ANNUAL REPORT COMPREHENSIVE RESEARCH ON RICE
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PROJECT TITLE: Crop rotations in California rice systems – baseline assessment of challenges and opportunities

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OBJECTIVES AND EXPERIMENTS CONDUCTED TO ACCOMPLISH OBJECTIVES:

This project had the following objectives. The overall goal was to understand the advantages and disadvantages of crop rotations and their potential role in advancing the long-term sustainability of the California rice industry, particularly from a weed management perspective.

1) Document the benefits and challenges growers experience with rotations, focusing on economics and weeds, for both rotating and non-rotating growers.
2) Determine the different types of rotations being used, to understand why growers choose their crop sequences and how rotations impact weed control.
3) Determine why other growers are not practicing rotations, which will help inform barriers to adoption. Simultaneously, determine conditions required for rotations to be successful.
4) Quantify where crop rotations are currently practiced and the corresponding range of soil properties soil maps, land use maps, and geospatial approaches.
5) Synthesize responses to provide understanding of rotation feasibility and identify future research priorities based on grower input.

Table 1. Interview coverage by acreage within each county

County	Average rice acreage (2008-2019)	% of total	Acreage covered by interviews	% of total acreage interviewed	Difference (acreage interviewed vs. actual)
Colusa	140,630	28	14156	20.6	-7.1
Butte	95,050	19	11055	16.1	-2.6
Glenn	76,970	15	1921	2.8	-12.4
Sutter	107,360	21	15779	23.0	1.9
Yolo	33,760	7	13948	20.3	13.7
Yuba	36,130	7	5445	7.9	0.8
Placer	10,580	2	1237	1.8	-0.3
Sacramento	3,950	1	496	0.7	-0.1
Other	3,615	1	4600	6.7	-6.0
TOTAL	**508,045**		**68637**		

Interviews took place across the major rice producing counties with 43 growers. These growers managed a total of 68,637 acres of rice, roughly 15% of total rice acreage. Generally the amount of acres in each county was representative of the total, with some overrepresentation in Yolo and underrepresentation in Glenn and Colusa.

Major research activities were grower interviews which took place during summer and fall 2020. Focus groups could not be conducted to due COVID restrictions. Analysis of land use maps and soil properties also occurred throughout this research period, as described below.

A total of 43 semi-structured interviews were conducted, lasting up to 1 hour each. Interviews were held with growers throughout the Sacramento Valley with a focus on the top rice producing counties: Colusa, Butte, Glenn, Sutter, Yolo, Yuba, Placer, Sacramento, and Others (including San Joaquin). Table 1 shows the area of actual rice acreage and rice acreage covered by interviews in each county.

Roughly 47% of the growers interviewed were considered rice only growers, while another 26% were considered to rotate using conventional methods or organic methods. Another 26% had both continuous rice and rotated field in their operations. Our goal was to give equal attention to rotation and non-rotation growers, which explains why the interview acreage was somewhat lower than actual rice acreage for Glenn and Colusa (i.e. less rotations there).

Interview questions were designed by all project collaborators to meet the objectives above. They were also tested with several growers to ensure the questions were clear and made sense. To analyze these interviews, conversations were recorded with grower permission and transcribed. Transcriptions were uploaded to a qualitative coding software (NVIVO) which was used to explore responses by analyzing themes and relationships. We could not interview all growers who rotate, hence outcomes and conclusions are representative of growers with similar profiles but cannot be extended to whole sector. Importantly, nearly all of growers interviewed are active in the industry and work closely with extension or other industry leaders.

Growers identified themselves either as *rice grower, farmer, or diversified grower*. If growers identify as farmers or diversified growers, they only had rice in for 1-2 years and then followed this by multiple kinds crops. In general, these growers had larger operations, more equipment, and more diversified crop experience. Almost all growers that were organic rice growers had rice in one year and then fallowed a year. A smaller number of organic rice growers (3) had rice in multiple years before fallowing. If growers were organic and identified as diversified grower or farmer, they maintained multiple types of crops, often including cool season forage like rye or barley, and beans or corn in the summer. Non-organic growers who rotated and identified as rice growers had rice in for 2 years or more, up to 10, and then followed this by multiple years of other crops, usually around 2-5 years.

SUMMARY OF 2020 RESEARCH (major accomplishments), BY OBJECTIVE:

1) *Document the benefits and challenges growers experience with rotations, focusing on economics and weeds, for both rotating and non-rotating growers.*

During interviews, growers were asked a number of open-ended questions such as “How do rotations benefit your operation?”, “Talk to me about the benefits of rotations?”, or “How could rotations benefit your operation?” Grower responses are summarized below:

<u>Weed Control</u>
All growers interviewed emphasized the ability for rotations to improve weed control. Weed control was discussed in terms of reducing resistance to herbicides and reducing weed populations. Growers who practiced conventional rotations reported that they have reduced the number of spray aplications needed to control weeds.

> **“It’s a lot, but they keep complaining to me about how they had to spray their rice fields 4 times this year and that cost a lot of money, and I said, ok well I sprayed once.”**

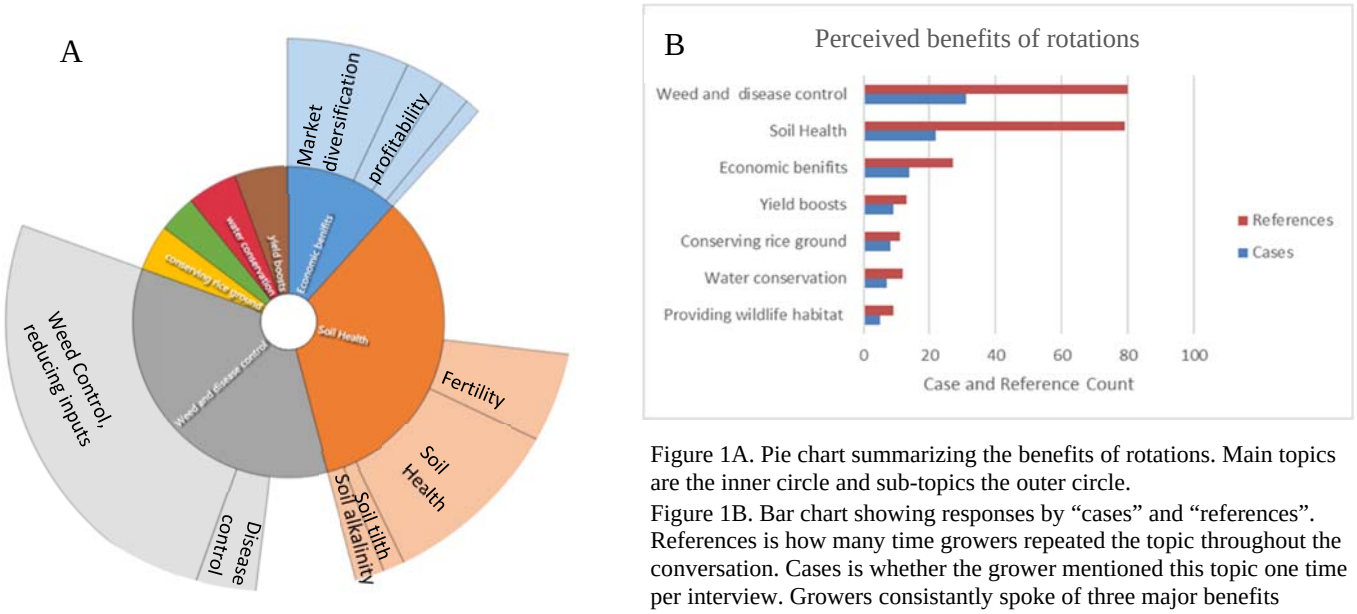

Figure 1A. Pie chart summarizing the benefits of rotations. Main topics are the inner circle and sub-topics the outer circle.

Figure 1B. Bar chart showing responses by "cases" and "references". References is how many time growers repeated the topic throughout the conversation. Cases is whether the grower mentioned this topic one time per interview. Growers consistantly spoke of three major benefits including weed control (the most important benefit), soil helath (ranked second), and economic resiliance (ranked third).

These growers had diversified rotations which included crops like safflower, tomato, corn, and other field crops. Within these rotations, many growers reported that the crops used different chemicals and this was a key factor reducing resistance. Growers who had both rice only operations and rotations confirmed this same expirience, using their continuous rice operations as a comparision.

> **"Specifically related to rotation…I can say between the two ranches we have much less resistance pressure down there then we do up here. Up here because of the resistance we have a limited arsenal of herbicides. Of that limited arsenal I would say 35-40% of them have the same chemistry."**

The second way growers discussed the ability for rotations to improve weed control was in reducing weed populations in the field. However, there were variations in responses, which often corresponded with the duration of time in rice versus out of rice. Growers reported that the longer you were out of rice, weeds were less intrusive compared to fields out of rice for a brief priod. Similarly, the longer you were in rice, the more challenging weeds became. Likely more attractive to rice only growers, was a substantial reduction in herbicide use required to control weeds when proper rotations were implemented.

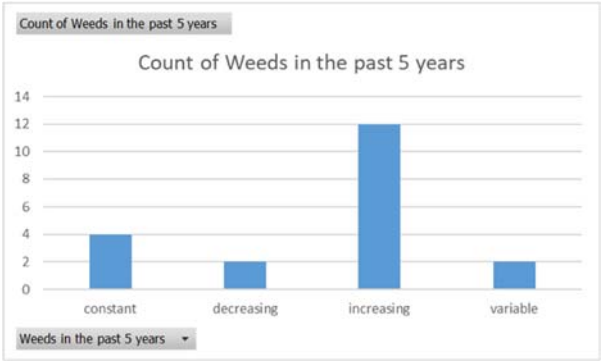

Figure 2: The majority of growers who rotate stated that weeds have increased over a period of 5 years, despite reporting the major benefit of rotations to be more effective weed control.

Nonetheless, determining how effective rotations were for weed control was not always clear. Growers who held rice in place anywhere from 3- 8 years, before rotating out, declared

that after rotations they had a “bump in yields”, and “clean fields”. However, over time this bump would reduce and the weeds would increase. Meanwhile, organic producers reported that weed control, although described as a motivation for using rotations, was not proving effective, and they described a scenario where in more recent years, organic production was not as sustainable. Many organic growers indicated that they were not sure if the management practice of fallowing a year and planting rice the next would work in the long-term because weeds were getting worse. Similarly, when growers who rotated were asked to rate how their weeds have been over a period of 5 years, the majority, conventional and organic alike, responded that weeds were increasing. This was surprising and requires future research.

Soil Health

“Fertility I think is the most. We have some ranches, one ranch that we have had in the long-term organic rice and vetch seed rotation for 15 20 years and we don’t add any additional fertilizer.”

“I’ve noticed the soil changing here for the better. Some of the fields now that we’re into the first rotation- this is our sixth year here- and some of the fields going into rotation now are coming out much better than they were in the past.”

Soil health was documented as a second major benefit of rotations by increasing soil fertility and improving soil tilth. Growers who rotated also spoke of a general soil health increase over time, stating that soils were “improving”. When asked to rate the major benefits of rotations, growers stated weed control as number one and soil health as number two, mostly because soil health was considered a long-term benefit, while weed control was more immediate.

Despite the ranking of soil health as a secondary benefit, during the interviews, the theme of soil health was repeated nearly as much as weed control (Figure 1B), signifying the high importance and motivations for using rotations to achieve soil health benefits.

Economic benefit

The other major benefit of rotations was economic diversity and increased profitability. Growers who rotated talked about how they had very diverse markets which helped to increase marketing resilience during times of price drops. By having multiple options, they increase their portfolio and resilience to market shocks. Complementing the market resilience was a perception of increasing profitability, because they had reduced input costs and had a higher yielding rice crop.

It is important to note that there was no rice only grower that rated economic factors as a benefit (Fig. 3). Instead, they discussed rotations as not profitable and not sustainable economically. This contrasted with growers who rotate stating that rotations were more profitable. This will be further discussed under objective 3 in the barriers to adoption section.

…and another reason to rotate down there is water. water is much more expensive down there then it is up here. So, by comparison rice takes about 5-and-a-half-acre ft, chickpeas take one which saves us like 10s of thousands of dollars in multiple fields

“The third reason would be to maximize my profit I guess is the best thing to say, because there are some years when I don’t make as much money on the rotational crop, but it leads to higher profit on my other crops and I have less expenses.”

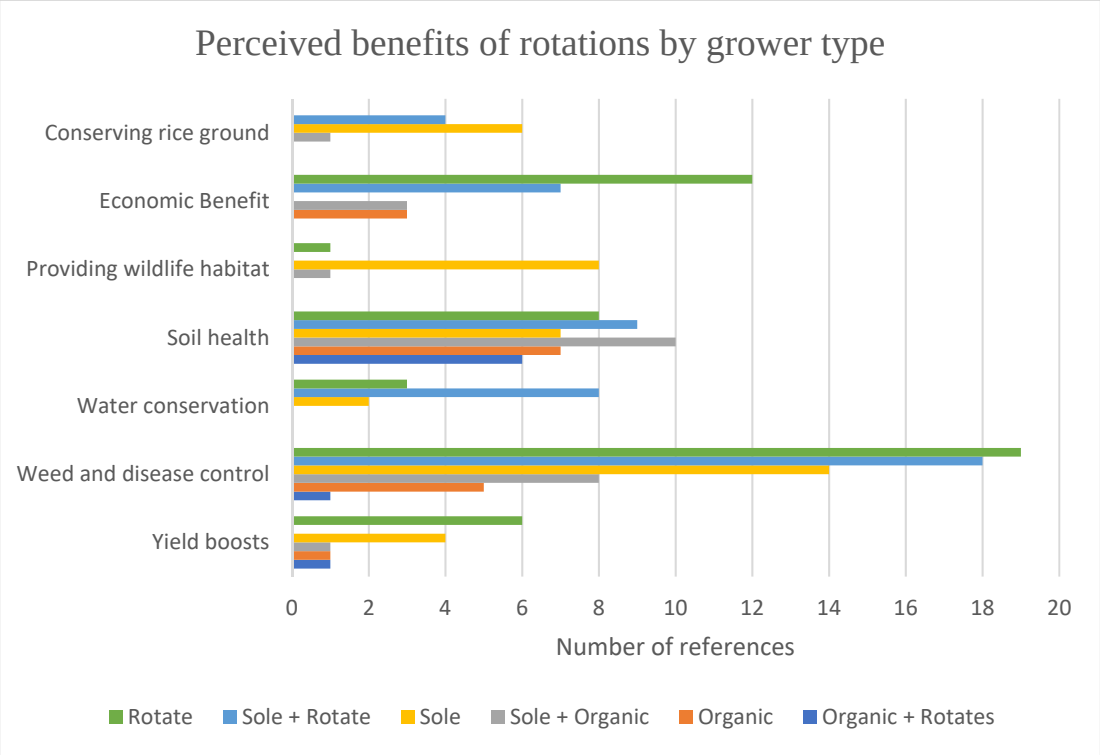

Figure 3: Perceived benefits of crop rotation by grower type. Sole = rice-only grower. "Number of references" is the number of times growers made a reference to that topic in interviews (higher number of references indicates a higher ranking of importance). Even though economics was a major benefit, no rice-only growers talked about this as a potential benefit. Weed and disease control, and soil health were talked about by all grower types. Rice-only growers dominantly spoke about weed control.

Water Conservation, Wildlife Habitat, Conserving Rice Ground

Some of the other areas that came up for benefits of rotations included conserving rice ground, conserving water, and, if a winter crop was left later into spring, increasing wildlife habitat. In regard to conserving rice ground, some growers discussed a potential for rotations to keep rice ground in rice and not other crops, and keeping it productive in the long-term. Related to conserving rice ground is the ability to conserve water. In certain regions, where water is more expensive, decreasing water use was a motivation for using cop rotations. For these locations, rotations with drought tolerant summer crops could help decrease water costs. Also, as the weather becomes more unpredictable and drought occurs more often, growers would have the ability to produce on ground that otherwise would lay fallow. In addition, having a fall crop remain late into spring before harvest could provide wildlife habitat. NRCS programs focusing on fallowing cover crops for increased wildlife habitat is one incentive program supporting a rice grower's decision making. However, increasing other winter forage production that is left later into the spring could also offer habitat.

2) *Determine the different types of rotations being used, to understand why growers choose their crop sequences and how rotations impact weed control.*

Although this study cannot capture all of the different types of rotations growers are using, we were able to document three prominent types that varied depending on the grower, the landscape, and the soils. The three types of rotations gathered from the interviews are defined as “rotations with vetch”, “row crop rotations”, and rotations with forage crops or cool season crops, understood here as “alternative rotations”.

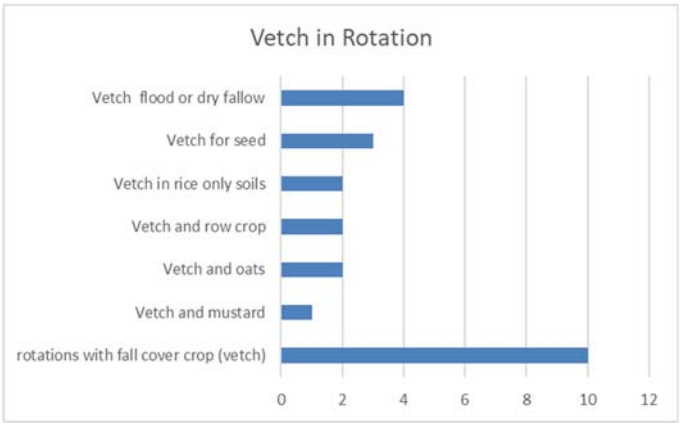

Figure 4: Different ways vetch is used in rotations. Ten growers discussed vetch, and four use it in a flood/dry fallow rotation.

Vetch – Reported in Sutter, Yolo, Yuba, and Butte

Vetch rotations were the most broadly used across different regions. Organic growers report using a rice-vetch-fallow sequence. In some years, depending on how well the vetch grew, these growers would harvest the vetch for seed and sell it, or use it for their next year’s crop.

“[Each] year usually we will fly vetch seed on after or while rice is still tillering and then it’s all about the year. On a year like this last we had a lot of vetch because it was a dry winter; we get a wet winter and almost nothing grows. We throw it out there every year.”

Vetch was either flown on while rice was still tillering or flown on after harvest in fall. If the seed was flown on before harvest, the emergence would happen after harvest and the vetch could climb rice stalks to build biomass. Specific wild vetch species, if left to produce seed in the field could become established and emerge on its own without any new seed input. Although vetch is a low value system, it also added value by increasing soil organic matter and nitrogen supply. Some growers combined vetch with oats to be used for dairy feed or a second form of cover crop mixture. Importantly, growers who had this vetch fallow system reported that their soils were not conducive for other crops, and this was a motivation for only using vetch, suggesting that vetch tolerates heavier soils than other crops.

“Yeah, oh there is probably about 2/3rds of the rice acers that we have we just do every other year rotation with a vetch seed crop and these are on the soils that would be considered rice soils, sole rice soils like up in butte county and Sutter county you have both types you have heavy clay soil.”

In general vetch is a low risk, low cost, low value crop that can be used as a tool in rotations, either by itself, or as a fall green manure before planting a different summer crop. In the next rotation group, “row crops”, some growers reported using vetch intermittently in this regard.

Row Crops - Reported in Sutter basin, Colusa (Sutter boarder), and Yolo.

Growers who rotated with row crops used a mixture of crops such as sunflower, safflower, beans, vine seed, corn, tomato, and wheat. The rotation sequences were often referred to as "flexible" and were largely influenced by weather and markets. If growers had heavier clay soil conditions and a very wet spring, they would choose to plant rice, or beans because beans could be planted later in the summer. If rice price was high, then growers reported leaning more heavily on rice for more years.

"Yeah, right now our three main crops are tomatoes, sunflowers, and rice. But we mix in some garbanzo beans, some beans, and we have some vine seed but that's just little stuff. I mean we raise about 80 acres of specialty vine seed. But that's the three crops. But then if something needs a break, we will through in some garbanzo beans, oh and we have corn, so corn is in there, we have been trying to raise less corn because of the price."

Growers who rotate with row crops would often not grow the higher production crops such as tomatoes, sunflower, or vine seed themselves. Instead, they will negotiate with another grower to come in and grow the crops for them, taking on a landlord role or entering into a crop share agreement. These relationships were profoundly important in influencing rotation options. It was the key factor allowing most rice growers who didn't have the proper equipment or experience to grow more profitable crops that they otherwise couldn't grow (Table 2 - Feasibility matrix).

"I rent around every year half of the land every year. And that changes based on the crop rotation. The other half is farmed by someone else. For crop rotation purposes we like to have a field or two of tomatoes every year. Since I don't farm tomatoes, we contract them out to tomatoes growers."

Many of these growers reported using sunflower or safflower as a tool following rice, if rice has been in the ground for multiple years, too "clean up the ground" and prepare it for a more profitable crop. Recently growers are switching to sunflower if they can get a contract, as the price has increased for sunflower and safflower has decreased. Despite this change, growers report safflower being more effective in weed control then sunflower.

"Typically, nobody really wants to plant a crop into a field that was just in rice because it is usually in bad shape. So, to get from rice to row crops, like tomatoes, you have a tough year in between. That used to be safflower, very low input, low-income crop, but it did a good job, you don't irrigate safflower, you plant in spring, harvest in august. It opens up the soil, and then the tomato farmers like coming in after that. In more recent years we have been using sunflower's instead of safflower, there is more money in sunflowers, frankly."

Secondly, safflower is more logistically feasible because it uses similar equipment as rice and does not require a lot of labor (see Table 2 - feasibility matrix). Finally, growers reported a diversity of soil types that they rotated row crops on. However, most of the time these soils were qualified as lighter than "those rice only soils". There was not enough information to confirm this through field sampling. This is an area for future research.

<u>Alternative rotations – Sutter (not basin), Yolo, Yuba</u>

These types of rotations were specific to grower's operation and a bit more unique. They were mostly found in areas where rice and pasture dominate the landscape, or growers have developed their own markets. In rice and pasture landscapes, growers chose to rotate crops that could tolerate their soil limitations, and the ability to integrate a hay crop, or cool forage crop into their rotations, because they had a hay operation, or cattle operation which made the choice profitable.

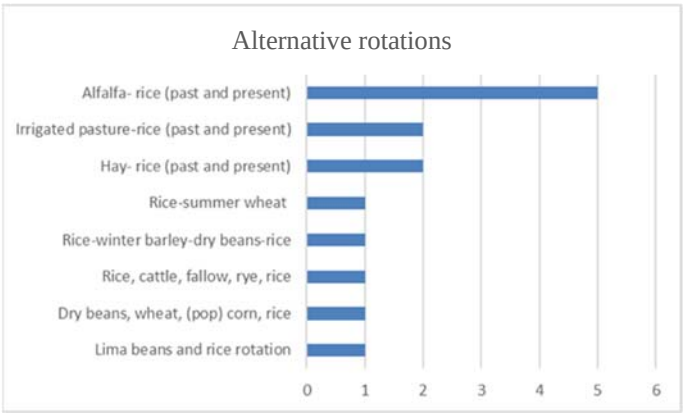

Figure 5: Shows the number of growers practicing different types of "alternative" rotations. Records do not reflect the number of growers practicing these rotations alone, but a combination of past rotations, current rotations, and growers who mention someone they know doing this type of rotation. A total of 7 growers interviewed currently use one of these rotations.

To integrate cool forage crops into a rotation, a summer crop, or fallow would have to follow this. One grower had a system that would manage both, depending on the weather, where barley was grown followed by beans if they could get them in on time, or fallowing, if not. Beans were described as having the ability to be planted later in the season and required similar equipment as rice. There may be an opportunity to provide an incentive for increasing dryland wildlife habitat for nesting birds if the cool season crop was left into spring for habitat. This has not been investigated outside of vetch and wheat, but growers have expressed that wildlife habitat would be an incentive for rotating their fields.

> **"Seems like the rye grass does good and everything else doesn't. Planted peas with fava beans all that stuff and usually I just wasted money on seed. Rice and pasture is around me. [In this area] there are some neighbors that are nothing but cattle and nothing but rice."**

Feasibility matrix

Based on the interviews, we were able to better understand the feasibility of implementing different crops into rice production environments. Table 2 shows a crop feasibility matrix which provides information on crop profitability, production costs, soil tolerance, equipment, water usage, and rotation support offered. This is currently in a qualitative format which provides a sense of feasibility and crop purpose. However, future research will seek to quantify some of these values to provide more precise information for growers, with the goal of identifying proven crops that have worked in specific environments.

Interviews suggested that crops that tend to be more profitable, such as tomatoes and sunflowers, are also more logistically challenging to implement. These crops also tend to take different equipment and therefore many rice growers contract them out. Therefore, in the short-term they are less feasible, although more profitable. On the other hand, crops like safflower, beans, vetch, rye and barley may be more feasible, as they have low input costs, and take similar if not the same equipment as rice. Therefore, we identified these crops, and crops similar such as sorghum, as more feasible to implement as a rotation in the short-term, and suggest focusing on "logistically feasible" crops in future research.

Table 2: Crop Feasibility Matrix. For each crop, this compares information on profitability, production costs, soil tolerance, equipment, water usage, and rotation support offered.

Crop	Profitability	Production costs	Contracts available	Rotation support	Equipment requirement	Soil tolerance	Irrigation requirements	Growing season
Sunflower	High	High	Yes	Intermediate crop	Different harvester and planter	May tolerate heavier soil as long as not waterlogged	Low to no irrigation required	Spring-summer
Safflower	Low	Low	No	Intermediate crop	Same	May tolerate heavier soil as long as not waterlogged	Low to no irrigation required	Spring-summer
Tomato	High	High	Yes	Rice following tomatoes does well	Different harvester and planter	Perception need lighter ground	High irrigation, drip tape	Spring-summer
Beans	Variable	Low	Yes	Can tolerate growing after rice & planted later into planting season	Same	May tolerate heavier soil as long as not waterlogged	Low to no irrigation required	Can be planted later into summer
Vine seed	Variable	High	Yes	Small market	Different harvester and planter	Requires lighter soils	Drip	Summer
Vetch	Low	Low	No	Provides nitrogen and breaks down rice straw, offers wildlife habitat	Same	May tolerate heavier soils	No irrigation required	Fall-winter
Rye	Low	-	No	May do better in rice ground compared to wheat.	Same	May tolerate heavier soils	Flood irrigation tolerant	Fall-winter
Barley	Low	Low	No	May do better in rice ground compared to wheat.	Same		Flood irrigation tolerant	Fall-winter
Wheat	Low	-	No	Can be grown as a winter or summer crop. Tomato growers like to follow wheat.	Same	Growers report poor yields and drowning out in rice environments		Fall-winter or summer

Alfalfa	Moderate	Low	No	Growers who have rotated alfalfa with rice report a high rice yield from nitrogen.	Same			
Oats	Low	Low	No	Can be mixed with vetch or hay for a forage crop	Same	May do well in combination with vetch or other forage crops	If grown with vetch no irrigation required	Fall or summer

Impact on Weeds

Growers who rotate reported that the type of crop in rotation is not very important for improving weed control. Rather, just being out of rice, in a non-flooded soil is important. However, as noted above, there is a link between the crops grown that require a different mode of action for herbicide use in order to decrease resistance. Further research is needed to identify these crops. The major weeds that are being impacted by rotations are grasses and sedges, or the semi aquatic weeds that can still grow in non-flooded environments.

3) *Determine why other growers are not practicing rotations, which will help inform barriers to adoption. Simultaneously, determine conditions required for rotations to be successful.*

The combination of factors preventing growers from incoporating rotations is displayed in Figure 7. Some growers claimed they or their family members had rotated in the past. These growers recounted experiences with crops which never yielded well due to field conditions such as flooding, or alkalinity issues. Furthermore, growers reported that they stopped rotating when markets of certain crops dissipated. Growers who never rotated said their fields were too flat and deconstructing leveled land to allow for drainage was seen as too costly. Complementing these challenges are limited contracts and limited markets for other crops in rice-only regions. Together, growers felt like the combination of soil/environmental barriers with the marketing difficulties meant they were left with no profitable options for rotational crops. In general, rice only growers felt like rotations didn't pay and were not feasible due to limitations such as high overhead costs in the form of land payments, lacking proper equipment for rotation crops, and having enough land or labor.

"Economics, it's just not worth it. like I said the majority of our land is on rented ground. It's not worth it to the landlord or to us to put in a typical rotation crop like safflower or wheat. Safflower is about 500$ a ton crop and I will only get a ton if that. So, you get 500$ a ton so you are pretty much guaranteed less then 500 total dollars. The landlord is going to want, now a days the rice rent is up to about 400 + dollars. Especially down in the major districts. At the end of the day, a bad rice crop pays more than a good safflowers crop."

Finally, many rice-only growers lacked experience and knowledge of how to incorporate rotations. Growers are more likely to be influenced by what is round them, and what their family is set up for. Most rice growers come from families and communities focused on rice. Whereas most rice growers who rotate come from family and communities with more diverse agricultural

backgrounds. Despite these complex limitations, it was evident that environmental limitations, specifically soil and the ability to grow other crops that were susceptible to wet conditions, were the dominant barrier preventing more growers from adopting rotations. However, experience, available markets and infrastructure still play a crucial role in supporting rotation feasibility or limiting adoption.

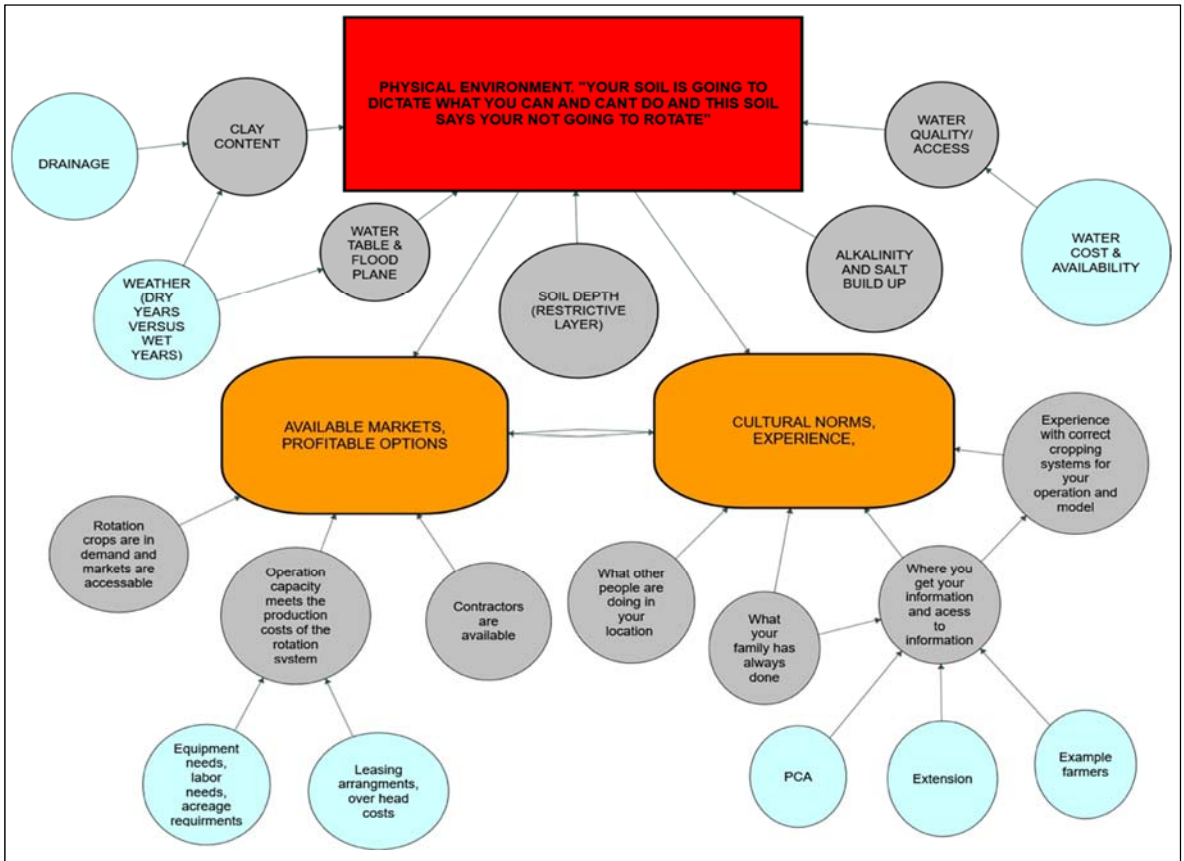

Figure 6: A conceptual model demonstrating various factors influencing grower decision-making for or against crop rotations. Dominant factors (red) that influenced growers' ability to rotate were *soil type* and *environmental conditions*. Secondary factors (orange) that influenced growers' decision-making were *marketability* of crops and *culture*. Primary (grey) and secondary (blue) influencing agents are examples forces operating within each factor. Arrows point towards direction of influence. Depending on the growers' circumstances they were more or less likely to think rotations were an option.

In contrast, interviews with growers who rotated presented specific conditions required for successful rotations. This included having lighter, more loamy soils which supports drainage; having access to contractors, diverse markets, and flexible land payments or ownership of land; having appropriate infrastructure such as equipment and land size, and approximation to regions where rotations are already occurring, which will increase access to information. All of these requirements help to create conditions for successful rotation.

4) Quantify where crop rotations are currently practiced and the corresponding range of soil properties using soil maps, land use maps, and geospatial approaches.

Rice rotations were mapped using the USDA Cropland Data Layer (CDL), a raster-based data set built with Landsat and Modis satellite data with 30-meter resolution. This data set consists of annual crop maps for 2008 to 2019, allowing rice rotations to be examined back to 2008. To improve our estimates of acreage, the CDL was clipped with field boundary polygon data provided by Land IQ, a private mapping company based in Sacramento, CA. Field boundaries, pixels, or portions of pixels, that are not within field boundaries are excluded, i.e., a riverbank that the CDL has falsely classified as rice.

Map of Two Major Rice Growing Counties
Map Images Credit by Luke Salvato 9/21/2020
NASS CDL (2008-2019) with LandIQ field boundaries
https://rpubs.com/lasalvato/663899

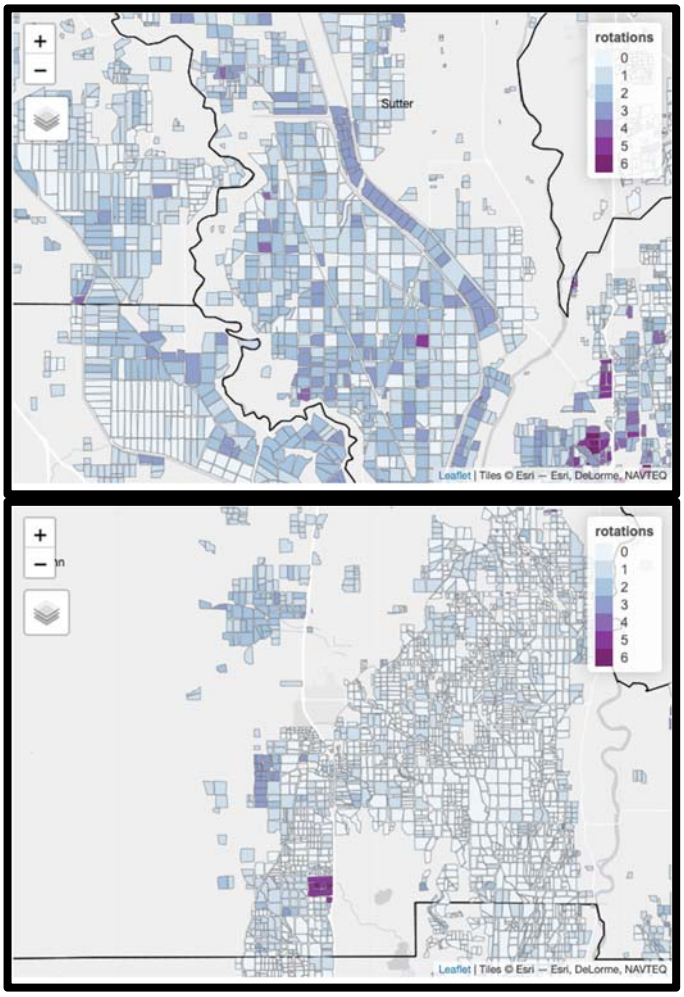

Figure 7: Top image of Sutter County rice acerage. Bottom image of Glenn County Rice acerage. Sutter County shows range of colors whith the majority presenting as rotated out of rice 2-3 times over a period of 11 years compared to Glenn County which shows fields out of rice dominating 1-0 years in the last elleven years. Thus, rotations are more commonly practiced in Sutter County.

Furthermore, the dominant pixel class within each field is computed, and the entire field is reclassified as this pixel type. This corrects for regions where, for example, there are a few

incorrectly classified pixels scattered across a rice field. This process allows analysis at the field level and also improves estimates of accuracy.

Using this custom data set we quantified the acreage and determined the locations of rice field rotations across the Sacramento Valley. Next, SSURGO spatial soil data (provided by the USDA NRCS) will be used to examine the soil characteristics of rotating rice fields, including soil texture, presence of a restrictive soil layer, depth to hardpan, and hydraulic conductivity.

5) Synthesize responses to provide understanding of rotation feasibility and identify future research priorities based on grower input.

During the interviews, growers were asked what type of research they would like to see on the topic of rotations and how they prioritized this type of research. In total, 80% ranked this research topic as neutral or high. Most growers who ranked rotations as neutral or low thought there wasn't much hope in making rotations feasible in rice systems, based on the barriers above (soil, markets, economics).

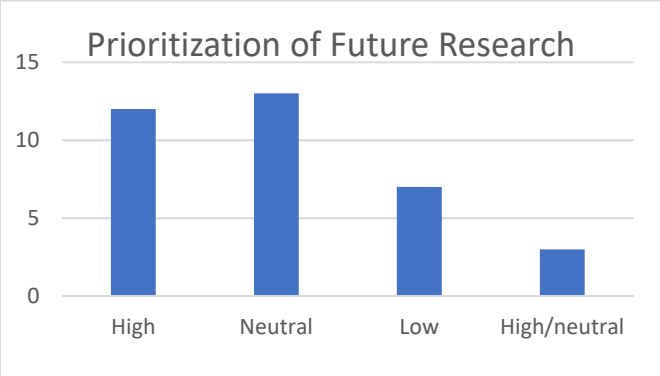

Figure 8: Priority ranking in interviews, with the majority of growers saying rotation research is a high priority or neutral.

Growers who rated this research as high were either growers who rotated already or were experiencing sever weed issues. Overall, the majority of rice only growers are expressing major challenges with weeds and think in the future they may have to change, but there is a range of urgency on this issue. They wish they could expand their tool belt for how to tackle weed issues as California is slow to register new herbicides.

When asked what type of research they wanted to see on the topic of rotations, the majority talked about researching profitable crops that would grow well in rice environments, expanding their options. There were some growers who were interested in seeing research like this that extended into integrating animals into the system as well. This seemed to correspond to rice only regions that were described as being suitable for rice and livestock.

Evaluating the economic advantages and disadvantages of crop rotation was another major area of research growers wanted to see more information on. Respondents said that conducting a cost analysis may provide more evidence of the economic advantage which would provide incentive for adopting rotations where feasible. There is immense risk that growers face when integrating other crops into their system, incurring costs in the form of higher labor demands, alternative equipment needs, and risks around unknown markets. Unknown crop options inhibit growers from taking this risk. Likewise, respondents expressed concerns about how to market the rotation crops, specifically, outside of regions where rotations are common. As part of a cohesive industry, rice growers have easy outlets for their product every year, however this does not extend to rotation crops. Therefore, a market analysis would be a good foundation understanding of marketing opportunities for other crops.

Growers also requested further analysis of how rotations support weed control and soil health, in relation to lowing input costs and increased crop health. Research that investigates the impact of

rotations on lowering inputs and input costs would be very valuable to understanding the feasibility and benefits rotations provide. In line with this, organic growers felt like there wasn't enough information for best management options with cover crops as well as how much additional nitrogen they added to soil, or how well they impacted weed pressure when used with a fallowing program.

Based on the outcomes of the interviews, it was determined that further research needs to understand not only how well alternative crops do in environments that are deemed as “rice only”, but further quantitative evidence on logistically feasible crops in rotation and their impacts on long term weed control, in terms of reducing inputs and controlling seedbanks. Furthermore, evaluating the economics of crop rotations by conducting a cost analysis and marketing analysis would help determine the economic feasibility of rotations for grower’s specific context and location.

Based on the interview findings and grower requests we are submitting a proposal for a second round of funding to investigate the economic concerns and potential weed control and soil health outcomes. Starting in 2021, we intend to compare weed and soil health indicators across multiple rice fields between rotated fields and rice only fields. At the same time, we will conduct surveys to collect partial economic budgets on rotation operations. We also plan to continue exploring geo-spatial data by examining the soil characteristics of rotating rice fields, including soil texture, presence of a restrictive soil layer, depth to hardpan, and hydraulic conductivity. The outcomes will provide transparent and comprehensive information for growers to make informed decisions for adopting crop rotations.

CONCISE GENERAL SUMMARY OF CURRENT YEAR’S RESULTS:

Interviews were conducted with 43 rice growers throughout the Sacramento Valley to understand the perceived benefits and challenges associated with crop rotations in rice systems. Interviews indicated that rotations could provide numerous benefits to both growers and the greater rice industry. There was strong agreement about the potential benefits for weed control and reduced reliance on herbicides at the farm-level. Similarly, growers who rotated described soil health as a primary benefit, important for improving soil tilth, while also decreasing the need for fertilizer and pesticide inputs. On an industry level, there was a sentiment that by expanding the tool belt of rice growers to deal with increasingly challenging herbicide resistant weed issues, rice land can be preserved for future generations.

At the same time, results suggest that there are many challenges including soil limitations, limited availability of contracts and markets for other crops, and limited experience and knowledge of other viable crops and required equipment for these crops. We developed a conceptual map outlining the primary factors influencing grower decision-making about rotations, highlighting what elements are required for success. Despite the barriers, rice growers showed an interest in the prospect of rotations as an opportunity to control weeds and reduce input costs. When asked how they prioritized this type of research relative to other topics, 80% ranked this research topic as either neutral or high.

Interestingly, one of the biggest areas of disagreement between growers was economics. Rice-only growers felt that rotations are simply not an option because they are not as profitable as rice

and therefore not economically sustainable. Contrasting this, those who rotate said that increased profitability through crop diversification was one of the main benefits of crop rotations. Appropriately, growers wanted more information on the economic advantages or disadvantages of rotations in order to help inform their decisions. Similarly, growers felt there was a lack of basic information about the impacts of rotations on rice yields, herbicide use, and soil health. These issues were highlighted in interviews as top priorities for future research.

More than any other concern, growers discussed the lack of viable options for alternative crops. They expressed the need for a crop that not only grows well on heavy clay ‘rice-only’ soils, but is easily marketable and economically competitive with rice. To illustrate the strengths and weaknesses of different crops being rotated with rice, we used the information from interviews to create a crop feasibility matrix. For each crop, factors in this matrix included production costs, soil and equipment requirements, profitability, benefits to the broader rotation, and others. This preliminary tool can help growers narrow down crops that other growers have successfully implemented in their operations. The direct benefit is that it provides growers with options to consider, based on soil limitations and how these crops fit into the broader economic picture.

This project is an important first step, but further research is necessary to address the uncertain benefits of rotations and further refine which crops are most promising for different soils and production environments. Of the different rotations currently practiced, next year we will conduct on-farm research comparing rotated fields to non-rotated fields. We will focus on the most logistically feasible alternative crops to highlight what's possible in soils that are typically used for rice production. Importantly, we will also measure impacts on the following rice crop in terms of economics, herbicide use, and soil health.

Appendix

Table 3: Matrix of growers who rotate summarizing their crop rotation, soil descriptions and surrounding landscapes

Grower type c=conv. o=organic	Rotation crops	Rotation county	Soil description	Surrounding landscape
C/echo	Bean- rice rotation.	Sutter	Mix of heavy clay and sandy loam soils. Clay adobe ground has alkali streaks.	In a very diverse area that has always been rotating.
C	Tomatoes sunflowers and rice, some beans, some vine seed and corn.	Sutter	Deeper loam soils	Row crops in the basin area. Diverse cropping region.
C	Rice sunflower, garbanzo, and contract out to tomatoes. Vetch and other cover crops.	Colusa + Yolo	Very heavy clays. It can be risky to try and grow another crop following rice.	Has 1500 acers of savanna rolling oaks. Rotations are in area in Yolo and Sutter boarder of Colusa.
C	Rice, tomatoes, vine seed, wheat, sunflowers. Beans occasionally.	Colusa	Light clay relative to other rice ground.	District RD108. Divers row crop area. But mixed with sole rice operations.
C	Rice, sunflower or safflower, then contracts it out to tomatoes. Other crops, vine seed and beans.	Colusa + Yolo	Soil is heavy clay (fields in Colusa)	Typically, all rice in area, but there's other row crops grown walnuts moving in.
C	Tomatoes, sunflower, corn, rice.	Sutter	Sutter soil is much lighter.	The landscape is changing, and it is becoming heavily influenced with the presence of trees, walnuts and almonds, depending on the area.
C	Rice, contract out to tomatoes, or corn, sunflowers or vine seed.	Sutter	Lighter soil in Sutter basin area.	Rotations all around. Diverse cropping area.
C	Rice, tomato, chickpea.	Sutter	Mixture of heavy black clay adobe and lighter soils. .	Trees coming in. Sole rice in Butte area has adobe clay and sole rice. Rotations in Sutter with lighter soil and rotations in area.
C	Rice, safflower or sunflower then tomatoes, melons and wheat.	Yolo	It’s pretty light in Colusa. The yolo stuff runs the spectrum, but not so heavy one can’t rotate in it.	Diversified crops and rotation common.
C	Corn, sunflower and melons, some vine seed.	Sutter	Some hardpan soils, some alkaline soils, some heavy clay. These soil types	Some sole rice, some sole row crop, some both

			have high risk and rotations are weather dependent.	
O+ C	Safflower, corn, tomatoes, sunflower, beans, milo, sorghum. Or a cover crop depending on soils type.	Yolo + Butte + Colusa	Have some soils that are sandy loam, or loamier, most soils are heavy clay unsuitable for row crops.	All field in Richvale, Butte county property sole rice region. Yolo is mixed crops.
O + C (past)	Vine seeds following rice, cucumbers, squash after the rice. Then tomatoes. (past)	Colusa	To the west of I-5, the soil has a deeper profile. for Glenn, some ridges with deeper soil and heavy clay towards Princeton.	Sole rice in heavy adobe clay and alkali areas. Row crops in deeper soil profiles, trees moving in.
O	Majority land is not conducive to row crops, so rotates with vetch. Some ground is "lighter", do occasional hay rotations which starts out as alfalfa overseeded with orchard grass then into rice.	Sutter	Mostly heavy clay "not conducive to row crops".	Mostly conventional rice in the area. Some livestock and hay operations in area as well.
O	Organic rice, beans, popcorn, wheat. Has own processing equipment and markets. Certain soils classified as "rice only soils" will only be rice and vetch rotations.	Sutter	Combination of heavy clay and illuvial soils, "better soils for other crops".	Mostly surrounded by rice. North is mostly alfalfa, not a lot of row crops in area. Trees moving in.
O	Organic rice, followed but cattle, fallow flood, rye, rice.	Yuba	Red, medium clay, some gravel. Can't grow other crops, it just "drowns out".	Rice and pasture in the area.
O	Irrigated pasture followed by rice for several years. When weeds got bad planted it in organic vetch and oats for hay to sell to organic dairies. (past)	Yuba + Sutter	Heavy clay suitable for rice and cattle.	Area is rice and pasture.
O	Rice, barley, fallow, beans. Has own brand.	Other	Its heavy clay high salt.	Other crops in the area are mainly cotton and alfalfa there are some processing tomatoes.
O	Tomatoes, corn, rice, beans with cover crops planted every fall in between.	Sutter	Clay loam	Diverse cropping region.
O	Vetch and fallow, summer wheat rotations on occasion	Sutter	They all have kind of a hardpan base under them. Not deep soil profile. Not very loamy.	Primarily rice.

O	Alfalfa, Barley, vetch, wheat, rice.	Yolo	Lighter soils.	Field crop, row crop, and converting into orchard.
O+ C	Safflower, corn, tomatoes, sunflower, beans, milo, sorghum. Or a cover crop depending on soils type.	Yolo + Butte + Colusa	Have some soils that are sandy loam, or loamier, most soils are heavy clay unsuitable for row crops.	All field in Richvale, Butte county property sole rice region. Yolo is mixed crops.

Table 4:Matrix of rice- only growers summarizing grower soil descriptions and their perceived barriers for adopting crop rotations

Grower type	Sole county/s	Soil description	1st barrier for rotation	2nd barrier for rotation
Rice Only	Colusa	"Heavy clay"	No profitable options to rotate with	Landlord relations and cultural practices "I like growing rice"
Rice Only	Butte	"Soil type good for growing rice"	"So, we don't rotate in our fields because the soil type is only good for growing rice."	Economics
Rice Only	Sutter, Sacramento, Placer	"Not a whole lot we can rotate on this soil. It's not tomato ground, it's not corn ground. They call it adobe over here."	"financially can't afford to"	Availability of a good crop to rotate with in these kinds of soils.
Rice Only, + Organic	Sutter	"Mostly super heavy clay"	Don't have the Infrastructure (equipment, and labor)	
Rice Only, + Rotate	Sutter	Alkaline streaks in soil.	Don't know where to send the crops, no markets and no profitable options to rotate with	
Rice Only	Colusa	"...hardpan clay type soil and very high in salinity."	"No viable crop that I can grow that would even meet my production costs."	The soil type is not conducive to any other crop.
Rice Only	Colusa, Yuba, Butte	"Red soil with a hard pan... heavy clay...heavy loam clay. The stuff at Marysville is a real powdery red dirt with a hard pan."	Culture [everyone around me grows rice], logistics of changing out of rice are too complicated.	"Probably not having to buy more equipment and have that extra expense."
Rice Only	Placer	"Red clay"	don't have the infrastructure or equipment	

Rice Only	Sutter	Light to heavy.	Soil limitations	“I don’t have the ground
Rice Only	Colusa	“Heavy clay”	“Economics aren't there”	not set up for it or logistics, and the ground itself, so the geographic area.”
Rice Only, + Organic	Yuba	“Red, medium, but we have some places with gravel in it. It's round red rocks that were here a million years ago somehow.”	Economics	
Rice Only	Colusa	“Really high PH and water stand, and the ground is heavy.”	Nothing else that is profitable would grow.	
Rice Only	San Joaquin	“It's pig dirt, it’s all decomposed, we call it organic. That’s why we have so much moisture on these fields.”	Lack of markets/profitable options	Soil
Rice Only	Butte	“The top two feet would be a heavy black dark clay nearly impermeable to water. Hardly any percolation to water because it's tight heavy clay”	Economics	Experience
Rice Only, + Rotation	Colusa	“Heavy clay and alkaline”	Soil type and its potential to grow other crops.	Physical Environment
Rice Only, + Organic	Yuba	Heavy clay	“Soil type, so our soil is horrible. Its heavy clay is really good for growing rice and cattle.”	
Rice Only	Butte	Clay	Logistics, and soil	Economics
Rice Only, + Rotate	Butte	“Heavy adobe soil”	Soil limitations	
Rice Only, + Rotate (past)	Glenn, Colusa	“To the west of I-5 the soil has a deeper profile. From 99 to Colusa, bad alkaline. For Glenn county, we have ridges and heavy clay towards Princeton.”	Economics	

Rice Only, + Organic	Fresno, Merced	"It's heavy clay. because it's heavy clay and there's a lot of salt in it."	Viable crop	Soil
Rice Only	Glenn	"Hardpan clay"	Viable crop	Challenges associated with the success of that crop
Rice Only + Organic	Sutter	"Tends to range from heavy clay to clay loam to a little bit loamier but mostly clay loam to clay"	Rotations are too expensive	I don't have equipment necessarily
Rice Only + Rotate (past)	Sutter	"This is a drained river valley so the soil's much lighter so really anything can grow here so we took advantage of that [in the past]"	"It doesn't fit with our current model" (culture and economics)	
Rice Only	Sutter, Sacramento	"This is badly drained soil. Heavy clay, adobe"	No profitable options	The ground is not profiled for other crops.
Rice Only	Sutter	"Heavy clay"	"I would lose income"	Soil/clay ground
Rice Only	Glenn	"It's a hard clay pack"	Soil type	Our soil type
Rice Only + Rotate	Sutter	"...flat land on a flood plain"	land is too flat and use the land for bird hunting.	
Rice Only	Colusa	"Heavy clays, alkali, we do have some excellent soils, so loam soils that would be more applicable"	cost - cost to transform is too high	Profitability of alternate crop,