Information trust and groundwater management: Evaluating the role of formal versus informal information sources in adoption of groundwater conservation practices among California farmers

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Abstract: The future of farming in many water-stressed regions will depend in large part upon sustainable management of groundwater. Understanding the drivers associated with uptake of groundwater conservation practices in agriculture is thus critical for policy, programmatic, and technical support development. While a rich body of research has explored farmers' conservation practice adoption, understanding of groundwater conservation practices is more limited, especially regarding the role of farmer networks and information sources. This study explores how information sources influence the actual and intended adoption of groundwater management practices in California, which instituted a statewide policy in 2014 to regulate and implement groundwater conservation practices. Using survey data from farmers (n=553) in three largely agricultural counties of California, we examine the extent to which farmers' preferred and actual sources for groundwater policy information are associated with adoption of groundwater conservation practices while controlling for farm and farmer attributes. We find that farmer trust in groundwater policy information from informal sources such as other farmers, social media, and popular media is negatively associated with both current adoption and intended future adoption of groundwater conservation practices. These findings suggest that policymakers and extension agents seeking to spread conservation information could tap into peer-to-peer networks and partner with a diverse range of organizations to ensure that they send trusted information to farmers. This analysis can help build a richer understanding of how farmers' groundwater management behavior is highly dependent upon social and policy contexts.

1. Introduction

As climate change has exacerbated the frequency and intensity of droughts globally, water-scarce regions have struggled to manage groundwater resources [1]. Few places embody the challenges of agriculture and groundwater management more than California, which has faced continual worsening episodes of drought for several decades, culminating in the summer of 2021 as the most severe recorded drought conditions in California's history [2]. But California is far from alone, as many regions are facing worsening drought conditions and are struggling to address water resource depletion [3]. Thus, addressing and managing the impacts of severe drought is an urgent global problem. Similar to other large agricultural regions that rely heavily on groundwater, without widespread adoption of conservation strategies, California could see a sharp reduction in suitable agricultural land during the next century [4]. California instituted a locally-driven regulatory policy in 2014 to develop and implement groundwater policies relevant to specific groundwater basins and regions. California's Sustainable Groundwater Management Act (SGMA) is a landmark piece of legislation that tasks local Groundwater Sustainability Agencies (GSAs) with crafting plans for water conservation [5].

However, SGMA is also incredibly complex, involving hundreds of GSAs, an extensive engagement process with potential users, and a complex network of information dissemination stemming from many different sources into the information ecosystem. SGMA provides a ripe opportunity to examine farmer networks due to the complexity and difficulty of policy communication under the legislation [6]. Information sources, as well as trust in information sources among farmers, are documented to influence adoption of conservation practices and policy support for conservation programs [7–12]. However, insufficient attention has been paid to the differences between formal and informal information sources in their potential influence on conservation practice diffusion [13,14]. Such oversight may be especially important in an active policy arena, where a variety of policy engagement opportunities exist amidst a suite of information sources. Here we use survey data from a sample of California farmers to examine the extent to which formal versus informal information networks are associated with adoption of groundwater conservation practices.

1.1 Characteristics of Conservation Adopters. Researchers have extensively studied the factors that influence whether farmers adopt new conservation practices on their farms [15]. Variables often found to be positively associated with conservation practice adoption include pro-environmental attitudes such as a farmer's belief in climate change [16–19], information access and intake [8,10–12,20], larger farm size [12,21,22], economic concerns and income level [10,23], a greater amount of formal education [24,25], and participation in conservation incentive programs [26]. One challenge in this literature is that the traits of adopters and non-adopters could differ by region and local climate [23,27]. Indeed, several systematic reviews of farmer adoption of conservation practices observe conflicting results across studies [13–15], indicating room for further research. Prokopy et al. [14] note that more research is needed on social and systems-level factors that could influence conservation behavior, such as information networks.

For policy efforts seeking to promote agricultural conservation, it is also important to understand the factors that influence farmers' intentions to adopt conservation practices in the future. As Fishbein & Ajzen [28] note in their theory of planned behavior, intention is closely linked to behavior but is not a perfect predictor, since perceived and actual barriers restrict behavior. Prior studies have found that social dimensions such as norms can influence farmers' intentions to adopt conservation practices [29] and that a range of farm and farmer characteristics such as farm size and education are positively associated with intention to adopt conservation practices [30]. The factors associated with intended adoption of conservation practices are not always identical to those associated with actual adoption. Niles et al. [31] find that among a sample of New Zealand farmers, certain climate change attitudes appear to be associated with intended but not actual conservation adoption. Thus, further research into both actual and intended adoption would prove fruitful.

1.2 Information Sources and Conservation Adoption. A farmer's decision to engage in a conservation practice does not exist in a vacuum, but rather is a social process [32]. Under the diffusion of innovations theory, information networks can influence whether an individual actor such as a farmer adopts an innovative practice, as well as how such practices spread through a population [33]. Moreover, Elinor Ostrom's social-ecological systems (SES) model emphasizes that individual resource users such as farmers are embedded in social, policy, and biophysical systems that impact their decisions in complex and intertwined ways [34]. It is thus crucial to understand whether and how the flow of information from policymakers to farmers, as well as among farmers, is associated with conservation practice adoption. Owen [35] notes that collaboration and information-sharing seem to be key contributors to the success of adaptation strategies, and other researchers have similarly noted that information dissemination from policymakers and scientists is likely to play a substantial role in future efforts to adapt agriculture to climate change [4,27,36]. Prior research has repeatedly found a positive association between increased information access and adoption of conservation practices [8,10,12], as well as between farmer network involvement and conservation adoption [20,37].

Beyond the relationship of information and conservation behavior, the political science literature has further emphasized the importance of information *sources* in citizens' civic behavior. Researchers have observed that among the general public, the venues and sources from which people receive information — not just whether and how much information they receive — seem to be associated with attitudinal and behavioral shifts [38,39]. In particular, social media and informal information sources have been found to be important contributors to citizens' civic beliefs. Swigger [40] finds that frequent use of social media is associated with a higher degree of support for civil liberties. Relatedly, Anspach and Carlson [41] observe that reliance on information from social media can result in people having misinformed beliefs about key political issues.

These findings from political science suggest that information sources could similarly affect the behavior of farmers. However, Prokopy et al. [14] indicate a need for further research to better understand how farmer networks might impact conservation behavior. While some kinds of informational and organizational affiliations may be positively associated with conservation behavior, others might be negatively associated with such behavior or have no effect. The kinds of information farmers receive is diverse, and the effects of this information might likewise be varied. Indeed, there have been some attempts to analyze the complexities of farmer information networks in prior literature. McBride and Daberkow [11] draw on a survey of US farmers (n = 3,193) and note that the relationship between interpersonal information and adoption of conservation practices is stronger than the relationship between mass media information and adoption. More recently, Arbuckle et al. [7] assess climate attitudes among a sample of Iowa farmers (n = 1,276), finding that farmers who trust environmental interest groups are more likely to indicate that they favor climate adaptation in agriculture, while farmers who trust agricultural interest groups are less likely to indicate that they favor climate adaptation. The authors thus suggest that farmers who trust industry actors might differ in their climate-related beliefs and actions from farmers who trust environmental interest groups or other groups. Further, Garbach and Morgan [9] examine the role of social versus technical learning in influencing farmers' adoption of novel pollinator management practices. Using a quantitative network analysis of a survey of Michigan growers (n = 367), the researchers find that network connections with government agencies, technical service providers, and neighbors have different relationships with practice adoption. Still, prior literature has underemphasized how formal sources of information, such as government entities and extension agents, might differ in their effects on conservation adoption from informal sources, such as interpersonal communication among farmers, social media, and popular media.

1.3 Exploring Farmer Networks in the California Context. In California, as in many other regions, groundwater overuse — much of which is caused by agricultural irrigation — has contributed to depleting aquifer levels and reduced water quality [42]. Farmers often turn to aquifers when other water sources such as reservoirs and streams are unavailable, particularly during droughts [43]. California's Sustainable Groundwater Management Act (SGMA), enacted in 2014, aims to promote groundwater conservation in part through the creation of local Groundwater Sustainability Agencies (GSAs). GSAs are tasked with instituting local plans for managing groundwater, which are intended to bring about sustainable groundwater levels prior to the 2040s [42]. The legislation is still in the process of being implemented [44].

Implementation of SGMA provides an opportunity to study the complexities of farmer networks due to the multitude and diversity of actors involved. The implementation process relies heavily on cooperation across multiple levels of government. The act involves 264 individual groundwater agencies communicating with farmers in the development of local plans, as well as involvement from a host of different actors including extension agents, the California Department of Water Resources, the State Water Resources Control Board, city governments, county governments, irrigation districts, and water districts [6,44–46]. Additionally, the legislation requires GSAs to communicate with a range of "interested parties," such as farmers and others who use groundwater, nongovernmental entities, environmental justice organizations, and disadvantaged groups [6]. Relationships among farmers are also an important consideration for groundwater management plans. For instance, tension can arise between farmers who drill their own water from wells and those who rely on water from their local irrigation or water district [43]. Relatedly, farmers who retrieve groundwater independently rather than through a local irrigation or water district may be less integrated into farmer social and institutional networks [47]. Accordingly, analyzing networks both among farmers and between farmers and institutions is important for researchers seeking to understand SGMA implementation. One important part of analyzing these networks is assessing how information about groundwater is communicated by local, regional, and state public institutions [45].

Researchers have explored the factors contributing to local management plan adoption [48], farmer sentiments towards SGMA implementation [49], the role of social networks in SGMA implementation [45], and the relationship between science and policy in SGMA implementation [50]. Méndez-Barrientos et al. [47] examine how opposition to government intervention appears to motivate farmers to get more involved in the SGMA implementation process. However, the role of information dissemination in groundwater management is an underexplored topic. Given the centrality of local governance within SGMA, the legislation presents a unique opportunity to examine the relationship between farmer information networks and conservation behavior.

To that end, this study assesses the factors contributing to adoption of groundwater conservation practices among farmers in California. Specifically, we ask the following: (1) Which sources do farmers use and trust for information related to SGMA? (2) To what extent is trust in and use of information from formal or institutional sources associated with current and intended future adoption of groundwater conservation practices? (3) To what extent is trust in and use of information from informal sources, such as other farmers, popular media, and social media, associated with current and intended future adoption of groundwater conservation practices? We hypothesize that farmers who trust and receive information from formal SGMA information sources will be more likely to engage in groundwater conservation behavior, while farmers who trust and receive information from informal SGMA information sources will be less likely to engage in groundwater conservation behavior.

2. Materials and Methods

2.1 Data Collection Methods. In 2017, a mail survey on groundwater management was piloted for 137 farmers in Yolo County, California based on the results of 20 farmer focus groups [49]. The survey was then reworked for three additional counties: San Luis Obispo County, Madera County, and Fresno County. These three counties represent a range of crops grown, irrigation needs, and GSA formation processes. Farmer mailing lists were obtained through county-level pesticide reporting lists and the USDA Organic INTEGRITY database. The research team conducted meetings with County Farm Bureaus and water agencies to understand local groundwater needs and organizational interests while developing the survey. In partnership with the County Farm Bureaus, mail surveys were co-branded with the County Farm Bureau logo and accompanied by a letter from each County Farm Bureau president. In accordance with the survey methods outlined by Dillman et al. [51], farmers were sent an initial postcard advertising the survey, after which they were send the mail survey. Farmers who did not fill out the initial survey were sent a reminder postcard and a second mail survey.

The goal of the 2019 survey was to learn about groundwater management in California, with a particular emphasis on the implementation of SGMA and farmers' perceptions of the implementation process. The survey also contained a range of additional questions on topics including groundwater management practices used by farmers, climate beliefs and attitudes, and farm and farmer demographics. Additionally, the survey included some open-ended questions. In total, there were 553 respondents between the three counties. The majority of the responses were from Fresno County. (n = 359, 65%), with smaller samples in San Luis Obispo County (n = 101, 18%) and Madera County (n = 93, 17%). Data analysis for this paper was conducted in StataSE Version 17 [52].

2.2 Variables and Transformations. The outcome variable for our statistical models is farmer use of groundwater conservation practices. The survey asked farmers to indicate from a list which groundwater practices they currently use and which they are likely to use in the future. For each practice, farmers are grouped into one of three nominal categories related to their current adoption: uses the practice; does not use the practice; or not applicable. For intended future adoption, farmers are grouped into one of seven categories: a six-point Likert scale ranging from very unlikely to very likely; and not applicable. Our analysis does not cover all practices listed on the survey. Instead, we only include the following practices that we consider to constitute conservation practices: drip irrigation; water monitoring technology; fallow fields; soil moisture sensors; change to a less water intensive crop; and leaf sampling to measure plant-water status. We do not include the following practices: drill more wells; restore existing wells; make existing wells deeper; pump more groundwater than previous years; purchase additional water; purchase crop insurance; and reduce livestock stocking rates. While these practices could be helpful from an individual farmer's perspective, they are not included within the category of groundwater conservation practices as they are not specifically strategies to reduce groundwater use and meet local GSA goals. Although "reduce livestock stocking rate" could reduce groundwater use, we exclude this variable as it might further complicate interpretability given that it only applies to livestock farms.

We include a range of farm and farmer predictor variables in our models. The first set of variables relate to farmers' network embeddedness and information interactions. The first independent variable corresponds to whether the farmer indicated that they participated in SGMA implementation events. Four of the independent variables in the models pertain to the information that farmers trust and receive related to SGMA. The survey included a list of sources for SGMA information, ranging from formal or institutional sources such as University of California Cooperative Extension and local irrigation or water districts, to informal sources such as other farmers, social media, and popular media. The survey asked each farmer to select both which sources they trust for SGMA information and which sources of information they actually receive. These information sources present different conceptions of how novel practices could spread through a population. As Arbuckle et al. [7] suggest, farmers who place trust in different kinds of sources for climate-related information could have different conservation attitudes or behaviors, and this might also be true of SGMA information sources [44]. We also include an independent variable indicating the number of sources from which the farmer received SMGA information, to control for the possibility that observed relationships could be due to the amount of information farmers receive rather than which sources they receive.

Our models also contain a range of farm and farmer demographic controls, including: total acres managed; whether a farm grows crops and/or livestock; farmer participation in voluntary agricultural programs; education; and having some land in “white areas” that are not part of irrigation districts. We include this final variable to control for the fact that farmers not integrated into irrigation districts and who may thus rely on groundwater could have different irrigation needs, information networks, and perceptions of the SGMA implementation process. We do not include farm income as a control variable to preserve sample size in our models, since there were 128 missing values for income and income was correlated with education in the sample.

Table 1

Descriptions of Variables, Scales, and Transformations for the Multiple Linear Regressions

Variable name	Measurement scale	Question and/or content	Transformation (if applicable)
Model 1 outcome variable: degree of current adoption of groundwater practices	Continuous	Please indicate, in response to water scarcity, if you currently use the following practices and your likelihood to use the following practices in the future	Performed multiple correspondence analysis on three-level variable (adopted; not adopted; not applicable) and used predicted coordinate as outcome in model 1

		Practices included in analysis: drip irrigation; water monitoring technology; fallow fields; soil moisture sensors; change to a less water intensive crop; leaf sampling to measure plant-water status	
Model 2 outcome variable: likelihood of intended future adoption of groundwater practices	Continuous	Please indicate, in response to water scarcity, if you currently use the following practices and your likelihood to use the following practices in the future Practices included in analysis are identical to those in model 1	Grouped somewhat to very likely together and somewhat to very unlikely together to create three-level variable (intends to adopt; does not intend to adopt; not applicable); performed multiple correspondence analysis on three-level variable and used predicted coordinate as outcome in model 2
Participation in SGMA events	Binary	If you have personally participated in SGMA related events, which of the following have you done and when? Events listed: attended a SGMA meeting; served on a board related to SGMA; testified on a SGMA issue; voted on GSA agency formation. Fill-in responses for SGMA event participation are not included.	Transformed to binary variable indicating whether farmer participated in any of the listed events
Trust in SGMA information	Continuous	Would you trust information on SGMA from this source? List of sources: Commodity organization/grower cooperative; County Agricultural Commissioner; Department of Water Resources; GSA-Eligible Entities meetings/working groups; Local Irrigation or Water District; Other farmers; Popular Media (e.g., newspapers, radio, television); Social Media (e.g., Facebook, Twitter); State/Regional Water Resources Control Board; University of California Cooperative Extension. Only information sources	Performed principal component analysis on the set of binary variables indicating whether farmers trust each source for SGMA information; used predicted coordinates for two dimensions with eigenvalues > 1 as independent variables in the multiple linear regressions

		listed on all three county versions of the survey are included in our analysis.	
Use of SGMA information	Continuous	Have you received information on SGMA from this source? List of sources is identical to those for trust in SGMA information	Performed principal component analysis on the set of binary variables indicating whether farmers use each source for SGMA information; used predicted coordinates for two dimensions with eigenvalues > 1 as independent variables in the multiple linear regressions
Total acres managed	Continuous	How many total acres do you manage - all land owned, leased or managed?	
Crop	Binary	In a typical year, how much of the following crops, animals or land do you manage/own? [Followed by extensive list of crops and livestock, along with an "other" option]	Transformed to binary variable indicating whether farmer said they have any crops on their operation
Livestock farm	Binary	In a typical year, how much of the following crops, animals or land do you manage/own? [Followed by extensive list of crops and livestock, along with an "other" option]	Transformed to binary variable indicating whether farmer said they have any livestock on their operation
Participation in voluntary programs	Binary	Does your farm participate in any of the following voluntary programs? List of programs: Agricultural Conservation Easement Program; State Agricultural Water Enhancement and Efficiency Program; State Landowner Incentive Program; State Water Enhancement Program; Conservation Reserve Program; Conservation Stewardship Program; Environmental Quality Incentives Program; Organic/biodynamic certification	Transformed to binary variable indicating whether farmer uses any of the listed programs
Education	Ordinal	What is the highest level of formal education you completed?	

		Education levels: some high school; high school diploma; trade school, apprenticeship or on job training; college education, no degree; college education, associate's degree; college education, bachelor's degree; graduate education, master's degree; graduate education, doctorate degree	
Presence of some land in an uncovered "white area"	Binary	Farmers were shown a map of Groundwater Sustainability Agency districts in their county and asked which districts, if any, their parcels are located in	Transformed to binary variable indicating whether any of their parcels fall within "white areas" not covered by irrigation districts

We perform factor analysis techniques on several variables to group farmers into categories based on their conservation practice use and SGMA information preferences. First, regarding the outcome variables of conservation practice use, we transform intended future adoption into a three-category nominal variable by grouping somewhat to very likely together and grouping somewhat to very unlikely together. The goal of this is to simplify interpretability of the models. We preserve the "not applicable" responses rather than dropping them to maximize sample size, meaning that both current and intended future adoption are three-category nominal variables. Then, on both current and intended future adoption, we run a multiple correspondence analysis (MCA), a technique used to determine underlying structure in datasets of categorical non-binary variables with identical categories [53].

The MCAs suggest that in both datasets, the data can be grouped in two-dimensional space with one of the two dimensions corresponding to farmers' likelihood to adopt the conservation practices [Fig 1-2]. We use the results of the MCA to predict the coordinates for each individual farmer, and we in turn use these predicted coordinates as the outcome variables for our regression models. For both current and intended future adoption, we use the second dimension as a proxy for a farmers' willingness to adopt groundwater conservation practices, since this dimension appeared to sort farmers by their willingness to adopt. Moreover, we negate this dimension for ease of interpretability, such that more positive values correspond to a greater current or intended future likelihood to adopt the practices.

Fig 1

Multiple Correspondence Analysis of Adoption of Groundwater Conservation Practices

Note. 1 = Not applicable; 2 = Has not adopted practice; 3 = Has adopted practice.

Fig 2

Multiple Correspondence Analysis of Intended Future Adoption of Groundwater Conservation Practices

Note. 1 = Not applicable; 2 = Somewhat to very unlikely to adopt practice in the future; 3 = Somewhat to very likely to adopt practice in the future.

We also perform a transformation on the variables related to farmers' trust in and use of SGMA information to group farmers by their information intake preferences. A principal component analysis (PCA) is a statistical technique used to reduce dimensionality in a set of binary variables, and the dimension coordinates for each data row can be used as predictor variables in a multiple linear regression [54]. In our case, the goal of the two PCAs we conduct is to better understand whether the information sources represent distinct information pathways for farmers. We carry out a PCA on the binary variables indicating whether the farmer trusts each source for SGMA information, as well as a second PCA on the binary variables indicating whether the farmer receives each source for SGMA information [Table 2]. Farmer responses for trust in information sources and actual receipt of information are both used since they may have different relationships with farmer behavior. Trust levels could be indicative of the networks to which farmers feel most connected, while the information sources they actually receive could indicate how receiving certain kinds of information shapes behavior.

The PCA on the trust in SGMA information sources reveals two components with eigenvalues > 1. The first component is composed largely of trust in formal or institutional information sources, such as public entities and University of California Cooperative Extension, with other farmers and popular media being the weakest aspects of this component. The second component is composed largely of trust in more informal or interpersonal sources, particularly social media and popular media, although the component is also composed to a slightly lesser extent of trust in certain institutional information sources such as the State/Regional Water Resources Control Board. The PCA for information received reveals two similar components: the first is composed more of farmers who trust SGMA information from institutional or formal sources, whereas the second is composed more of farmers who trust SGMA information from informal sources such as social media, popular media, and other farmers. This suggests that there is some basis for thinking that there are different groups of farmers who are more trusting of formal versus informal or interpersonal SGMA information. We then predict the coordinates for each individual farmer and use their coordinates for the first and second components in each PCA as independent variables in the model.

Table 2

Principal Component Analysis of Trust in and Receipt of SGMA Information Sources

	PCA for trust in SGMA information sources	PCA for SGMA information sources received

SGMA information source	Component 1 eigenvectors	Component 2 eigenvectors	Component 1 eigenvectors	Component 2 eigenvectors
Commodity organization/grower cooperative	0.305	-0.292	0.317	-0.195
County Agricultural Commissioner	0.311	-0.364	0.320	-0.139
Department of Water Resources	0.362	0.060	0.371	-0.026
GSA-Eligible Entities meetings/working groups	0.326	-0.155	0.348	-0.330
Local Irrigation or Water District	0.302	-0.289	0.295	-0.291
Other farmers	0.229	0.087	0.325	0.117
Popular Media (e.g., newspapers, radio, television)	0.289	0.556	0.256	0.535
Social Media (e.g., Facebook, Twitter)	0.307	0.559	0.224	0.665
State/Regional Water Resources Control Board	0.375	0.079	0.371	0.042
University of California Cooperative Extension	0.334	-0.189	0.304	-0.076

Note. Components are preserved if their eigenvalue is greater than 1.0.

2.3 Statistical Models. We run two ordinary least squares (OLS) multiple linear regression models, as the outcome variable is a continuous variable corresponding to each farmer's predicted coordinates from the MCA results. Model 1 corresponds to degree of current adoption of groundwater conservation practices, and model 2 corresponds to likelihood of future adoption of groundwater conservation practices. Both regression models include controls for fixed effects by county to account for geographic variability or variability across the three survey versions.

The OLS regression models are as follows:

$$Y_1 = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \lambda + \alpha$$

$$Y_2 = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_4 X_4 + \beta_5 X_5 + \lambda + \alpha$$

Where Y_1 = Likelihood of current adoption of groundwater conservation practices, or dimension 2 of the MCA; Y_2 = Likelihood of intended future adoption of groundwater conservation practices, or dimension 2 of the MCA; β_0 = constant or baseline; X_1 = Participation in at least one SGMA event; X_2 = Trust in formal SGMA information, or component 1 of the SGMA information trust PCA; X_3 = Trust in informal SGMA information, or component 2 of the SGMA information trust PCA; X_4 = Receiving formal SGMA information, or component 1 of the SGMA information receipt PCA; X_5 = Receiving informal SGMA information, or component 2 of the SGMA information receipt PCA; λ = Farm and farmer characteristic controls; and α = County fixed effects. An alpha level of 0.05 is used for statistical tests. All variables are standardized for these statistical tests so that variable coefficients can be compared.

3. Results

There is a wide range in the degree of farmer adoption of conservation practices [Fig 3]. The top practice in terms of current adoption is drip irrigation (57.59%), and the lowest is shifting to less water intensive crops (5.33%). There is a similarly large range in the percentage of farmers intending to adopt each conservation practice in the future. 45.74% of farmers participated in at least one event related to the implementation of SGMA. The majority of farmer respondents grow at least some crops (90.74%), with a much smaller percentage having at least some livestock (15.06%). Only 28.28% participate in at least one voluntary agricultural program.

The median number of sources received for SGMA information is 1. 4.31% of farmer respondents have some land in a "white area" not covered by an irrigation district.

Fig 3

Percentage of Respondents Who Use or Intend to Use Each Groundwater Management Practice

Note. Values indicate the percentage of respondents who stated that they currently use or intend to use each practice among valid responses to each question. For intended future use, answers for somewhat likely, likely, and very likely are grouped together.

Table 3

Summary Statistics for Dependent, Independent, and Control Variables

Variable	Number of valid responses	Percentage of respondents (unless otherwise indicated)
Participated in at least one in SGMA event	551	45.74%
Total acres managed	520	Mean = 747 Std. dev. = 2,419
Crop farm	551	90.74%
Livestock farm	551	15.06%
Participation in voluntary programs	488	28.28%
Education	538	
No college education		12.64%
College education, no degree		13.94%
College education, associate's degree		8.36%
College education, bachelor's degree		44.98%

Graduate degree		20.08%
Number of sources received for SGMA information	487	Median = 1
Presence of some land in an uncovered "white area"	511	4.31%
County	551	
San Luis Obispo County		64.79%
Madera County		18.33%
Fresno County		16.88%

The two OLS regressions suggest that several independent variables are significant ($p<0.05$) predictors of current and intended future adoption of groundwater conservation practices [Table 4]. In assessing whether farmers had currently adopted groundwater conservation practices, trust in informal sources of information, such as social media, popular media, and other farmers, is negatively associated with adoption of groundwater conservation practices ($p=0.019$). Likewise, for the future adoption model, trust in informal SGMA information sources is also negatively associated with likelihood of intending to adopt groundwater conservation practices in the future ($p=0.039$). Participating in SGMA events, receiving information from formal or informal sources, and the number of sources received for SGMA information are not significantly associated with current or future adoption of groundwater conservation practices.

A number of farm and farmer characteristics are positively associated with adoption across both models. In the current adoption model, total acres managed ($p=0.039$), participation in voluntary conservation programs ($p=0.002$), and higher formal education level ($p=0.002$) are positively associated with adoption of groundwater conservation practices. On the other hand, farms with livestock (p=0.001) are less likely to adopt these practices on average. For the intended future adoption model, total acres managed (p=0.036), participation in voluntary agricultural programs (p=0.002), and having crops on the farm (p=0.014) are all positively associated with intention to adopt groundwater conservation practices in the future.

Table 4

Multiple Linear Regressions of Current and Likely Future Adoption of Conservation Practices

	Model 1 outcome variable = Degree of current adoption of groundwater conservation practices		Model 2 outcome variable = Likelihood of intended future adoption of groundwater conservation practices	
Predictor variable	Coeff.	Standard error	Coeff.	Standard error
Constant	-0.0004038	0.0143172	0.0054823	0.0141231
Participation in SGMA events	0.018019	0.0153048	0.0223187	0.0150965
Trust in formal SGMA information (component 1)	0.0063448	0.0142232	0.0128318	0.0141658
Trust in informal SGMA information (component 2)	-0.0331658*	0.0140629	-0.029169*	0.0141047
Receipt of formal SGMA information (component 1)	-0.0719765	0.1454701	0.0162852	0.1451436
Receipt of informal SGMA information (component 2)	-0.0127375	0.0137472	0.0010571	0.0136678
Total acres managed	0.0298743*	0.0144224	0.0306743*	0.014578
Crop farm	0.0306672	0.0192317	0.0461826*	0.0186702
Livestock farm	-0.0490019**	0.0143937	0.0107511	0.0143984
Participation in voluntary programs	0.043883**	0.0141742	0.0441584**	0.0141916
Education	0.0494057**	0.0157749	0.0198002	0.0156153
Number of sources received for SGMA information	0.1160643	0.1467198	0.0064802	0.1463477
Presence of some land in an uncovered “white area”	0.0097681	0.0147752	0.0092545	0.0149157
San Luis Obispo County (compared to baseline of Fresno)	0.020312	0.0150269	-0.0273826	0.0150088

Madera County (compared to baseline of Fresno)	0.0282226	0.0151345	-0.0006158	0.0148885

Note. * indicates p < 0.05 and ** indicates p < 0.01 for a two-tailed significance test. Number of valid observations is 398 for model 1 and 368 for model 2.

4. Discussion and Conclusion

Our analysis attempts to discern the differences between current adopters, likely future adopters, and non-adopters of groundwater conservation practices among California farmers. We find that trust in informal sources for SGMA-related information, such as social media, popular media, and other farmers, is significantly negatively associated with current and intended future adoption of groundwater conservation practices. As Prokopy et al. [14] indicate, different information sources may have disparate effects on farmer behavior. Indeed, we find that trust in and receipt of formal sources for SGMA information is not significantly associated with either current or intended future adoption of groundwater conservation practices. Our results suggest that not all kinds of information and organizational participation are associated with agricultural conservation behavior. Farmer networks are not all the same, so researchers should not assume that network involvement will necessarily be associated with an increase in a farmer's likelihood to engage in conservation behavior.

Several observed relationships in our models are consistent with findings from prior research. For example, we find that participation in voluntary agricultural programs is significantly positively associated with current and intended future adoption of conservation practices, consistent with Lambert et al. [26]. Additionally, we find that a higher level of formal education is significantly positively associated with current adoption of conservation practices, consistent with Barbercheck et al. [24] and McCann et al. [25]. However, education is not significantly associated with intended future adoption of conservation practices. This suggests that, as Niles et al. [31] note, the characteristics of current adopters of conservation practices versus intended future adopters of conservation practices might be different.

This study also shows some inconsistencies with prior research. We do not find a significant relationship between farmer participation in SGMA events and current or intended future adoption of groundwater conservation practices. By contrast, prior research indicates that organizational participation and network involvement may be associated with farmer adoption of conservation practices [20,37]. However, given that the implementation of SGMA was still ongoing in 2019 when the survey was distributed, and events including meetings and votes on GSA formation were not completed, these findings may reflect an early aspect of the policy process. Moreover, we find that the number of information sources a farmer receives related to SGMA is not significantly associated with adoption of conservation practices, inconsistent with some prior studies that find a positive relationship between information access and conservation behavior [8,10].

Our findings suggest that a farmer's quantity and sources of information are less important in predicting groundwater conservation behavior than which information the farmer trusts. This relates to a broader cultural phenomenon of tribalism that extends beyond farmers. Researchers have observed that trust is a key factor in information networks [55]. Individuals tend to have higher levels of trust in their own social groups when those groups are small, homogenous, or closed-off [56], which may be the case among farmers. Farmers may trust their own social circles over regulators or government entities, since other farmers can better understand their lived experiences and values. Moreover, social media has altered the way that people consume and trust information. On the one hand, social media has facilitated peer-to-peer information-sharing networks. However, these platforms can also foster echo chambers in which people filter out unwanted information. This can lead to homogenous thought, misinformation, and "fake news" [57,58]. Relatedly, which information people trust on social media is largely about *who* is sharing the information, rather than just the content of the information [59]. In that sense, farmers may trust information on social media since this mode of communication shows them people they agree with and information that aligns with their worldview.

Therefore, policymakers seeking to promote sustainable management of groundwater should consider not only whether their information is reaching farmers, but also whether farmers trust that information. Farmers who trust peer-to-peer networks over formal sources of information may have less faith in institutions and may be doubtful of policy efforts to encourage groundwater conservation. Public institutions such as state agencies, extension agents, and local irrigation and water districts should seek to send trusted information to farmers, perhaps by tapping into peer-to-peer networks and by engaging with a diverse range of organizations to convey information that will be trusted across different farmer groups [44,45]. Formal and informal information sources present disparate ways of spreading knowledge about groundwater practices. While information from public sources is highly curated and controlled, information from social media, popular media, and other farmers is unregulated and self-selecting. Formal sources provide the sort of technical guidelines that are helpful for implementing new management strategies on a farm, while informal information provides a way of sharing what farmers have found in their own experience works well in managing water resources [9]. Policymakers may thus need to adjust their modes and methods of communication to better reach farmers who trust informal communication networks.

There are several limitations in this analysis. For one, the total number of valid responses in each of the OLS regression models was limited by nonresponses to survey questions. Further, survey data is retrieved from three counties in California, so the findings may not apply to farmers in other geographic areas in California or beyond. Likewise, the politically contentious nature of groundwater issues in California [43], as well as the uniqueness of SGMA as a strategy for conserving groundwater [6], could limit the ability to generalize these results to other US states. Additionally, assessing likely future adoption on a survey is an imperfect measure of farmers' intentions to adopt conservation practices in the future, since farmer answers could be influenced by desirability bias. Nevertheless, this study can help researchers, policymakers, and extension agents better understand how farmer information networks relate to adoption of groundwater conservation practices in California.

Future research should continue to explore other kinds of information and organizational participation to further understand the complexities in the relationship between farmer networks and adoption of conservation practices. We explore only information related to SGMA, meaning that researchers could continue to examine the extent to which other kinds of information are associated with conservation practice adoption. Relatedly, grouping all of the conservation practices into one MCA dimension does not provide the potential to explore which exact practices are underlying these relationships. Future studies could thus examine which specific groundwater conservation practices are behind the relationships observed in these models. Studies could also analyze the communication strategies of different sources for SGMA information to explore how their information dissemination methods vary and how this might relate to farmer groundwater conservation practices. Finally, future studies could examine farmer information flows using a social network model to provide a richer understanding of how farmers may receive information from multiple sources simultaneously.

This study uses survey data from California farmers to examine the extent to which farmers' preferred and actual information sources for groundwater policy are associated with current and intended future adoption of groundwater conservation practices. We find that farmer trust in information from informal sources such as social media, popular media, and other farmers is significantly negatively associated with current and intended future adoption of conservation practices, but that other information network variables included in the regression models do not have significant associations. Our analysis highlights that policymakers or extension agents aiming to effectively or efficiently disseminate information about conservation practices should consider not only whether their information reaches farmers, but also whether farmers trust that information. Policymakers may find that turning to informal and peer-to-peer avenues of communication could help them tap into the networks that some farmers trust for staying informed on groundwater policy.

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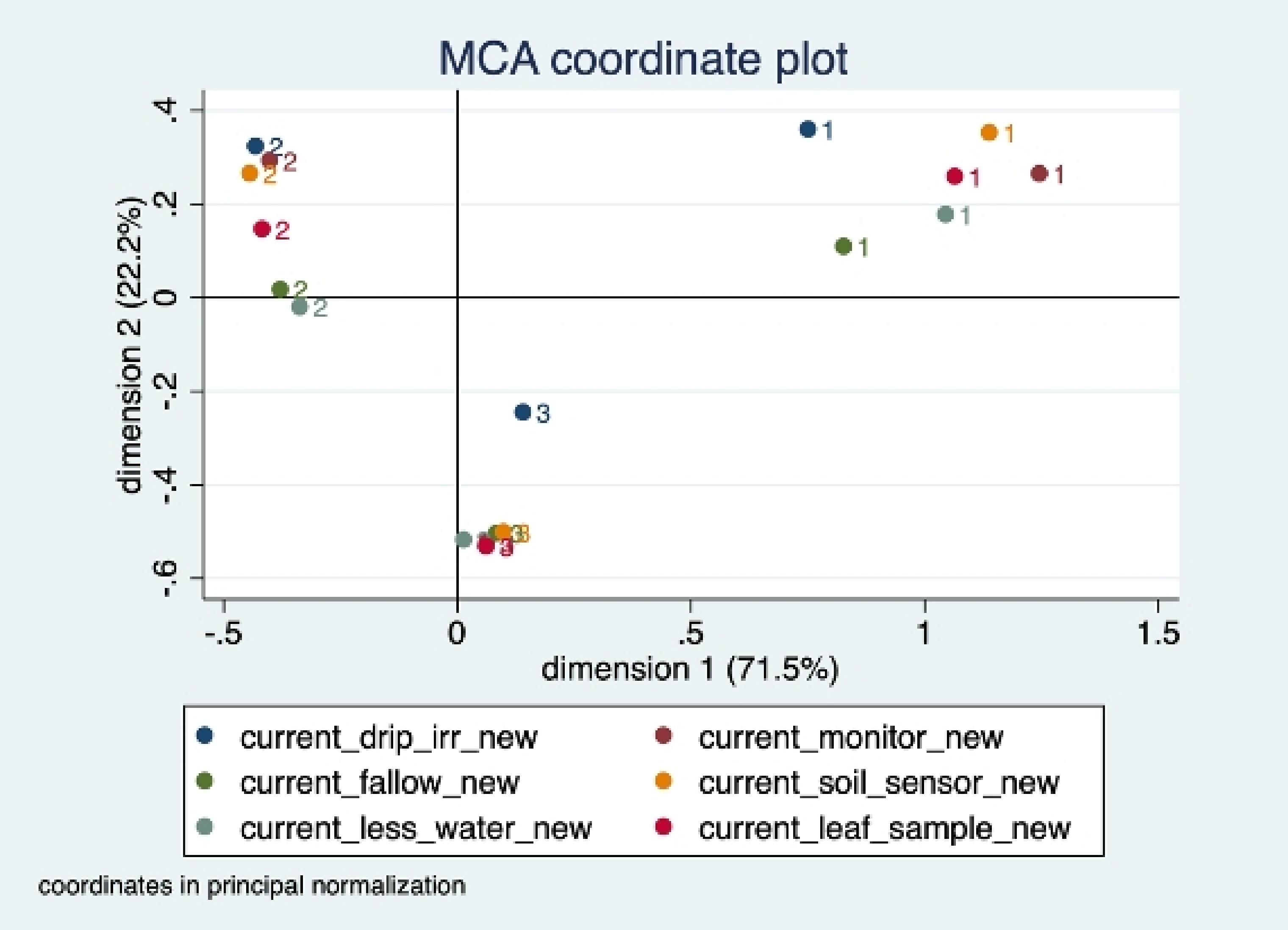
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-.2
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current_drip_irr_new
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current_less_water_new
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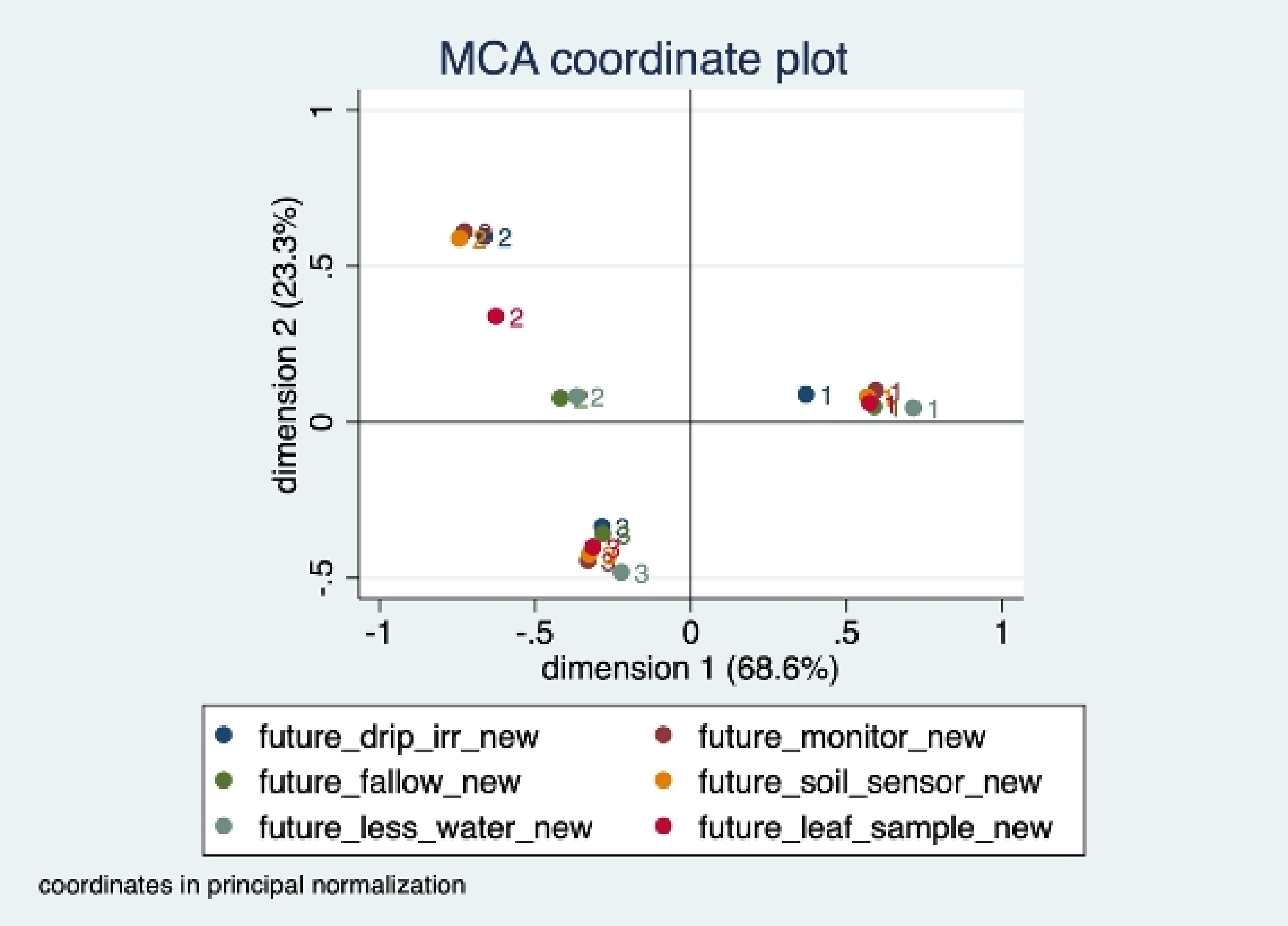
coordinates in principal normalization

Fig1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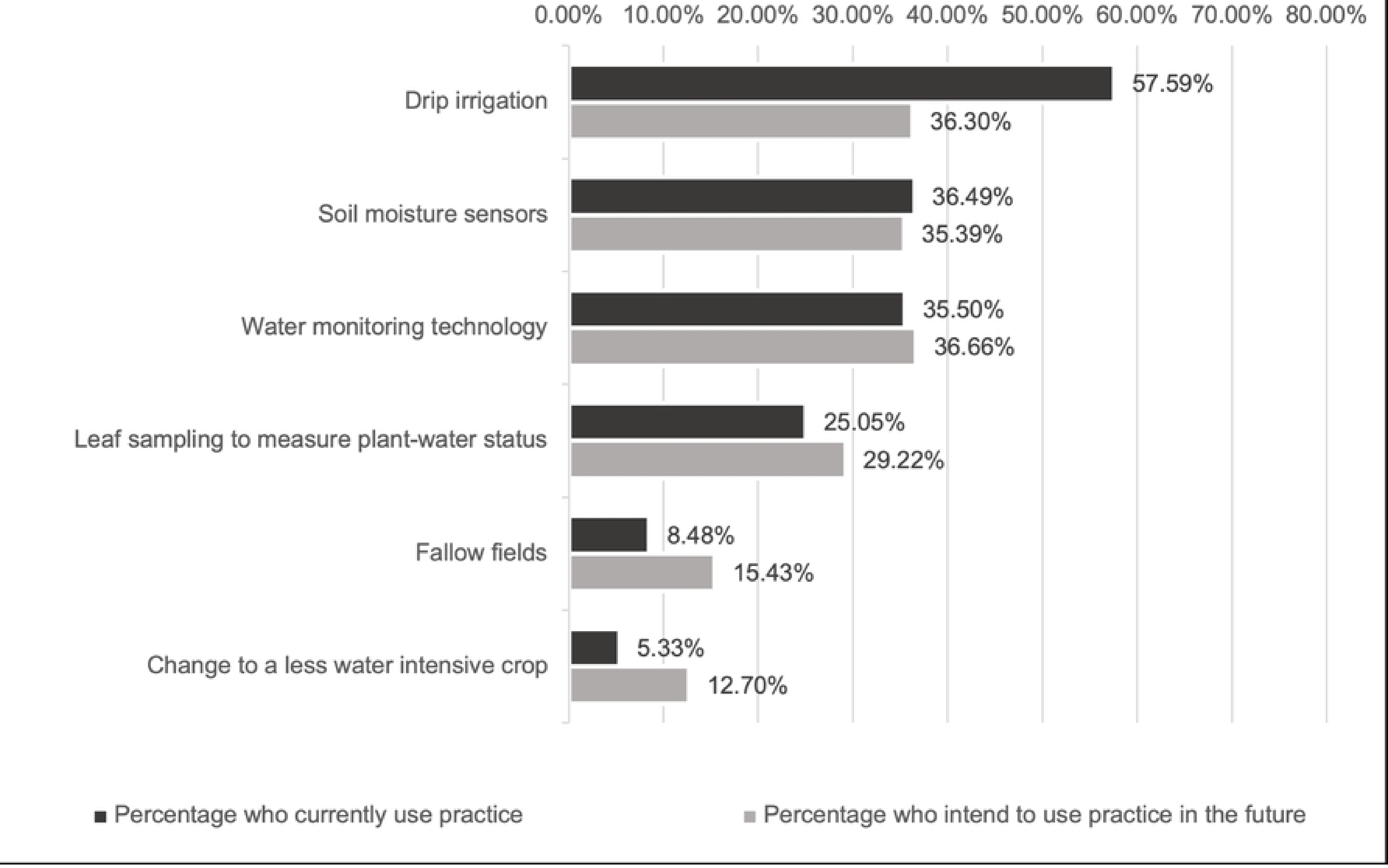
coordinates in principal normalization

Fig2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Drip irrigation
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36.30%
Soil moisture sensors
36.49%
35.39%
Water monitoring technology
35.50%
36.66%
Leaf sampling to measure plant-water status
25.05%
29.22%
Fallow fields
8.48%
15.43%
Change to a less water intensive crop
5.33%
12.70%
Percentage who currently use practice
Percentage who intend to use practice in the future

Fig3