019). Adoption of conservation practices is highly farm specific requiring attention to the agronomic context and on farm information sources in order to overcome knowledge barriers.

A key finding from our study resulted from our interaction model examining the differences between practice challenges for fruit and nut growers Many studies have shown farmers are more likely to adopt a practice that is easy to test before adoption (Ghadim et al., 2005; Pannell et al., 2006; Miller et al., 2019). Information-rich nut growers have access to evidence of practice efficacy from numerous research trials, and identification of practice efficacy as a challenge significantly reduces the probability of adoption for nut growers. This finding demonstrates separate patterns of adoption and information use patterns for specific practices and groups of growers (Tucker and Napier, 2002; Lubell et al., 2011). Farmers experience barriers differently, thus requiring different approaches for engagement. Fruit growers may benefit from more research of conservation practices for specific fruit crops due to the limited transferability of horticultural knowledge between fruit crops. Ongoing engagement with information sources coupled with incentives to establish onfarm trials, and flexible support tools over time to enable innovation is needed to further increase adoption (Klerkx et al., 2010; Reimer et al., 2018). At the same time, more efforts are needed to leverage information networks, and incentive onfarm information sources to act as "conservation entrepreneurs" (Lubell et al., 2014; Eanes et al., 2019). Our results suggest room to close knowledge barriers for fruit growers, while experimenting with new approaches to further increase adoption among agronomically intensive nut growers, allowing for greater reduction in N pollution to air and water.

CONCLUSIONS

This study supports our hypotheses that agronomic and knowledge barriers to adoption differ between fruit and nut growers. These results help to explain the variance in adoption of conversation practices across agroecosystems. Furthermore, these patterns of adoption and information use for specific practices and growers implies different approaches are needed to increase future engagement. Our results also show a greater sensitivity to risk from challenges among nut growers compared to fruit growers. The lower practice adoption and higher reported barriers suggests that fruit growers may benefit from more research on conservation practices for specific fruit crops. Finally, experimentation with new approaches to further increase adoption among agronomically intensive nut growers is a viable strategy to further reduce N pollution to groundwater over time. As orchard agroecosystems represent some of the largest acreage and most resource intensive crops in California, continuing to understand barriers to adoption in order to increase adoption of key conservation practices is critical to realizing success on reduced N pollution and promoting climate-smart and regenerative agriculture initiatives. Our results shed light on future opportunities for research and education, while also offering a case study for other regions and agroecosystems to address the need for linking agronomic and knowledge barriers to adoption.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by IRB Administration - UC Davis Office of Research. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

SDSK: Conceptualization, resources, methodology, formal analysis, data curation, writing – original draft, writing – review & editing, funding acquisition, visualization, supervision, project administration. JR: Conceptualization, methodology, writing – review & editing, project administration. ML: Conceptualization, formal analysis, writing – review & editing, funding acquisition, supervision. MS: Methodology, formal analysis, writing – review & editing. PB: Conceptualization, resources, writing – review & editing, funding acquisition, supervision

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fagro.2022.915378/full#supplementary-material

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