Salinity and Crop Choice in the Sacramento-San Joaquin Delta

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Executive Summary

This report examines the effect of salinity on crop changes in the California's Sacramento-San Joaquin River Delta. Delta water quality is important for the roughly 500,000 acres of farmland in the Delta, and approximately 3 million acres of farmland that receive water diverted from the south Delta by the Central Valley Project and State Water Project. Due to the Delta's complex hydrology and the many economic interests diverting water from the Delta and its watershed, it is important to understand how salinity affects Delta agriculture.

In this report, we compiled georeferenced parcel-level, panel data on crops grown and irrigation water salinity for 2007-2016. The time period under study includes dry and wet years which allowed us to capture a wide variation in irrigation water salinity levels, as well as crops planted, in order to estimate the effect of irrigation water salinity on crop choice at the parcel level.

There are over 70 different crops grown in the Delta. We used prior research that has established 4 categories of relative salinity tolerance of crops (T = Tolerant, MT = Moderately Tolerant, MS = Moderately Sensitive and S = Sensitive) to group similar Delta crops into 17 crop groups. Analysis of temporal trends in acreages of each crop group show that, although there is some annual variation in acreage, the highest acreage in the Delta in all years is in the Moderately-Sensitive (MS) field crop group, particularly corn and alfalfa. This is followed by the Moderately-Tolerant (MT) crop group, which includes field crops such as wheat, oats, safflower, rye etc., and the Sensitive (S) crop group, which includes fruit and nut orchards and berries. For example, in 2016, MS crop group comprised 57% of the acreage, MT crops comprised 17% of the acreage, S crops were on 14% and T crops, which include barley, asparagus and beets, were planted on less than 1% of the Delta acreage.

Parcel-level crop change analysis showed a wide variation in the persistence of crops on a field. Permanent crops like grapes and orchards tend to stay on the parcel for the entire time period of analysis and are less likely to be responsive to short-run year-to-year variations in irrigation water salinity. Others like beans, grains, oats, and truck and berry crops (such as strawberries and tomatoes) tended to be switched every 2-4 years on average, often as part of crop rotations.

Using data from the salinity monitoring stations in the Delta, we estimated irrigation water salinity levels for each parcel in the dataset. We have used average growing season (April-August) irrigation water salinity throughout this report. We find that irrigation water salinity during the growing season varies tremendously across locations in the Delta and is generally higher in dry years. As expected, parcels in northern Delta have lower irrigation water salinity than parcels in southern and western Delta, in all years under study. In critically dry years of 2008, 2014, and 2015, average growing season (April-August) irrigation water salinity in all parcels in the sample was 499.52 µS/cm, dropping to 392.79 µS/cm in dry years (2007, 2009, and 2013), and to 311.34 µS/cm during below normal years (2010, 2012, and

2016). In the single wet year (2011) in the sample, mean salinity was 228.49 µS/cm. Trends in irrigation water salinity observations show that it varies more across locations in the Delta than from year-to-year at the same location.

In order to rigorously test the effect of changes in irrigation water salinity on crops planted, we frame our central hypothesis as follows: All else equal, as growing season irrigation water salinity levels increase, growers will plant relatively more salinity-tolerant crops and fewer salinity-sensitive crops. The parcel-level panel data compiled in this report, allows two kinds of analyses to test this hypothesis: a comparison of crops and irrigation water salinity in parcels in different locations of the Delta (cross-sectional analysis), and analysis of crop switch at the same parcel over time (fixed-effects analysis). We present both analyses using multinomial logit models. Model 1 is a cross-sectional multinomial logit model; it evaluates the impact of salinity on crop choice across parcels and over time in the Delta. In contrast, Model 2 is a fixed-effects analysis multinomial logit model; it restricts attention to only those parcels that underwent a crop change during the time period of analysis, and evaluates the role of irrigation water salinity in inducing that crop change. Because Model 1 and Model 2 analyze the panel data differently, they are not expected to give identical results. A comparison of their results, however, helps us get a more complete picture of the role of irrigation water salinity in shaping cropping decisions across parcels in the Delta, over time.

Results of Model 1 and Model 2 showed that locations with lower irrigation water salinity during the growing season (April-August) tended to have more parcels in orchards and vineyards. In particular, Model 1 found significant evidence that farmers have avoided planting higher-valued and permanent crops such grapes and salinity-sensitive fruit and nut orchards in areas of the Delta with higher levels of irrigation water salinity. Even though acreage in orchards and vineyards has increased over 2007-2016, this increase has occurred in relatively lower-salinity, northern parts of the Delta. Also, results showed that higher irrigation water salinity increased the odds of growing moderately-tolerant and tolerant vegetable groups such as squash and artichoke, asparagus and beets.

Results of Model 2 give evidence that farmers are responding to irrigation water salinity increases by switching to relatively salt-tolerant crops like pasture and moderately-tolerant field crops such as safflower, rye, forage hay, Sudan grass and sorghum. We also found that higher irrigation water salinity discourages growers from growing relatively salinity-sensitive vegetable crops such as cucumber, pumpkin, potatoes etc. Higher irrigation water salinity also increases the odds of switching into moderately-tolerant orchards such as olives, pomegranates and pistachios.

Overall, the results show that salinity has some effect on crop choice in the Delta over the past decade. While irrigation water salinity in the growing season may not be the primary driver of crop choice in most parts of the Delta, the results have policy implications because the recent increase in the regulatory limit for irrigation water salinity in the central and south Delta could have larger impacts than expected. In addition, it is important to note that crop choice is only one negative impact of salinity on farmers – we focus on it because it is the most readily observable impact. Farmers can still be negatively impacted by lower yields, higher management costs, and long-term soil degradation even if their crop choice is unaffected. Thus, this analysis should be interpreted as a lower-bound, partial assessment of salinity impacts in the Delta

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1. Introduction

Increases in salinity in surface or groundwater is a growing problem in California's Central Valley and many arid regions of the world. Crop yields decline if root-zone salinity is higher than what the crop can tolerate at that stage of growth. Salinity increases can reduce crop yields, affect crop choices, and increase production costs, thus reducing farmer incomes.

The Sacramento-San Joaquin Delta is an important area to study the effects of irrigation water salinity on agriculture. The Delta is the area where the Sacramento and San Joaquin rivers come together before reaching San Francisco Bay and flowing out to sea. It is one of California's most historic farming areas and includes roughly a half million acres of cropland that are usually irrigated by diversions from the channels of the nearby rivers and sloughs. Much of the Delta was originally marshland, but was reclaimed in the 19th and early 20th century, and the land is protected by levees. Salinity has long been an issue for farmers in the Delta as saline water encroaches into the Delta from San Francisco Bay when freshwater outflows are low, and saline water also enters the Delta from the San Joaquin River due to runoff from irrigated fields upstream.

Salinity in Delta waters not only affects farmers in the Delta itself, but also impacts farmers in the San Joaquin Valley that import water from the Delta. The Central Valley Project and State Water Project are large water diversions in the south Delta that supply water to approximately 3 million acres of cropland south of the Delta in the San Joaquin Valley. The export of water from the South Delta affects water quality in the Delta in complex ways. The large diversion of freshwater that would otherwise flow through the Bay can cause salinity to move into the west Delta from the Bay, and the increased irrigation of land in the San Joaquin Valley from south Delta diversions can return salinity to the Delta through the San Joaquin River. On the other hand, the operation of the CVP and SWP can reduce salinity in parts of the Delta by releasing stored water from reservoirs in Sacramento River watersheds and pulling the freshwater through the interior Delta to the pumps. Delta water salinity could also be affected by climate change as sea-level rise can increase salinity intrusion from the Bay and effect the storage and release of freshwater in upstream reservoirs.

As a result of this complex hydrology and multiple economic interests, the management of salinity in the Delta can be an area of controversy. For example, in the late 1980s, farmers on Sherman Island in the West Delta sued the Department of Water Resources, accusing increased pumping from the State Water Project for their saline irrigation water. The State settled the lawsuit in 1991, ultimately buying out the farmers who could no longer grow most crops (Ellis, 1991). One of those farmers was quoted by the Los Angeles Times "I used to average 5.5 tons per acre of corn… Now we're in a situation where we can't grow corn because it is a salt-sensitive crop. We've completely zeroed out in production."

In recent years, Delta water quality has been subject to a regulation known as D-1641, which required the water projects to maintain salinity in the south and central Delta below 700 µS/cm during the April to August growing season. In early 2019, after several years of consideration and hearings, the State Water Resources Control Board adjusted the growing season maximum up by 41% to 1,000 µS/cm. This change was opposed by Delta farmers, and supported by the SWP and CVP because it will increase their operational flexibility, particularly in dry years when the previous standard was not always met. In making the change, the SWRCB stated "Recent analysis of southern Delta water quality and crop salinity requirements shows that the existing salinity conditions in the southern Delta are suitable for all crops and that the existing April through August salinity objective is lower than what is needed to reasonably protect agricultural beneficial uses." (State Water Resources Control Board, 2018, page 2)

The goal of this report is to present a detailed analysis of the effect of irrigation water salinity on crop choice in the Delta. This report is organized as follows: Section 2 reviews relevant literature and outlines the general study approach, Section 3 gives a detailed outline of the research methods and describes the data sources, Section 4 presents the summary statistics of the data, particularly trends in crops and salinity. Section 5 presents the multinomial logit models and results, and finally Section 6 presents the conclusions.

2. Literature Review and Study Approach

A common approach to measuring the effect of salinity on agricultural production in the economics and policy literature is the use of programming models in which individual agents maximize profits given crop prices, costs of production, and constraints on land and water availability, including different salinity conditions. This approach combines agricultural production economic models with hydrologic models and estimate the change in agricultural output of a region relative to a baseline year. For example, Medellín-Azuara et al. (2014) study the effect of different salinity scenarios on cropping patterns and crop revenues in the Sacramento-San Joaquin Delta relative to the baseline of 2007. Similar approaches have been applied to studying farmers' adaptation responses to salinity. For example, Knapp et al. (2014) study optimal response to salinity and drainage management problems with several programming models at the regional scale using baseline data from San Joaquin valley. Their analysis shows how the optimal response to drainage management, such as drainage water reuse, evaporation ponds or alternative irrigation systems, is affected by economic and hydrologic conditions.

The programming approach generates predictions of the effects of changing conditions that are consistent with economic theory and the specific parameters assumed in the models. However, the results are highly-sensitive to these assumptions which can be based on limited data and untested for accuracy. For example, Medellín-Azuara et al. (2014) follow the assumption of Hoffman (2010) and "assume sufficient drainage exists in irrigated areas to avoid salt accumulation in the root zone." Thus, the model assumes soil conditions are uniform and that irrigation water salinity up to 1000 µS/cm has no effect on crops in the Delta.

As a result, Medellin-Azuara et. al.'s simulations of various salinity increase scenarios in the Delta show that increased salinity over the current baseline conditions would have only small effects on Delta agricultural revenue. They explain this finding as follows, "Total crop revenue losses from these salinity increases generally remain small because areas in the Delta with the greatest salinity effects now mostly grow lower-value crops" (Medellín-Azuara et al., 2014, p. 14). This explanation begs a question, why are lower valued crops more common in areas of the Delta most affected by increased salinity? If there is a pattern between salinity and current plantings, it suggests that their assumptions about the thresholds where salinity begins to harm crops and variation in salt accumulation in the soil, could be inaccurate, at least in some locations of the Delta.

The analysis presented in this report takes a different approach to the problem of estimating the effect of salinity on agricultural production. We adopt a data-based statistical approach. We compile a parcel-level panel data of crop choice and salinity and estimate multinomial logit models of crop choice with observed salinity as a covariable. The estimated parameter on salinity is the relative odds of choosing one crop or a group of crops over a base outcome. Recent work has recognized the need for parcel-level data-based approaches to understanding crop choice; for example, a recent study by Welle and Mauter (2017) used high resolution (30 m) satellite imagery to compile field-level crop data for the entire Central Valley and then estimated yield and revenue losses from increase in salinity using crop-specific salinity induced yield-loss functions. Welle and Mauter (2017) used similar data for one year, 2014, but their analysis did not allow for crop switching.

This approach was first applied to the Delta in the Delta Protection Commission's 2012 Economic Sustainability Plan. This report expands and improves on that initial analysis in several dimensions. First, we conduct a parcel-level analysis with an expanded data set extending through 2016. Second, we use a larger number of carefully constructed crop groups to add more detail to the modeling. Finally, our parcel-level analysis allows us to create a panel data set and estimate the multinomial logit model with parcel fixed effects to control for unobserved factors influencing crop choice. The use of repeat observations on crops planted on a parcel, combined with time-series and cross-sectional variation in salinity across parcels, allows us to consistently estimate the effect of salinity changes on crop choice. Our analysis only looks at crop choice and thus does not include all of the negative effects of salinity on agriculture. For example, our analysis would not show if a farmer suffered yield loss or increased management costs due to salinity that were not large enough to induce a change in crop type.

3. Methods and Data

3.a. Methods

The analysis presented here was conducted in three sequential steps:

***Step 1**:* Annual geo-referenced, field-level data on crops and salinity were compiled in a GIS database. Field data were placed within recorded land ownership (tax parcel) and irrigation district boundaries in ArcGIS and data on characteristics of each field, such as soil type, slope/elevation, and shallow groundwater depth were added. Section 3.b. outlines the data sources for each data series, and Appendix A details the process of Step 1.

Step 2: Using data from Step 1, we built a parcel-level panel dataset of crops and salinity. In building the panel data we processed crop names so that a single crop was attributed to each field and restricted the analysis to the largest field within a tax parcel, as a result built a parcel-level panel data. Detail of the process and assumptions involved are given in Section 4.

***Step 3**:* Using the panel data from Step 2, multinomial logit models were used to evaluate the effect of salinity on farmers' crop choice. Detail of model specifications and results are given in section 5.

3.b. Data Sources and Construction of Parcel-level Panel Data

This section details the data sources and the key trends in crops and salinity in the study area.

3.b.i. Crops

One of the most important datasets needed for this analysis is field-level data on crops planted in the Delta. A panel dataset would be ideal, as panel data has multiyear field-level observations on crops and salinity, spanning drought and non-drought years to capture a wide variation in salinity in order to estimate the effect of salinity on crop change. The analysis presented in this report uses California Agricultural Commissioners and Sealers Association (CACASA) data for 10 years, 2007-2016, as the primary source of data for crops planted in the Delta.

CACASA is self-reported data on the chemicals and pesticides farmers apply to their fields and the crops they grow. While the focus of our study is on salinity and not pesticide use, the CACASA data provided the crop information that we needed to understand field-level changes in cropping in the Delta.[1] CACASA data had a coverage of about 195,000 acres in 2007 and has increased each year to about 394,000 acres in 2016. While the coverage has improved in successive years, it is less than about half a million acres of agricultural area in the Delta. Therefore, a concern may be that CACASA land use may not be representative of the Delta agriculture. We investigated this concern by comparing land use in CACASA data to the most extensive field-level coverage of satellite data available from LandIQ.

Comparison with LandIQ for 2014 and 2015 showed that CACASA coverage in the Delta is high: 87% and 84% for 2014 and 2015, respectively. Of the area not covered by CACASA, the largest land use is pasture. This may be because pesticide permits are not required as often for pasture as for other crops.[2] Of the areas where CACASA and LandIQ overlap, we found concurrence in both data sets. For most crops, acreages and fields match across the two data sources quite well. For example, the difference in orchard acreage is 3% and in alfalfa acreage is 11% in 2014. See Appendix B for details on the concurrence check between CACASA and LandIQ data. Finally, conversation with county staff has revealed that less-than-100% coverage is due to data availability in GIS format rather than omissions in reporting of pesticide use by growers. This assuaged our sample selection concern.[3]

Thus, despite some limitations, we concluded that CACASA data are the best available data for developing a consistent time-series of field-level crop choice to build a panel data of repeated observations on the same field over time. No other data set, to our knowledge, gives us a 10-year time series. Other sources of data, such as DWR's Land Use Surveys, are not available consistently for the study area. LandIQ data were only available for two years, 2014 and 2015, both drought years. Restricting the analysis to these two years would give a smaller and non-representative sample of the environmental conditions in the Delta.

3.b.ii. Land Ownership

A tax parcel is a contiguous agricultural area owned by one owner. Since the delineation of crop fields in CACASA can shift spatially from year to year, we combined the CACASA field

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[1] In California, all agricultural applications of pesticides are reported, including geographical location, crop treated, and date of application. Complete agricultural pesticide use reporting has been a California requirement since 1990, with restricted pesticide usage reported pre-1990. Under the program, all agricultural pesticide use must be reported monthly to county agricultural commissioners, who in turn, report the data to Department of Pesticide Regulation (See https://www.cdpr.ca.gov/docs/pur/pur16rep/16sum.htm#eval). Data based on pesticide use reports in California have been increasingly used by researchers, particularly in the field of public health.

[2] Pasture is a relatively stable land use; data analysis in the section 4b shows that 80% of the time (8 of 10 years in the sample) pasture land stays in pasture.

[3] In 2011, Counties implemented CalAgPermits, a standardized, web-based system for electronic reporting pesticide use and helping county agricultural commissioners to issue restricted-materials permits. Availability of PUR data in GIS has been occurring at different paces in different counties (https://www.cdpr.ca.gov/docs/pur/pur16rep/16sum.htm#calag)

data with each county's tax parcel boundaries. This gave us a spatially-stable framework on which to pin the often-shifting crop data, allowing us to examine cropping decisions from the landowners' perspectives.

A tax parcel can contain multiple crop fields, each with different crops; however, the majority of the tax parcels (57%) contain a single crop field. In the remaining cases, we restrict the analysis to the largest field within the tax parcel and thus examine one field per parcel.[4] This is a reasonable assumption because, in a majority of the cases, the same crop was grown in the second field or crops belonged to the same crop group (see section 4.a. for a discussion of how crop groups were constructed); or the second field was uncultivated. Of the fields included in the analysis, a majority (80%) reported a single crop.[5] In the remaining 20% of multi-cropped fields, data cleaning showed that the second land use was either the same crop, the same crop group as defined in Table 1, or uncultivated land. In a minority of the cases when two different crop groups were planted, we chose the first crop listed as the crop on that field. This allowed us to examine one crop per parcel in a parcel-year panel data.

3.b.iii. Salinity

Crop yield reductions occur when salts accumulate in the root zone to such an extent that the plant is no longer able to extract sufficient water from the salty soil solution, resulting in a water stress for a significant period of time. If water uptake is appreciably reduced, plant slows its rate of growth (Ayers and Westcot, 1994). Applied water salinity can influence root zone salinity.[6] For example, if irrigation water is saline, salts can accumulate in the soil at higher concentrations than they existed in irrigation water because evaporation and plant uptake extract water from the soil leaving the salts behind. Most irrigation in the Delta is from surface water (Wilson, 2014), and we use surface water salinity as a proxy for root zone salinity in this study.

It is important to note the shortcomings of this approach. Accumulation of salts in the soil depend on not just irrigation water salinity but also on soil properties, shallow groundwater depth, and farming practices such as leaching, irrigation systems, or other reasons. So, while it is important to note that irrigation water salinity is not the same as soil salinity, we unfortunately do not have data on soil salinity at the parcel level. Therefore, we rely on irrigation water salinity data at the parcel level as a proxy for root zone salinity at the parcel level. Our use of irrigation water salinity is consistent with current policy as it is the measure

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[4] 16% of the parcels report two fields, 7.5% report three fields and the remaining 20% of the sample reports 4 or more fields.

[5] The raw CACASA data reported a far higher number of crops planted in each field but careful data cleaning, which involved spelling checks, or putting together slightly different name variations (e.g. "SUGAR BEETS" and "SUGARBEETS"), we were able to reduce the number of crops markedly.

[6] As Ayers and Westcot (1994) explain, the relationship between ECe (soil salinity) and ECw (irrigation water salinity) is generally positive, and is greatly influenced by soil conditions, leaching fraction, and other factors.

used in Delta water quality regulatory standards and monitoring. In the rest of the report salinity refers to irrigation water salinity.

A network of USGS and CDEC monitoring stations are used to monitor salinity in surface water (Burau et al., 2016); Figure 2 shows the location of monitoring stations in the Delta. Monthly averages of salinity for the growing season (April-August) were calculated for 2007-2016. The decision to choose April-August window was based on the best available information about irrigation in the Delta.[7] We used spline interpolation method to assign a monthly salinity value to each parcel in the sample. See section 2 In Appendix A for detail on the salinity data interpolation methods. Irrigation water salinity is measured in micro Siemens per centimeter (µS/cm).

3.b.iv. Soil Type, Slope, and Shallow Groundwater Depth

Local environmental conditions affect crop choice, and the impact of irrigation water salinity. For example, soil type can affect leaching requirements. We obtained soil quality, land slope, and shallow groundwater depth data from the USDA Soil Survey Geographic Database (SSURGO). We also obtained elevation for each parcel as a proxy control for flood risk and groundwater depth.

4. Spatial and Temporal Trends in Crops and Salinity

Based on the methods and sources described in section 3, we have compiled a panel data of parcels spanning 10 years, 2007-2016. The data includes about 22,000 observations.

4.a. Crop Groups and Total Acreages

The CACASA data shows more than 70 different crops are planted in the Delta. In order to conduct a tractable crop-change analysis, crops were grouped with similar crops such as grasses, grains, orchards, vegetable and berry crops, etc. as done in ESP (2012). However, each of these groups contains crops that vary in their relative salinity tolerance. For example, the grain group includes wheat, which is moderately tolerant (“MT”); barley, which is tolerant (“T”); corn and rice which are both moderately sensitive (“MS”). Therefore, we broke out sub-groups based on relative salinity tolerance of crops.

Previous research on the response of crops to salt in the root zone has developed four categories for relative salt tolerance of crops: T = Tolerant, MT = Moderately Tolerant, MS = Moderately Sensitive, and S = Sensitive (Ayers and Westcot, 1994). The salt tolerance of crops is not an exact value but depends on many factors such as climate, soil conditions, stage of plant growth, and farmers’ soil and water management practices. Though these

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[7] This time frame may not accurately reflect actual irrigation times for all locations in the Delta. Research is needed to ground truth this assumption.

factors might not be fully captured in experimental settings (Hanson et al., 2006), these categories are useful benchmarks to group crops with similar salinity tolerances.

Table 1 lists the main crops grown in the Delta, as reported by CACASA data, and their assignment to the crop groups used in this analysis. In some cases, an entire crop group is designated to a single crop. For example, pasture, corn, tomatoes, barley, and grapes occupy entire crop groups. Other groups contain several crops, e.g., in moderately-tolerant field crop group (F_MT) 39% of parcels have safflower, 22% have rye, 12% have Sudan grass, and 9% have sorghum. Similarly, the fruits and nut orchard group (O_S) have roughly equal percentage of parcels in almonds (26%), pears (25%), walnuts (20%), and cherry (19%) orchards, along with smaller percentages in various other fruit orchards.

Figure 3 shows the distribution of acreage based on relative salinity tolerance. By far, the highest acreage in the Delta in 2016, 57%, is in the Moderately Sensitive (MS) crop group, followed by the Moderately Tolerant (MT) and Sensitive (S) groups, each of which represents about 17% and 14% of percentage acreage, respectively, in 2016. The smallest acreage, less than 1% in 2016, is in Tolerant (T) crops. Figure 3 also shows the change in percentage acreage over 2007-2016: acreage has decreased for MS crops, from a high of 69% in 2007 to about 57% in 2016. The acreage in S group has increased, from 7% to 14%, as market forces has led farmers throughout the Central Valley to shift towards nut orchards, especially almonds. Acreage in MT group has increased as well from 12% to 17%, while acreage in T group has decline from a 2% of the acreage in 2007 to less than 0.5% in 2016.

Figures 4-7 present percentage acreages for all crop groups within each relative salinity tolerance category. As Figure 4 shows, alfalfa and corn are the two largest crops by acreage in the MS group, and in the Delta as a whole. However, acreage of both crops decreased during our period of analysis (alfalfa from 25% to 15% and corn from 21% to 13% of the reported acreage). Acreage in tomatoes fluctuated, reaching its lowest acreage in 2013 at 6%, but recovered somewhat in 2014 and 2015. Grapes and vineyards have increased from 8% to 12% of the acreage, and the rice group (G_MS_R) has fluctuated around 2% of the acreage.

Figure 5 shows acreage distribution in the moderately-tolerant (MT) group. In this group as a whole, grains (G_MT), which largely include wheat and oats, is the largest crop by percentage acreage, followed by field crops (F_MT), which includes safflower, rye, etc. Moderately-tolerant orchard group (O_MT_O) which is largely composed of olives is less than 1% of the Delta acreage but has more than doubled in acreage. Other crop in the MT group representing relatively small percentage of Delta acreage—e.g., artichoke and squash, and turf grass-- are relatively stable in percentage acreage from year to year.

Figure 6 shows the breakdown of the S crop group. The largest acreage in this group is in fruit and nut orchards, largely almonds, pears, cherries and walnuts, which has also experienced an increase in acreage from about 4% to 10% in the Delta. Dried beans acreage has held steady at 2-3% for the entire period. Salinity-sensitive vegetable and berry crop group, largely comprising of berries, carrots and green beans is less than 1% of the agricultural acreage in the Delta.

Figure 7 shows the distribution of crops in the Tolerant (T) group. As a whole, this group does not exceed 2.5% of agricultural area of the Delta. Asparagus (TB_T_A) has markedly declined from more than 2% to less than 0.5% of agricultural acreage. Barley (G_T) acreage has fluctuated over the years but has never exceeded 0.2% of the Delta.

4.b. Parcel-level Crop Change in the Delta

Figures 3-7 presented in the previous sections how the change in aggregate crop acreage, which reveals little about the parcel-level change in crops. For example, if farmer A switches 20 acres of alfalfa into tomatoes, while farmer B switches 20 acres of tomatoes into alfalfa, the overall acreages will show no change in crop acreages of tomatoes and alfalfa even though there is a 40 acres of crop change *at the parcel level*. Parcel-level analysis of crop change is made possible by examining the panel nature of the data, specifically the between and within variation. This analysis will help us understand which crop groups are more or less persistent i.e. more or less likely to be switched from year to year.

Table 2 shows the between and within variation in crop groups by relative salinity tolerance. The between percent tells us what percentage of parcels had a given crop at least once during 2007-2016. Results in Table 2 show that 24% of the fields had an S crop at least once during 2007-2016; 81% of the fields had an MS crop at least once; 48% of the fields had an MT crop at least once; and only about 3% of the fields had an T crop at least one of 10 years in the sample. Within percentage shows, conditional on a field ever growing that crop, what percent of time (i.e. years) it stayed in the same group. In other words, the within column gives us a measure of the stability or persistence of the crop group. Results show that conditional on a field ever growing an S crop, it stayed in the S crop group (e.g., beans or orchards) 52% of its observed values i.e. about 5 years. Similarly, conditional on a field ever having an MS (e.g. alfalfa and corn) crop, it stayed in the MS crop group 78% the time i.e. for about 7-8 years.

The persistence of T and MT crop group is about the same; conditional on a field growing a T or MT crop, 41-42% of the time (i.e., about 4 years) the field stayed in the respective crop group. Though tolerant crops represent no more than 2.5% of total Delta area, results in Table 2 show that it is also a less persistent crop choice--i.e., fields are coming in and out of this group quite often. Only 42% of the fields that have a T crop stay in this group, but the rest switch over to other crops.

Table 3 shows the between and within variation for each of the 17 crop groups. Vineyards, pasture, fruit and nut orchards and olives are the most stable crop groups. Fields in vineyards (V_MS_G), Pasture (P), and orchards (O_S), vineyards(V_MS_G), and olives

(O_MT_O) tended to stay in the same crop 88%, 73% and 68%, and 62% of the time, respectively. The next most persistent crop group is alfalfa (F_MS_A), another multiyear crop. Corn, which along with alfalfa is one of the two of the most commonly-grown crops, has within variation of 40%. The crop groups that switch most often are beans, rice, barley, and vegetables crops.

4.c. ***Spatial and Temporal Variation in Salinity***

Salinity varies tremendously across locations in the Delta and is generally higher in dry years. Figure 2 shows salinity data observed at the monitoring stations during growing season (April-August) for each year in the sample. We used the Water Year Hydrologic Classification Index for Sacramento Valley to group years into Critical (2008, 2014, 2015), Dry (2007, 2009, 2013), Below Normal (2010, 2012, and 2015) and Wet (2011).[8] As expected, northern Delta has lower salinity levels in all years and southern and western Delta salinity levels are much higher, particularly in drier years.

Figure 8 shows the growing season (April-August) salinity average values in each of the three Delta Water Agencies (DWAs), representing broadly the northern, central and southern locations in the Delta (see Figure 1 for locations of irrigation districts). While salinity levels move somewhat together in the Delta region, southern delta has the highest salinity, followed by Central and Northern DWAs. 2011 was a wet year, and as noted in Table 4 earlier, had the lowest salinity levels in this period of analysis. Salinity levels were higher in other years, after declining from 2007-2011, it started rising again and peaked at 2015 (a critically dry year) before dropping again in 2016.

Data from the monitoring stations were used to estimate parcel-level irrigation water salinity data as described by methods in section 3.b.iii. Table 4 shows the parcel-level mean and variation in salinity for April-August, again grouped by the degree of dry conditions in the Sacramento Valley. In critically dry years of 2008, 2014, and 2015 mean salinity in all parcels in the sample was at 499.52 µS/cm, dropping to 392.79 µS/cm in dry years (2007, 2009, and 2013), and to 311. 34 µS/cm during below normal years (2010, 2012, and 2016). In the single wet year (2011) in the sample mean salinity was 228.49 µS/cm.

An important aspect of salinity observations across the Delta is that salinity varies more across locations in the Delta than from year-to-year at the same location-- i.e. between variation is greater than within variation, as shown in Table 4. Moreover, this cross-sectional variation increases markedly in drier years. This could have important implications for differences in location-specific salt concentration in soil, salinity management practices, and preferred crop choices.

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[8] Water Year Hydrologic Classification Index for Sacramento Valley obtained from http://cdec.water.ca.gov/reportapp/javareports?name=WSIHIST

5. Multinomial Logit Models of Crop Choice

In order to understand the effect of salinity on crop changes, we use the multinomial logit model (McFadden, 1973; Chamberlain, 1980). Multinomial logit model predicts crop choice, conditional on values of included explanatory variables including salinity, soil types, and other characteristics of land/farm operation predisposing growth of certain crops. The set of crop choices consists of crop groups described in section 4.a. The goal of this analysis is to understand whether one or more explanatory variables, particularly salinity, increase the likelihood of choosing a particular crop over a base outcome.

We assume that growers are profit-maximizing--i.e., given soil conditions (including salinity), crop prices and costs, they make annual crop choices to maximize profits. We hypothesize that, all else equal, as salinity levels increase, growers will plant relatively more salt-tolerant crops and fewer salt-sensitive crops. Additional factors affecting land-use decisions include field characteristics, such as soil quality, parcel size, slope, and elevation of the parcel.

Previous work has used the multinomial logit model to estimate the impact of salinity on crop choice in cross-sectional analyses (e.g., DPC, 2012; MacEwan et al., 2016). MacEwan et al. (2016) compile data on crops planted in about 1 million acres in Kern County, California and estimated a cross-sectional multinomial logit model of crop choice. Their results show strong support for the hypothesis that growers respond to changes in salinity, soil, and slope by changing planting decisions. These researchers find that a 1 dS/m (equivalent to 1000 µS/cm) increase in salinity leads a 5.2% increase in the odds a farmer plants relatively salt-tolerant cotton while decreasing the odds of growing salt-sensitive orchards by 4.8%. Multinomial models have also been useful for understanding crop choice in response to climate change (Seo and Mendelsohn, 2008) and farmers' irrigation technology choices (Green et al., 1996). The current study is the first, to our knowledge, to examine of the effect of salinity on crops grown on specific parcels over time in a panel data framework.

5a. Models

We use two alternative multinomial logit models to estimate the effect of current year growing season (April-August) water salinity on crop choice:

<u>Model 1: Pooled cross-sectional multinomial logit model</u>**:** Similar to previous work (DPC, 2012 and McEwan et al., 2016), we estimate a cross-sectional model for the pooled data for 2007-2016, adding several control variables and annual dummy variables. The final dataset was comprised of 22,375 observations of crop choice for over 2,900 parcels. In addition to allowing comparison with previous studies on salinity and crop change, an advantage of this modeling approach is that it allows for estimation of the effects of time-invariant variables such as soil quality and elevation on crop choice. A disadvantage is that it may suffer from omitted variable bias.

Model 2: Fixed-effects multinomial logit model: The fixed-effects multinomial logit model was developed by Chamberlain (1980) and updated by Pforr (2014). Model 2 takes advantage of the panel nature of our data i.e. repeated observations on the same parcel, and estimates the effect of salinity on *crop switch at the parcel level*. This model allows us to reduce the omitted variable bias that may be present in Model 1 by assigning fixed effects to each parcel, which could be particularly useful in controlling for unobservable parcel-specific soil conditions, ownership characteristics or salinity management practices. A drawback is that coefficients of time-invariant variables, such as soil conditions or slope or elevation, cannot be estimated. In order to allow for model convergence we remove the earlier and lower data years of 2007 and 2008 and estimated it for 2009-2016. Also, because this model examines changes in crop choice for individual parcels, parcels that did not change crop group even once over this period were dropped from analysis (mostly vineyards and orchards), leaving 13,440 observations, about 60% of the observations used in Model 1.[9]

We present the results of each model in section 5c, but it is important to note *ex ante* that Models 1 and 2 are expected to give different results regarding effects of salinity on crop choice. Model 1 is cross-sectional, meaning it evaluates the impact of salinity on crop choice both for a given parcel over time and across parcels throughout the Delta (both within and between variation). In contrast, Model 2 evaluates changes in crop choice only for a given parcel over time (within variation). Recall that in the Delta within variation in salinity is smaller than between variation. Moreover, there is a large cross-sectional difference in cropping patterns in the Delta as a result of differences in factors (e.g., existing soil conditions) that make certain regions more favorable for some crops. Both patterns were discussed at length in sections 4.b. and 4.c. So, Model 1 that pools both these variations would be expected to pick up a larger set of effects of salinity on crop choice than Model 2. In contrast, Model 2 turns off cross-sectional variation and relies only on variation in growing season salinity from year to year to estimate the effect of growing season salinity on *crop switch at the parcel level*. *Ex ante* Model 1 and Model 2 cannot be expected to give identical results but can be regarded as complementary models to understand of the role of salinity in crop choice in the Delta.

5.b. Variables

Outcome variable: Parcel-level crop choice: The outcome variable is the list of crop groups as explained in section 4.a. for a description of the 17 crop groups used in the analysis.

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[9] Fixed effects model drops observations that do not undergo a change in the dependent variable (crop group) even once during 2009-2016. Of these dropped observations vineyards was the largest group (31%), followed by sensitive fruit and nut orchards (25%), corn (13%), and alfalfa (7%). This matches quite well with stability of crop groups discussed in section 4.b.

Explanatory variable of interest: Parcel-level Salinity: Salinity is the main variable of interest (*salt_growing)* We use average current year salinity levels for April-August to explain crop choice.

Control variables: Explanatory variables should control for all characteristics of the parcel that impact crop choice. Variables included are as follows, and their names used in the regression output in the parenthesis. The summary statistics of these variables are given in Table 5.

- *Parcel Acreage (parcel_acreage).* This is the total area of the parcel (acres).
- Slope *(*slopegradw)*.* Indicates the percent gradient of the soil surface.
- Elevation (*elevation)*. This could be an important factor for several cropping decisions on several low elevation islands in the Delta. This variable captures the elevation of the midpoint of the parcel from the sea level. Measure in meters, this variable was generated in GIS using the USGS 10-meter resolution Digital Elevation Model.
- Water Table Depth (*wtdepaprju*). April-June minimum*:* This variable accounts for the fact that increased water tables impact the salinity levels in the soil if groundwater carries salts into plants' root zones (Hoffman, 2010).
- Soil irrigated capability class (*Soil_Index*). This numerical index (ranging from 1-8) indicates the suitability of the soil for growing crops, accounting for soil textures that are unfavorable to crop growth; salinity levels; erosion potential, and other factors (U.S. Bureau of Reclamation, 2005). Higher values of the index mean the soil is less suitable for irrigation.
- Available water storage capacity, 50 cm. (*aws050wta*). This is an indicator of the soil's ability to store water, which varies for loam, clay, silt, and other soil types. Storage capacity can be calculated at various depths, as crop growth depends upon water availability at the root zone. The variable included in our analysis was storage at 50 cm values of 25, 50, 100, and 150 cm were all very highly correlated (correlation coefficient of 0.83 or higher), yielding nearly identical results for all potential values of this variable. Units for water storage are centimeters of water.
- Annual dummy variables for years 2008-2016 (*year_2008 to year_2016)*. These annual variables capture overall trends in prices, costs or weather that affect the entire Delta. The year 2007 is the reference year for dummy variables capturing the impact of years 2008-2016 in Model 1. In Model 2, 2009 is the reference year.

5.c. Results

We assign the alfalfa group (F_MS_A) as the base crop choice. We choose this moderately-sensitive group as the base choice because it is the most common crop in the Delta, and it would be economically meaningful to understand farmers' decision to grow something other than the most common choice. For all specifications reported below, estimated coefficients represent relative odds of growing another crop relative to the alfalfa group. Coefficients greater (less) than one mean that the crop group in question is more (less) likely to be grown relative to alfalfa.

5.c.i. <u>Results of pooled cross-sectional multinomial logit model (Model 1)</u>

Table 6 presents results of Model 1. Note that Table 6 is split in 2 parts to show full results of all 17 equations estimated. Coefficients for current year growing season water salinity (*salt_growing*) are greater than 1 with p-values less than or equal to 10% for the following crops groups: dried beans (B_S), corn (G_MS_C); tomatoes (TB_MS_T); moderately-tolerant truck and berry crops (TB_MT); and asparagus (TB_T_A). This means increasing salinity increases the likelihood of growing these crop groups, relative to alfalfa. Conversely, moderately-tolerant field crops (F_MT, e.g., safflower, rye, forage hay/silage, Sudan grass, sorghum); the rice and grain group (G_MS_R); vineyards (V_MS_G); orchards (O_S) and turf crops (TF_MT) are less likely to be grown (negative coefficients for *salt_growing*).

In line with our hypothesis, we find that higher salinity increases the odds of growing moderately-tolerant and tolerant vegetable groups which include squash and artichoke (TB_MT) and asparagus and beets (TB_T_A), relative to alfalfa. We also find that higher salinity reduces the odds of growing the salinity-sensitive orchard group which is primarily composed of includes almonds, pears, cherries and walnuts (O_S), grapes (V_MS_G), and the rice group (G_MS_R).

Counter to our hypothesis, we find that higher salinity increases the odds of growing dried beans (B_S) which are relatively salinity sensitive, but reduces the odds of growing moderately-tolerant field crops which include safflower, rye etc. (F_MT). Crop groups with statistically insignificant coefficients for salinity, indicating they are no more or less likely to be grown as alfalfa due to salinity changes, include pasture, tolerant and moderately-tolerant grains such as wheat and oats (G_MT) and barley (G_T) and the moderately-tolerant orchard group including olives and pistachios (O_MT_O). These results are counter to our hypothesis as well, as we would expect higher salinity to increase planting of relatively-tolerant crop groups.

Coefficient estimates for annual dummy variables (*year2008 to year2016)* show annual trends in odds of planting each group relative to the omitted year of 2007, all else equal. Coefficients are positive and statistically significant for wheat and oats (G_MT), indicating increased planting of these crops in all years. Annual dummy variable coefficients are also positive and significant from 2012-2016 for the vegetables and berry groups (TB_MS and TB_S), orchards (O_S), and vineyards (V_MS_G) indicating an increased planting of these crop groups. An interesting example is that of orchards where the magnitude of the annual dummy variables peaks at 3 in 2015. This means the relative odds of planting orchards are about 3 times the odds of planting alfalfa in 2015, relative to the omitted year (2007). These trends in the Delta, also visible in Figure 6, are in line with recent trends of increasing acreage of orchards in the Central Valley (Johnson and Cody, 2015).

Juxtaposing the results of the annual dummy variables with those of the salinity variable, discussed in the preceding paragraphs, we see that increasing salinity decreases the odds of growing orchards and vineyards, yet there is a strong positive temporal trend toward orchard planting. This suggests that increase in orchards is concentrated in lower salinity locations in the Delta. Similarly, salinity has no effect on moderately-tolerant grain crops (G_MT or G_T) or sensitive/moderately sensitive truck and berry crops (TB_S and TB_MS), but the odds of planting these crops increased over time. This suggests that planting decisions are driven not driven just by annual salinity but also by factors such as crop revenues and costs, or location- or farmer-specific conditions such as pre-existing soil conditions or farmers mitigation of changes in surface water salinity.

Turning now to the some of the main results of control variables: results of the soil variable (*Soil_Index*) show that increases in the soil index (i.e., poorer soil quality) increases the odds of growing pasture, moderately-tolerant field crops (F_MT), rice, most grains including corn, and sensitive truck and berry crops. Poor soils reduce the odds of growing orchards, beans, moderately-tolerant truck and berry crops, and moderately-tolerant orchard crops (relative to alfalfa). Size of the farming operation (*totalfieldacres)* also impacts crop choice. All else equal, larger parcels with greater total field acres have higher odds of growing rice, corn, asparagus, MT orchards, and tomatoes. Most crop groups also showed significantly different patterns for the variable of the ground elevation from sea-level (*elevation).* All else equal, parcels located at relatively higher elevations have higher odds of beans, rice, barley, tomatoes, but lower odds of growing asparagus.

Table 7 presents the marginal effects of our focal variable, growing-season salinity, on crop choice. Values are elasticities, or the percent change in the odds of growing the crop group in question (relative to alfalfa) for a one-percent change in salinity. With regards to the crops significantly impacted by salinity changes, we see the following results: a 1% increase in salinity decreases the odds of growing moderately-tolerant field crops by 0.11%; the rice group by 1.11%; orchards by 0.55%; vineyards by 0.88%; and turf crops by 2.1%. Conversely, a one percent increase in salinity levels increases the odds of growing dried beans by 0.40%; corn by 0.32%; tomatoes by 0.29%; moderately-tolerant truck an berries by 0.41%; and asparagus by 0.54%.

5.c.ii. Results of fixed effects multinomial logit model (Model 2)

Table 8 shows the full results for the Model 2 of our focal variable, growing-season salinity levels, and annual dummy variables. Note that Table 8 is split in 2 parts to show full results of all 17 equations estimated. Results show that increase in growing season salinity increases the odds of pasture (P), the moderately-tolerant field crop group (F_MT) which includes safflower, hay, rye etc., and moderately-tolerant orchards (O_MT_O) which include olives, pistachios and pomegranates. Also, increases in salinity reduce the odds of growing moderately-sensitive vegetables group (TB_MS).

Results of the annual dummy variables in Table 8 show a positive time trend for moderately-tolerant field and grain crops (F_MT and G_MT), orchards (O_S) and vineyards (V_MS_G), This is the same temporal trend seen in Model 1 and in Figures 4-6. We find that all of these results are consistent with our hypothesis and somewhat different from Model 1 discussed in the previous section. Next, we compare the results of both models and explore the reasons for the differences and what they reveal about the effect of salinity on crop choice in the Delta.

5.c.iii. Main Results and Discussion

In order to allow for easier comparison of results in both models, we present the estimated salinity coefficients for Model 1 and Model 2 in Table 9. We also present results of pooled cross-sectional model for the smaller set of observations used to estimate the fixed effects model, and call it Model 1.1. Note that the overall pattern of the results of Model 1.1. is largely unchanged from Model 1 described previously in section 5.c.i., indicating that the estimation methods of Model 1 and Model 2, rather than the smaller subset of observations, are driving the differences in results. In the discussion below, we compare results of Models 1 and 2.

The majority of orchards and vineyards are being grown in locations with relatively lower salinity, in particular the northern areas of the Delta. For this reason, Model 1 estimated a negative relationship between growing season salinity and odds of growing orchards and vineyards. However, while parcels in locations with lower salinity are more likely to have orchards and vineyards, results of Model 2 show that a parcel is not likely to *switch* into or out of orchards due to *annual* changes in the salinity of irrigation water. These results make sense for permanent crops, a high sensitivity to spatial variation in salinity but low sensitivity to annual changes.

A comparison in results for tomatoes and tolerant vegetables (TB_MS_T, TB_MT and TB_T_A) reveals similar insights. Taken together, these crop groups, while grown throughout the Delta, are largely concentrated in the southern Delta where salinity is higher on average. The cross-sectional Model 1 therefore finds a positive association between increased salinity and the odds of growing these crops. Model 2, however, shows no effect of growing season salinity in inducing a switch into these crops, as was the case for orchards and vineyards discussed above. So, while parcels in locations with relatively higher salinity are more likely to have tomatoes and tolerant vegetables, all else equal, results of Model 2 show that a parcel is not likely to *switch* into or out of these groups due to annual variation in salinity of irrigation water.

Next, Model 1 found no impact of growing season salinity on the odds of growing moderately-sensitive vegetable crops (TB_MS). This is plausible because, as is the case for tomatoes, these moderately-sensitive vegetables are grown all over the Delta in both higher and lower salinity locations. However, results of Model 2 show that higher salinity levels induced farmers to switch out of these crops due to annual increase in salinity, such as during a drought. In a similar vein, the moderately-tolerant orchard group (O_MT_O) that includes olives, pistachios and pomegranates, are located in all locations. It is only in Model 2, after controlling for all parcel-specific factors, that we show that higher salinity had significantly higher odds of switching into moderately-tolerant orchards.

Finally, whereas Model 1 found salinity had no impact on odds of growing pasture/forage type crops, Model 2 shows that the odds of switching the parcel into pasture (P) and safflower, rye, forage hay group (F_MT) are significantly higher in response to higher growing season salinity. Recall from section 4.b. that F_MT was a one of the crops more likely to be switched around in the Delta (average persistence of about 3 years); this fact, combined with the results of Model 2, indicates that this crop rotation with F_MT crops could be a strategy for salinity management. Pasture is concentrated in the northern and western locations i.e. locations with both higher and lower salinity levels, a likely reason why Model 1 had not picked up a strong cross-sectional effect.

To conclude, the pooled mutinomial logit model (Model 1) showed mixed results for the hypothesis that increasing salinity will increase the odds of growing relatively salt-tolerant crops. Consistent with our hypothesis, higher salinity is associated with higher odds of growing tolerant and moderately-tolerant vegetable and berry crops and less likely to grow orchards and vineyards. As we discussed above, this is evidence that, by and large, locations in the Delta with lower salinity tend to have relatively salinity-sensitive crops. However, we also saw some results counter to our hypothesis, such as the association between higher salinity levels and increased odds of growing some salt-sensitive crops (e.g., beans) and decreased odds of growing tolerant field crops.

These mixed results likely occurred because there are other factors, besides salinity, that impact crop choice, and some factors that affect planting decisions (parcel-level soil conditions or farmer's salinity management practices) are not observed by the researcher. Given that there is no current data on soil salinity in the Delta and how it is changing over time in different locations in relation to the salinity of applied surface water, the fixed effect model (Model 2) is useful in that it allows us to capture unobserved differences in parcel characteristics and that might underlie crop choice decisions. We found that higher salinity leads to switching parcels into pasture, safflower, rye, hay crops and switching out of moderately-sensitive vegetable crops.

6. Summary and Conclusions

As profit maximizers, farmers change crops in response to many factors, such as market conditions (e.g. price of crops, labor costs), environmental conditions (e.g. salinity, droughts), or state and federal regulations. Our goal in this report was to estimate the effect of irrigation water salinity variations in inducing the observed crop changes in California's Sacramento-San Joaquin Delta. Increase in salinity above a threshold level decrease crop yield. The threshold is higher for relatively salinity-tolerant crops such as barley, but lower for relatively salinity-sensitive crops like almonds and berries. Therefore, our key hypothesis was that increase in irrigation salinity would be associated with a greater planting of relatively salt-tolerant crops, and less planting of relatively salt-sensitive crops.

We compiled annual geo-referenced data on crops and irrigation water salinity in the Delta for 2007-2016. Northern Delta parcels have lower irrigation water salinity than southern and central parcels. We also found that irrigation water salinity varies tremendously across parcels in the same year, particularly in drier years.

We used information on relative salinity tolerance of crops to group the crops grown the Delta. Aggregate trends in crops show that although there is some variation in acreage from year to year, the highest acreage in the Delta in all years is in the Moderately-Sensitive (MS) crop group, particularly corn and alfalfa, followed by the Moderately-Tolerant (MT) crop group which includes field crops such as wheat, oats, safflower, rye etc., and the Sensitive (S) crop group, which includes fruit and nut orchards and berries. For example, in 2016, MS crop group comprised 57% of the acreage, MT crops comprised 17% of the acreage, S crops were on 14% and T crops were on less than 1% of the Delta acreage.

Field-level analysis showed a wide variation in the persistence of crops on a field, some like grapes, pasture, fruit and nut orchards tended to stay on the field for nearly the entire time period of analysis; others like beans, barley, safflower, hay, and vegetables are switched more often, about every 2 to 4 years. The multinomial logit analysis of crop change showed that some of these changes are driven by variation in salinity of irrigation water.

We used two alternative multinomial logit models to understand crop choice, where a crop group is chosen by grower in response to current growing season (April-August) irrigation salinity levels. Results of Model 1, which pools cross-sectional and time-series variation in crops and salinity, showed mixed support of our hypothesis. Locations that are low salinity tend to have higher odds of growing orchards, and vineyards; however, counter to our hypothesis, higher salinity was associated with higher odds of growing some salt-sensitive crops (e.g., beans), and tolerant field crops.

Recognizing that Model 1 may not be fully controlling for unobserved differences in parcels, we estimated Model 2, the fixed effects model. Overall, in the fixed effects model, where we can control for unobserved and time-invariant heterogeneity in parcels, we find evidence that farmers are responding to salinity increase by growing relatively salt-tolerant crops like pasture and moderately-tolerant field crops such as safflower, rye, forage hay, Sudan grass and sorghum. We also found that higher salinity will discourage growers from growing relatively salinity-sensitive vegetable crops such as cucumber, pumpkin, potatoes etc. Increased irrigation water salinity also increases the odds of switching into olives, pomegranates and pistachios. These four overall results are in line with our hypothesis regarding the effect of salinity on crop choice.

After a crop is planted, growers may manage yield effects of salinity by adopting certain management practices, including applying additional irrigation to leach soils of excessive salt, changing irrigation methods, timing or source of irrigation, and/or draining shallow groundwater. These are well known salinity management practices (Wichelns and Qadir, 2014). In some cases, farmers may change the crops they plant in order to maximize profits. In our data, we are able to observe crop choice and changes in crop choice over a 10-year period, but not crop yields or farmers' salinity management practices. Thus, we are able to observe only one kind of response to salinity-- i.e. crop change, so our results should be interpreted as measuring a portion of the total response to salinity changes in the Delta.

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