Agricultural Trade Policy and Water Quality: Evidence from the Mexican Hass Avocado Import Program*

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Abstract

The 2016 Mexican Hass Avocado Import Program opened the U.S. market to fresh Hass avocados from all of Mexico, conditional on individual states meeting strict phytosanitary requirements. We provide hydrology-based empirical evidence that the 2016 program led to improvements in Mexico's surface water quality. Our difference-in-differences estimates illustrate improvements of 12 percent in biochemical oxygen demand (BOD), 11 percent in chemical oxygen demand (COD), and 10 percent in nitrogen concentrations. We argue that the program encouraged farmers to adopt cleaner production methods with lower pesticide and fertilizer applications that, in turn, resulted in these water quality gains.

Keywords: Trade, Avocados, Water Quality, Agriculture, Mexico

JEL Codes: Q01, Q12, Q25, Q28, Q56

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1 Introduction

Economists have long debated the association between international trade and economic growth (Irwin, 2025; Kneller et al., 2008; Winters, 2004). While trade can be globally beneficial, how it influences environmental outcomes remains a key focus in the economics literature (Alam et al., 2011; Lopez, 2017; Strutt and Anderson, 2000; Levinson, 2009; Sunge and Ngepah, 2020; Wang et al., 2023; Antweiler et al., 2001). Specifically, when environmental externalities are not accounted for in one of the trading countries, increased pollution may offset trade gains (Mahmood, 2023; Tanaka et al., 2022). Yet we know relatively little about the magnitude of such pollution haven effects and the effectiveness of corrective policies adopted by the importing country to mitigate pollution damage.

In this paper, we exploit a unique regulatory setting in which the importing country, the U.S., required an extensive set of quality requirements for avocado production throughout Mexico in 2016. Before 2016, Michoacán was the only Mexican state authorized to export Hass avocados to the U.S., as it was the sole region that met the USDA's strict phytosanitary requirements. The USDA opened trade to all other Mexican states in 2016 while requiring that the exported avocados met rigorous pest-control guidelines for shipments to the continental U.S., Hawaii, and Puerto Rico.

We apply a difference-in-differences research design to quantify changes in Mexican surface water quality indicators between avocado-growing municipalities ("treated") and non-avocado-growing counterparts ("control") before and after the enactment of the 2016 Mexican Hass Avocado Import Program. Our identification strategy hinges on the implicit assumption that observed differences in water quality would be similar across treated and control municipalities in Mexico. Our empirical model incorporates a suite of fixed effects to account for both time-varying differences in water quality common across municipalities, while controlling for month-by-year varying unobservable shocks to water pollution. We estimate dynamic treatment effects through an event study research design and perform several robustness checks, including placebo tests and additional hydrology-based empirical specifications that account for spatial spillovers, to conclude that changes in water quality are directly attributable to the 2016 Avocado Import Program.

We find that that the 2016 program resulted in improvements of 12 percent in biochemical oxygen demand (BOD), 11 percent in chemical oxygen demand (COD), and 10 percent in nitrogen concentrations. Meeting USDA phytosanitary standards requires Mexican avocado producers to adopt more structured orchard-management practices—such as mandatory pest surveillance, trapping, record-keeping, and compliance inspections—that collectively reduce reliance on broad-spectrum pesticide applications.[1] Because pesticides and fertilizers are complementary inputs in avocado production (Huang et al., 2024), reductions in pesticide use lower the marginal productivity of fertilizers, leading growers to apply less nitrogen and phosphorus. In addition, the USDA's strict monitoring and documentation requirements incentivize more disciplined and efficient agrochemical management, further reducing excessive applications. While data limitations preclude direct empirical tests of changes in pesticide and fertilizer use, our findings of improved nitrogen concentrations in surface water are consistent with reduced fertilizer runoff. We interpret these water quality improvements as indirect evidence of improved agricultural production methods from phytosanitary compliance. This is in line with the fact that phytosanitary programs are concentrated in states that produce and export avocados to the US (Velázquez-Torres et al., 2025).

We provide multiple contributions to the literature. To the best of our knowledge, we provide the first comprehensive examination on the impact of the 2016 amendment to the Mexican Hass Avocado Import Program on surface water quality in Mexico. The study that is similar in spirit to ours is Williams and Shumway (2000), in which the authors examine how trade policies such as the North American Free Trade Agreement are

[1]According to Sangerman-Jarquín et al. (2014), avocado producers in Mexico rely on technology to control pests, weeds, and diseases.

likely to increase the use of chemical fertilizers in Mexico. We are also the first to show that a trade policy enforced by an importing country can generate environmental benefits abroad. The 2016 U.S. amendment to the Mexican Hass Avocado Import Program induced cleaner production practices among Mexican growers, leading to measurable improvements in surface water quality. Our next contribution is that we supplement quasi-experimental methods of causal inference with applications of hydrology-based empirical models (Keiser and Shapiro, 2019a; Paudel and Crago, 2021) to account for spatial spillovers associated with upstream-downstream pollutant flows. Our approach, therefore, provides econometric estimates of spatially explicit, and causally identified impacts on water quality that can be used to implement targeted, basin-level policy interventions. Finally, we offer evidence that the 2016 program led to a decline in concentrations of nitrogen in water sites. This indicates a reduction in agricultural runoff from lower applications of nitrogen fertilizers in response to the program's requirement of adopting cleaner agricultural production methods.

This article is broadly related to a growing literature on environmental impacts of international trade. Extensive research on repercussions of trade on environment has focused mostly on water consumption and scarcity around the world (Calatrava and Garrido, 2005; Zhong et al., 2023; Zhang et al., 2011; Biewald et al., 2014).[2] This has underscored the linkage between human consumption in one place and the appropriation of freshwater resources elsewhere (Mekonnen et al., 2024). Our work is also relevant to the broader literature on key determinants of agricultural water pollution. Applied econometric research on determinants of water quality has mostly focused on agricultural inputs such as fertilizers and crop prices (Paudel and Crago, 2021; Sarkar et al., 2024; Zhang and Abler, 2023), conservation programs such as the Environmental Quality Incentives Program (Liu et al., 2023), local regulations (Chen et al., 2026; Skidmore et al., 2023), water quality policies (Weng et al., 2024), and nutrient best management practices

[2]We note that there exists a growing literature on trade-induced environmental changes, including deforestation, farming sustainability and fertilizer-linked pollutants (Abman and Lundberg, 2020; Hu et al., 2025; Paudel, 2025).

(Soh et al., 2023). We complement these studies by showing that changes in agricultural trade policy involving a foreign country can influence local water quality gains.

The rest of this paper is structured as follows. Section 2 provides a brief background on the 2016 Mexican Hass Avocado Import Program. Section 3 describes the data used in the study followed by the empirical methodology in Section 4. Section 5 discusses main results and additional robustness checks. Section 6 concludes.

2 Background

2.1 Avocado Market

Until the early 1990s, California dominated the U.S. avocado market; fresh imports typically accounted for less than 1 percent of total U.S. consumption (Carman, 2019). In 1994, the North American Free Trade Agreement (NAFTA) was enacted, which opened up trade with the U.S. and Mexico. In 1997, the Mexican Hass Avocado Import Program began. This program only allowed Michoacán to export their avocados to 19 Northeastern and Midwestern states in the U.S. and Washington D.C. In February 2007, the U.S. opened the avocado trade with Mexico to all 50 U.S. states.

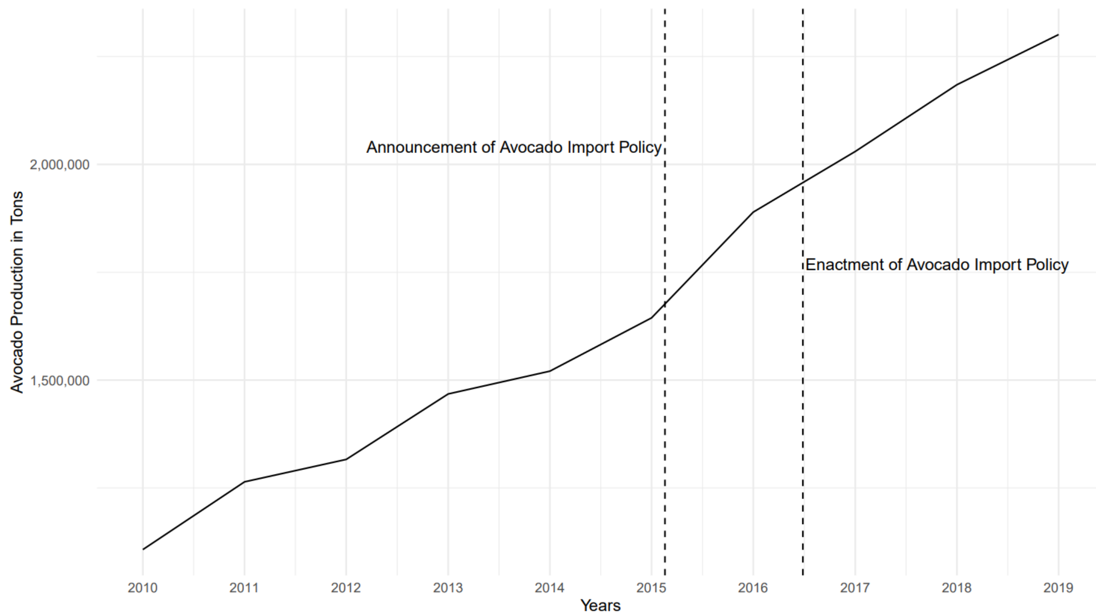
Michoacán, a central state in Mexico, is the world's largest producer of avocados and offers a unique climate highly conducive to the fruit's growth. The USDA's 2019/2020 annual report states that 76 percent of Mexican avocado production came exclusively from Michoacán (Elms, 2019). In 2018, Mexico was the top supplier of avocados to the U.S., with 87 percent of the U.S. market share. The other top-producing states are Jalisco and the State of Mexico, which account for 9.2 percent and 4.5 percent of the country's annual production, respectively. While Michoacán cultivates most of Mexico's avocados, total output in other Mexican states is also high. The same report shows that outside of Michoacán, Mexico produced 615,002 metric tons of avocado. This is on par with total production in the second and third largest national producers worldwide: the Dominican

Republic and Peru produced 665,652 metric tons and 571,992 metric tons, respectively (Elms, 2019).

In February 2015, the USDA proposed an amendment to the Mexican Hass Avocado Import Program. At the time, the U.S. only allowed avocados from the state of Michoacán to the U.S. Specifically, the Animal and Plant Health Inspection Service (APHIS) of the USDA announced the policy to allow for broadening the areas that could export to the US, provided they meet strict guidelines to reduce the risk of transmitting quarantine pests (Erickson and Owen, 2020). To export avocados to the U.S., interested Mexican states were required to comply with a comprehensive set of phytosanitary standards, including orchard certification, traceback labeling, pre- and post-harvest safeguards, packinghouse inspection, and port-of-arrival clearance procedures. A significant concern of the new policy was to ensure fewer pesticide residues on Mexican avocados. We note that gaining certification is arduous and requires several steps for farmers to obtain USDA export approval. Weak enforcement would likely lead to issues related to the pollution haven hypothesis because firms care about the expected cost of violating environmental rules, not necessarily laws on paper. When inspections are rare or penalties trivial, the effective cost of pollution falls, creating a strong incentive for industries to relocate to jurisdictions where regulators do not credibly enforce standards. The 2016 amendment involves heavy enforcement of regulations among all Mexican states in order to export avocados to the U.S.

The USDA enacted the amendment in June 2016. Shortly after this amendment's announcement, avocado production in Mexico increased. Figure 1 displays Mexico's national avocado production in tons. Avocado production steadily increased from 2010 to 2015, spiked up between 2015 and 2016, and then continued to rise after that. Figure A1 further documents the growth of production in 2016. Erickson and Owen (2020) also show that the value of avocado export spiked upward after the amendment. Indeed, Mexico's avocado export value increased from approximately 1.9 billion USD in 2015 to a little over 3 billion USD in 2023, with the US constituting about 80% of Mexico's total

Figure 1: Mexico's National Avocado Production from 2010 to 2019



The data for this figure comes from El Gobierno de México's Servicio de Información Agroalimentaria y Pesquera (SIAP). The image displays Mexico's total national avocado production in tons from the years 2010 to 2019. The announcement of the policy and its enactment took place in February 2015 and June 2016, respectively.

avocado exports (Higgins, 2024). This increased value of Mexican avocado exports offers clear incentives for avocado farmers to meet USDA phytosanitary criteria.

2.2 Avocado Production Practices

Avocado production requires many applications of agrochemicals. Mexico faces challenges in pesticide management, which includes the continued use of some pesticides banned elsewhere (OECD, 2021; Bejarano-González, 2018). Mexico's avocado production has become more monocultural in recent years. This monocultural production demands heavier fertilizer applications. Avocado production is mostly managed by smallholder farmers with limited knowledge of pesticides (Blanco-Muñoz and Lacasaña, 2011). This poses significant threats to the surrounding environment and human health (Islam et al., 2022).

There exists little information on pesticide types, usage patterns, and their environmental consequences in Mexico's avocado-producing areas. According to Merlo-Reyes et al. (2024), avocado orchards require extensive water resources, even during the dry season. Pesticide application varies depending on when an avocado tree is planted, the tree's age, the pests found in the field, and the economic status of individual farmers. Farmers apply fertilizers and pesticides every two weeks for recently planted avocado trees. As avocado trees mature, farmers switch to a monthly fertilizer and pesticide application schedule. We note that pesticides and fertilizers are complementary inputs in avocado production (Huang et al., 2024).

Research on the frequency of pesticide application is very limited; however, generally, Mexican avocado farmers spray pesticides regularly, ranging from four to twelve applications per year. Hass avocado trees can have up to four flowering flushes in Mexico. This allows for potentially year-round avocado production in mature avocado trees (Rocha-Arroyo et al., 2011). Avocado farmers must provide continuous management practices throughout the year. This requires heavy energy consumption and heavy pesticide input, which leads to unavoidable ecological impacts (Astier et al., 2014; Denvir, 2023). Notably, Merlo-Reyes et al. (2024) document presence of benomyl and paraquat among areas around Mexican avocado-producing regions. These are highly toxic and internationally banned. According to Merlo-Reyes et al. (2024), the pesticides most frequently reported by farmers include glyphosate, imidacloprid, and benomyl.

3 Data

3.1 Water Quality

Data on water quality comes from the National Water Commission in Mexico (CONAGUA).[3] We utilize water quality information from surface monitors located in

[3]CONAGUA is a technical advisory commission of Mexico's Ministry of the Environment and Natural Resources that published its water quality monitoring data through Gobierno de Mexico and is publicly available at: https://www.gob.mx/conagua/articulos/calidad-del-agua. It administers national waters,

rivers, lakes, dams, streams, springs, lagoons, wetlands, and oceans throughout the country. We explore biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrogen, and phosphorus levels in our analysis. Based on methods similar to Dube et al. (2016), we restrict our sample to municipalities with a population under 100,000 to study rural municipalities where agricultural pollution is a severe issue.[4] Our sample covers the years 2013-2019 and includes 1,257 monitors with at least one water quality reading per year.[5] This sample does not include data for Michoacán (the blackened-out state in the southwest corner of Mexico in Figure A2 that exported avocados to the U.S. and met the USDA regulations prior to the 2016 Program amendment.

Figure A2 in the Appendix shows the locations of the surface water quality monitors of both treated and control groups in the data sample. Our treated group includes monitors in municipalities that produced avocados in any year from 2003 to 2013.[6] We believe these municipalities are the most likely to work towards achieving avocado export certification. These municipalities have the capacity and practical incentive to change their avocado production capacities more so than control counterparts that did not produce any avocados before, or close to, the announcement of the 2016 Mexican Hass Avocado Import Program amendment. In total, 371 of the 1,257 surface water monitors fall under the treated group, and the remaining 886 ones fall under the control group. The 2016 Hass Avocado Import Program amendment was announced in February 2015. Only 9 municipalities in the surface

promotes social development, and manages and controls the country's hydrological system.

[4]Following Dube (2016), we use a 100,000-person threshold to distinguish municipalities associated with large urban population centers. While Dube applies this cutoff at the locality level, our analysis is conducted at the municipality level. We therefore adopt a simplified version of their criterion: municipalities with a total population of 100,000 or more are excluded from the rural sample.

[5]The original data from CONAGUA consists of an unbalanced panel data set that provides monitor readings from 2012 to 2023. Observations from 2012 are omitted due to the paucity of readings that year (The reading records start toward the last quarter of 2012). 2019 is the cut-off year because monitor readings become less frequent for the remaining years, and the COVID pandemic would likely heavily skew the empirical results.

[6]Data from Mexico's Agri-food and Fisheries Information Service (SIAP) for avocado production at the municipality level begins in 2003. This allows us to consider municipal avocado production the decade leading up to 2013.

water sample began producing avocados in 2015 and/or afterward. 7 of the 9 municipalities only sow and/or harvest 1 to 10 hectares of avocado a year, which is a very small amount. 2 of the 9 municipalities sow and/or harvest approximately 30 to 45 hectares yearly. This is a slightly higher production of avocados, but still not significantly large. Given that avocado production in these municipalities had not been around before the announcement of the 2016 amendment, it is doubtful that these avocado producers would strive to gain USDA export certification during the sample years.

The CONAGUA water quality data is bottom-coded. In particular, for almost all the data, BOD readings below 2 mg/L are recorded as " < 2", COD readings below 10 mg/L as " < 10". Readings below these thresholds indicate high-quality water. To make use of the continuous variation of these parameters in the main analysis, we replace the inequality BOD values with 1 and the inequality COD values with 5. Inequality values in the water monitor data represent water that has extremely low pollution. BOD and COD observations above these inequalities in the data are continuous.[7] Nitrogen readings are also bottom-coded. Nitrogen-Nitrite readings below 0.005 mg/L are recorded as " < 0.005", nitrogen-nitrate readings below 0.004 mg/L as " < 0.004", some readings of nitrogen ammonia as "< 0.003", and some readings of phosphorous are "< 0.001". Readings below these thresholds indicate low contamination. For continuous variation, we replace the inequality nitrite values with 0.0025, the inequality nitrate values with 0.002, the inequality ammonia values with 0.0015, and the inequality phosphorus values with 0.0005.[8] [9]

[7]There are only 3 observations that originally have a COD continuous value below 10 mg/L. Their values remain unchanged in the data manipulation.

[8]In the data, other inequality values for nitrate are < 0.031 and < 0.02. For Nitrite, there is also < 0.021. For ammonia, there is < 0.0035 and < 0.02. Lastly, for phosphorus, there are < 0.0014 and < 0.007. Water quality data gives these values when the pollution level is low. Thus, an exact number is not always recorded. For consistency, we apply the midpoint value for the lowest inequality value for each variable. Observations above these inequality values for each variable are continuous. There are a few observations below these inequality signs that have continuous values.

[9]Table A1 in the appendix provides further summary statistics of the variables in the analysis regarding observations, means, standard deviations, minimum values, 25th percentile, 75th percentiles, and maximum values.

3.2 Hydrologic Information

We make use of two geospatial datasets to generate information on binary indicators of upstream and downstream municipalities in Mexico. The first, known as HydroBASINS is a globally consistent dataset that divides the Earth's land surface into hierarchically nested sub-basins (Lehner and Grill, 2013). For this project, we use level 7 sub-basins corresponding to an average area of roughly 130 km^2 per sub-basin. Each sub-basin in HydroBASINS carries a unique identifier, including the identifier of the next sub-basin immediately downstream. The second, known as the INEGI Marco Geoestadístico, provides the boundaries of all 2,462 municipalities along with their standardized 2-digit state codes and 3-digit municipality codes within a state.

To differentiate upstream municipalities from downstream counterparts, we carry out three steps. First, we use a polygon overlay to assign each municipality to its primary sub-basin. For municipalities that span two or more sub-basins (common along watershed divides), we select the sub-basin covering the largest share of the municipality's area. Second, we construct the river network in which each sub-basin is a node with a directed edge running from every sub-basin to the sub-basin immediately downstream of it. Third, we generate binary indicators of whether a municipality has at least one upstream or downstream municipality in the network. This provides information on whether (i) a municipality is exposed to pollutants upstream of it, or (ii) a headwater municipality receives no river inflow from other Mexican municipalities.

3.3 Additional Covariates

Measures for total population and percent of the population with at least a high school degree come from the National Institute of Statistics and Geography in Mexico (INEGI) 2010 Censuses and Counts of Population and Housing.[10] Municipal-level data on annual

[10]From May 31 to June 25, the 2010 Population and Housing Census consisted of more than 106,000 interviewers who traveled throughout the country to visit each home. The micro-data for municipalities is

agriculture sown and harvested comes from Mexico's Agriculture-Food and Fisheries Information Service (SIAP).[11] We use municipality identifiers to match the census and agriculture data with the water quality data. While agricultural variables are available at the municipality-year level, covariates from the 2010 census exist at the municipality-level. In addition, municipal-level measures of monthly precipitation averages in inches for 30 years (1980-2010) come from Gobierno de Mexico through CONAGUA.[12] We match the precipitation and water quality data at the month and municipality levels.[13] Table A1 in the Appendix provides summary statistics of the main analysis.

3.4 Avocado Suitability Index

As a robustness check for identification, we utilize an avocado suitability index based on Dubrovina and Bautista (2014). Avocado tree roots are susceptible to soil types. They require both a large volume of water and low hydraulic conductivity. To compute the suitability of a municipality's soil, we take advantage of INEGI's detailed edaphology data to find out the predominant soil in each municipality.[14] Applying soil characteristics discussed in Dubrovina and Bautista (2014) and ISRIC World Soil Information, we can classify whether the soil is one of the following: Highly suitable, Suitable, Low Suitability, and No Suitability.

Figure A9 displays characteristics that constitute a soil's avocado suitability. A combination of a base saturation percentage below 42.4 percent and a clay content below 20 percent results in the most suitable soil type for avocado trees.[15] Other important

publicly available at https://www.inegi.org.mx/programas/ccpv/2010/microdatos

[11]Annual municipal data for both avocado production and total avocado production in Mexico covers 2003 to the present. The data from SIAP is publicly available through Gobierno de Mexico: https://nube.siap.gob.mx/cierreagricola/.

[12]Data for all weather stations come from CONAGUA and are publicly available through Gobierno de Mexico: https://smn.conagua.gob.mx/es/informacion-climatologica-por-estado?estado.

[13]For municipalities without weather station data, we take the average values of available weather station data from their contiguous counterparts.

[14]INEGI's edaphology data is publicly available on the following website: https://en.www.inegi.org.mx/temas/edafologia/

[15]Avocado trees require very distinctive conditions that are uncommon worldwide. Andosol is the only

factors impacting a soil's avocado tree suitability are its depth, aggregate shape, hydraulic conductivity, and clay content. Avocado trees grow best in soil with a depth greater than 48 cm. Soils that are angular blocky, granular, and/or powdery are suitable, while massive aggregate shapes result in no suitability. If the soil has a high base saturation, deep depth, and a crumb aggregate shape, then the soil's hydraulic conductivity and/or clay content decides its avocado suitability. In this case, low hydraulic conductivity is suitable for avocado trees, but very high hydraulic conductivity results in low suitability. In addition, if the hydraulic conductivity is high and the clay content is equal to or less than 28 percent, the soil offers low suitability. However, if the clay content is above 28 percent, then the soil is suitable. If the municipality's most common soil is highly suitable, then we give it a soil value of 3. We assign the municipality's soil value to be 2 if it is suitable, 1 if the soil has low suitability, and 0 if the soil has no suitability for avocado trees. We denote avocado soil suitability in municipality i as $Soil_i$. We base the value of soil on the most common soil in a municipality.

The second portion of the index takes into account a municipality's climate. Key climate components of a municipality's avocado suitability include mean annual temperature (Celsius), the ratio of precipitation (inches) to mean annual temperature (P/T), altitude (meters), and average temperature in January. Weather averages for mean annual temperature, precipitation, and the month of January at the municipal level come from SMN's 1980-2010 weather station averages. A municipality's altitude range comes from INEGI's edaphology data.

Figure A10 shows what determines a municipality's avocado climate suitability value. Like the soil calculations, a municipality can have one of the following values for avocado suitability: Highly Suitable, Suitable, Low Suitability, and No Suitability. Avocados are highly sensitive to frosts, heat waves, and water volume. A mean annual temperature equal

highly suitable soil based on the methods of Dubrovina and Bautista (2014). It is also the world's rarest soil. Michoacán has a large landmass of Andosol soil that helps make it arguably the most conducive climate for avocados worldwide.

to or below 11.9 Celsius is not suitable for avocado trees. If a municipality's mean annual temperature is above 11.9 Celcius and its P/T is below 40.6, then it has low suitability. In the same case, if its P/T value is above 40.6 and its altitude is above 2,505 meters, it has low suitability.[16] A high mean annual temperature, high P/T value, altitude below 2,505 meters, and an average January temperature equal to or below 15.7 would lead to a suitable climate. Otherwise, if a municipality's average January temperature is above 15.7 Celcius, the climate value depends on the magnitude of the P/T ratio. A P/T value, in this case, above 53.9 would result in a highly suitable climate, while a value below or equal to 53.9 represents a suitable climate. We give a value of 3 to a municipality with a highly suitable climate, 2 to a suitable climate, 1 for low suitability, and 0 for no suitability. We denote avocado climate suitability in municipality i as $Climate_i$. In the analysis, the avocado suitability index is labeled as AvoSuitability. The following is the calculation of the index: $AvoSuitability_i = \sqrt{Soil_i * Climate_i}$. The alternative index specification is $AvoSuitability_i = Soil_i * Climate_i + Soil_i + Climate_i + 2$. The alternative index specification is used as a robustness check in the paper.

4 Methodology

We employ the difference-in-differences (DID) research design to evaluate the impact of the 2016 Mexican Hass Avocado Import Program amendment on Mexico's surface water quality. For comprehensiveness, we focus on four key indicators of water quality used extensively in the literature: biochemical oxygen demand (BOD), chemical oxygen demand (COD), nitrogen and phosphorus in water sites. We estimate the following:

[16] Municipalities have varying altitudes. Based on Figure A10, if a municipality has an altitude range only above 2,505 meters then we classify the municipality has having low suitability. Otherwise, we also consider January temperature and/or the P/T value.

$$Y_{icmt} = \beta_0 + \beta_1(Post_t \cdot Treat_i) + \beta_2 Temp_{imt} + \beta_3 Prec_{cm}$$
$$+ \beta_4 Census_{c,2010} + \beta_5 X_{ct} + \alpha_m + \gamma_t + \delta_i + \varepsilon_{icmt} \quad (1)$$

where Y includes log-transformed water quality measures reported in monitor i, municipal c, month m and year t. *Post* is an indicator that equals 1 if the monitor's reading took place during and after January 2016, and 0 otherwise. The cut off for time treatment is January 2016. We choose this cutoff to account for farmers having up to the following annual year to make agricultural practice adjustments to work toward becoming avocado certified. *Treat* is an indicator that equals 1 if the monitor is in a municipality that grew avocados at any point during the 2003-2013 period, and 0 otherwise. We define the treated group in this way because municipalities that ever produced avocados during this pre-period are more likely to have the avocado production capacity and incentives to adhere to the 2016 policy amendment compared to municipalities that have no avocado production capacity or that first begin avocado farming at a later time. With these classifications, our analysis assesses water quality monitor readings from 2013 to 2019.

The specification outlined in (1) includes additional control variables and a suite of fixed effects. *Temp* is the log-transformed ambient temperature of a water monitor at the time of the water quality reading, in Celsius. *Prec* controls for monthly average precipitation, in inches, at the municipal level c over the period 1980-2010; *Census* is a vector of controls at the municipality level from INEGI's 2010 census that accounts for total population and the population percentage with at least a high school degree. X is a vector of controls at the municipality-year level, including the logged number of hectares of total agriculture sown and harvested, and a binary indicator for the 2017 earthquake with an 8.2 level magnitude that hit Oaxaca the hardest; this variable equals 1 if the monitor reading occurred in Oaxaca in 2017 and 0 otherwise. We additionally include fixed effects for months (α_m), years (γ_t), and monitors (δ_i). We cluster standard errors at the monitoring station level. Our coefficient of interest is the *Post*Treat* interaction term, which identifies the causal effect of the 2016 Program on surface water quality under the common DID assumptions. We note that we find no statistical differences in average BOD and COD values between the treated and control groups during the pre-shock years. Table 1 shows the summary statistics for the surface water quality data for 2013, 2014, and 2015.

For additional robustness, we repeat the estimating equation outlined in (1) in a restricted sample of treated municipalities and control counterparts that do not have any upstream municipalities. This allows us to test whether estimated parameter β_1 is susceptible to bias from potential spatial spillovers from upstream treated municipalities to downstream control counterparts. We also include major river basin fixed effects that control for all time-invariant determinants of water quality specific to watersheds such as size, main channel gradient, land slope, and other characteristics affected by topography and geography (Paudel and Crago, 2021).

Additionally, we run the specification (1) using binary indicators of water quality in a linear probability model. A common restriction for water effluent – and the maximum permitted concentration in surface water – is 10 mg/L of BOD (Qin et al., 2014; Luthy et al., 2015) and 50 mg/L of COD for water reuse according to the EPA (Dresser, 2004). For our binary indicators, BOD (COD) takes on a value of 1 if the water monitor has a reading above 10 mg/L (50 mg/L) and 0 otherwise.[17] We also test the results of BOD (COD) taking on a value of 1 if the water monitor has a reading above 2 mg/L (10 mg/L) and 0 otherwise. This allows us to evaluate whether variation occurs around the inequality values of BOD and COD that represent drinkable water quality.

[17]BOD and COD effluent regulation can vary from country, locality, and industry. We choose these thresholds to construct our binary indicators because they are commonly identified effluent limits in the literature.

Table 1: Summary Statistics of Water Quality Indicators, 2013-2015

	Treatment (N=5,131)		Control (N=12,350)			
Variables	**Mean**	**Std. Dev.**	**Mean**	**Std. Dev.**	**Diff. in Means**	**P**
BOD (mg/L)	19.5	188.9	17.5	81.2	2.0	0.460
COD (mg/L)	84.8	1,404.7	68.5	228.5	16.3	0.410
Temperature (Celsius)	27.9	5.2	27.8	4.9	-0.1	0.226
Precipitation (Inches)	104.3	99.1	104.4	99.4	-0.1	0.937
Sown in Thousands (Hectares)	14.0	17.5	23.2	27.1	9.2	< 0.001
Harvest in Thousands (Hectares)	21.3	23.3	21.4	24.3	8.2	< 0.001
Education (2010)	0.2	0.1	0.2	0.0	0.0	< 0.001
Population in Thousands (2010)	36.2	27.3	36.2	27.2	8.5	< 0.001

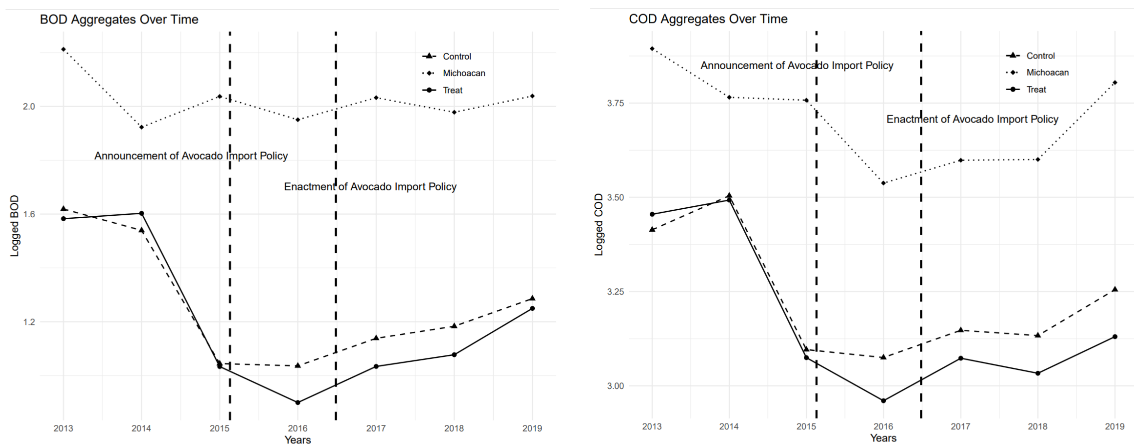
Note: This table provides summary statistics for the mean and standard deviation of different values among the treatment and control group. In the analysis sample, chemical oxygen demand and biochemical oxygen demand are the variables of interest. The table displays the standard biochemical oxygen demand (BOD) and chemical oxygen demand (COD) measures in mg/L at the monitor level. Temperature is in Celsius at the monitor level, sown is the amount of hectares of agriculture sown in a municipality, harvest is the amount of hectares of agriculture harvested in a municipality, education represents the percent of a municipality's population that has completed their secondary education in 2010 in decimal form. Population is the total population in a municipality in 2010. Sown, harvest, and population represent their respective values in thousands. Precipitation represents the 1980-2010 monthly average of precipitation in inches at the municipal level.

5 Results

5.1 Descriptive Findings

Figure 2(a) depicts the BOD aggregate average each year over time for the treatment group, control group, and the state of Michoacán. The BOD averages are almost identical for the treatment and control groups in 2013, 2014, and 2015. The import policy change was announced in February 2015, and in 2016 a noticeable gap develops between the treatment and control groups and lasts for the remaining years of the sample. The Michoacán line shows the higher water pollution in Michoacán compared to the rest of Mexico. Michoacán is the only Mexican state that does not need to change its avocado production methods because of the import policy change. We, therefore, do not include Michoacán in the empirical sample. Figure 2(a) also shows that Michoacán is not a good comparison group for the pre-treatment years of 2013 to 2015.

Figure 2(b) similarly depicts the COD aggregate average each year over time for the treatment group, control group, and the state of Michoacán. Once again, the COD values among the treatment and control groups are very similar in the pre-treatment years of 2013, 2014, and 2015. After the announcement of the policy change in 2015, a noticeable gap



(a) (b)

Figure 2: Annual trends in overall surface water quality indicators

Notes: This figure shows the annual aggregate average of logged biochemical oxygen demand for all surface water monitors in the treatment group, control group, and state of Michoacán. The figure covers the years 2013 to 2019. The dashed vertical lines emphasize that the USDA announced the policy to the public in February 2015 and enacted the policy in June 2016.

appears starting in 2016 between the treatment and control groups that continues through the following years. Figure 2 reveals a convex shape among the BOD and COD aggregate values for the treatment and control groups.[18]

5.2 Changes in BOD and COD

Table 2 displays the two-way fixed effects difference-in-differences analysis results in Equation 1. Columns 1-3 measure the impact of the 2016 Mexican Hass Avocado Import Program amendment on BOD levels in surface water; each column includes progressively more controls, and the results remain robust and statistically significant regardless of which controls are included in the model. Without controls, the *Post*Treat* coefficient is -0.119. These results suggest that the policy shift resulted in an improvement to surface water quality with a 12 percent decrease in BOD levels. Columns 4 - 6 display the results

[18] The data consists of an unbalanced panel set where monitor readings occur more or less frequently and among different months. This variation of when and how often different monitor readings take place in the data set may explain the convex trend of both the treatment and control groups in Figure 2.

for COD, and once again, the results are robust to the inclusion of various controls. The results suggest that the policy change led to an 11 percent decrease in COD, which is also an improvement in surface-water quality.

A 12 percent change in BOD is environmentally significant and in line with estimated effect sizes from other studies that explore the water quality impacts of policy change. For instance, Lipscomb and Mobarak (2016) shows that an expansion in administrative municipalities in Brazil led to worse water quality there, on the order of a 9 percent change. When evaluating the impact of the 2016 Mexican Hass Avocado Import Program amendment, based on Table 1, the sample mean of BOD is 19.5 mg/L in the treatment group. The results suggest the 2016 amendment impact is the equivalent of BOD decreasing from 19.5 mg/L to 17.16 mg/L. While BOD exceeding 4 mg/L is not considered acceptable for recreational use (Sigman, 2002), this is still a significant improvement in overall surface water quality.

Figure 3 displays the event studies for both the BOD and COD results. Both event studies include point estimates and their 95 percent confidence interval. Year 0 is 2016, when the policy amendment was enacted. Results are normalized in 2015 to better show the impact of the beginning of the treatment period in 2016 and onward. Both event studies show that the coefficient on the interaction term *Post*Treat* was not statistically significant prior to implementation of the policy shift, for either BOD or COD. These event studies and the statistical tests provided in Table 1 indicate that the results for BOD and COD do not violate the pre-trends assumption in the difference-in-differences framework.

In Figure 3(a), the BOD levels show a significant drop from 2016 to 2018; however, the results are not statistically significant in 2019 (denoted 3 on the x-axis of the image). Figure 3(b) shows that the COD dropped in 2016 among avocado-producing municipalities. The COD results are not significantly different from zero in 2017 (denoted 1 on the x-axis of the image) but remain statistically significant for 2018 and 2019. Together, these event study figures provide strong evidence that the import policy shift had a quick and positive

Table 2: Impact of the 2016 Mexican Hass Avocado Import Program on Water Quality

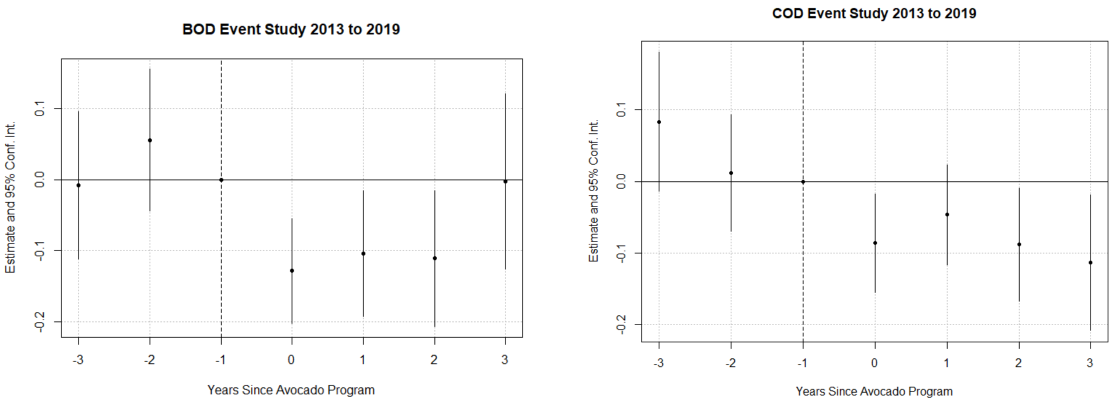
	BOD			COD		
	(1)	(2)	(3)	(4)	(5)	(6)
Post*Treat	-0.119***	-0.118***	-0.120***	-0.110***	-0.110***	-0.110***
	(0.044)	(0.044)	(0.045)	(0.031)	(0.031)	(0.032)
Month and Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Monitor FE	Yes	Yes	Yes	Yes	Yes	Yes
Temperature Control	No	Yes	Yes	No	Yes	Yes
Municipal level controls	No	No	Yes	No	No	Yes
N	36,705	36,705	36,705	36,705	36,705	36,705
R^2	0.589	0.589	0.589	0.529	0.529	0.530

Note: All robust standard errors are clustered at the water monitor level. Data for the table spans from 2013 to 2019. The coefficient of interest is Post*Treat. Post equals 1 if the observation took place after 2015, 0 otherwise. Treat equals 1 if a monitor is in a municipality that grew avocados between 2003 to 2013. The response variable in columns 1-3 is the logged value of BOD. For columns 4-6, the response variable is logged COD. Each column includes year and monitor fixed effects and controls for what month the monitor's reading took place. The temperature control is at the monitor station location at the time of the BOD or COD reading. The municipal level controls include the 8.2 magnitude earthquake that hit Oaxaca in 2017, logged hectares of agriculture sown and harvested at the municipal level, the percent of the population that has at least a secondary level of education, and the logged population. In addition, I control for municipal precipitation by taking the log(precipitation+1) value of the monthly average precipitation from 1980-2010. *** is significant at the 1 percent level, ** is significant at the 5 percent level, and * is significant at the 10 percent level.

impact on surface water quality in avocado-producing municipalities in Mexico. The timing of the policy's effect on water quality is likely due to the announcement taking place over a year before its enactment, giving farmers time to adjust to the implementation of the new policy.[19]

Table 3 displays the results of the binary methods, where odd columns display binary OLS results, and even columns show Logit average marginal effects. Columns 1 through 4 of Table 3 show the binary method results for BOD, and columns 5 through 8 provide results for COD. For both BOD and COD with binary OLS and logit methods, the findings consistently display a negative relationship between the interaction term and surface water quality. In addition, the results are very robust for both BOD (COD) thresholds of 2 mg/L (10 mg/L) and 10 mg/L (50 mg/L).

[19]Michoacán has high water contamination for several reasons. Sewage and industrial contamination plague the state's water systems. The state also produces numerous agricultural products. Thus, agrochemicals from the volume of agriculture produced heavily contribute to water contamination.



(a) (b)

Figure 3: Dynamic impact of the 2016 Mexican Hass Avocado Import Program on Water Quality

Notes: This figure plots the point estimate and 95% confidence interval of the coefficients on *Treated*Post* from the event study specification for BOD and COD. The time period spans from 2013 to 2019. -3 represents the year 2013, 3 is 2019, and 0 is 2016 (the year of the policy's enactment). We normalize the year 2015, which the figure displays as -1. Treatment in the analysis begins in 2016 (0 on the axis). The specification includes fixed effects at the month and year level and monitor location. It also includes municipality controls and controls for temperature at the monitor level. In addition, we control for municipal precipitation by taking the log(precipitation+1) value of the monthly average precipitation from 1980-2010. All robust standard errors are clustered at the monitor level.

Table 3: Impact of the 2016 Mexican Hass Avocado Import Program on Binary Indicators of Water Quality

	Dependent Variable: Binary water quality indicator above the threshold							
	BOD	BOD	BOD	BOD	COD	COD	COD	COD
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Treat*Post	-0.055***	-0.043***	-0.0532***	-0.0407**	-0.051***	-0.053***	-0.0232**	-0.0211**
	(0.018)	(0.016)	(0.0175)	(0.0162)	(0.013)	(0.014)	(0.0093)	(0.0100)
Month and Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Monitor Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Right Hand Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Thresh-Hold	2	2	10	10	10	10	50	50
Model	OLS	Logit	OLS	Logit	OLS	Logit	OLS	Logit
N	36,705	34,161	36,705	34,056	36,705	30,078	36,705	33,696
R^2	0.3493	0.2704	0.3518	0.2719	0.2998	0.2305	0.1436	0.1358

Note: All robust standard errors are clustered at the water monitor level. This table represents data from 2013 to 2019. The response variable in columns 1-4 is the BOD. In columns 5-8, COD is the response variable. BOD and COD are dummies equal to 1 if above the "Threshold", and 0 otherwise. The temperature control is at the monitor station location at the time of the BOD or COD reading. The municipal level controls include the 8.2 magnitude earthquake that hit Oaxaca in 2017, logged hectares of agriculture sown and harvested at the municipal level, the percent of the population that has at least a secondary level of education, and the logged population. In addition, We control for municipal precipitation by taking the log(precipitation+1) value of the monthly average precipitation from 1980-2010. *** is significant at the 1 percent level, ** is significant at the 5 percent level, and * is significant at the 10 percent level.

Finally, we repeat the estimating equation outlined in (1) in a restricted sample of treated muncipalities and control counterparts that do not have any upstream municipalities. Table A27 shows that the slope coefficient of our interaction term remains similar in magnitude and statistically significant across all four pollutants: BOD, COD, Nitrate and Phosphorus. Additionally, Table A28 presents estimates from (1) with addition of major river basin fixed effects and upstream drainage area. We do not see any major changes in magnitude of our estimated parameters. These two empirical analyses give us confidence that our estimated parameters are not confounded by potential spatial spillovers from upstream treated municipalities to downstream control counterparts.

5.3 Mechanisms

We offer suggestive qualitative and quantitative evidence on mechanisms through which the 2016 Mexican Hass Avocado Import Program improved surface water quality. Our qualitative evidence pertains to reduction in pesticide and fertilizer applications through adoption of integrated pest management practices necessary to meet the USDA phytosanitary standards. The quantitative evidence involves improvement in concentrations of nitrogen in water sites associated with lowered usage of nitrogen fertilizers. While data limitations preclude direct empirical tests of changes in pesticide and fertilizer use, reduction in nitrogen pollutants in surface water indicates lowered fertilizer runoff associated with cleaner agricultural production methods.

5.3.1 Qualitative Evidence: Pesticides

The USDA regulations on avocado imports are more stringent than Mexico's criteria for avocado farmers to sell locally. The 2016 U.S. policy change increased the value of avocado production in Mexico, incentivizing more farmers to meet USDA regulations to export avocados. The only way for Mexican avocado farmers to become certified is to change their agricultural practices and pest management methods drastically. It took Jalisco until 2022 to become certified, and they are the only state to be able to trade Hass avocados with the U.S. other than Michoacán. Several other states are currently working toward avocado certification. When Jalisco gained avocado certification, Jose Gallardo, the head of the Michoacán-Based Association of Mexican Growers, stated, "Today is a day of joy for everyone, knowing that Jalisco is here, but it is going to be happier when the State of Mexico comes, when Nayarit, Colima, Puebla, Morelos come" (Stevenson, 2022).

The following quote comes from the Federal Registry, "In accordance with the operational work plan, depending upon the nature of the pest detection, affected orchards may lose their export certification, and avocado exports from that orchard may be suspended until APHIS and the Mexican NPPO agree that the pest eradication measures taken by the affected orchard have been effective. As for the human health implications of pesticide usage, as stated previously, the FDA samples and tests imported fruits and vegetables for pesticide residues that may be harmful to humans." Public statements from the Association of Avocado Exporting Producers and Packers of Mexico (APEAM) suggest that Mexican avocado farmers are seeking to use less harmful pesticides; for instance, they are quoted as recently saying "Mexican avocado producers strive every day to reduce the use of chemical pesticides and instead, turn to more sustainable practices in their crops to improve their agricultural practices" (Orduña, 2023).

To meet USDA phytosanitary criteria, Mexican avocado farmers must apply agricultural methods that lead to less risk of pesticide residues. It requires more disciplined farm operations that lead to more efficient agrochemical management. Lower usage of pesticides is associated with improvements in surface water quality through soil colloids (from water erosion), dissolved phase in runoff, volatilization, dust particles, and spray drift (Kookana et al., 2005). In fact, there exists well-documented evidence on significant effects on surface water concentrations from changes in pesticide application rates (Chow et al., 2020). Research consistently finds that pesticide impacts BOD and

COD levels in surface water. This is because pesticides are organic compounds. They contribute to the total organic matter in wastewater, which then increases the demand for oxygen during microbial decomposition (An et al., 2025; Chen et al., 2007; Al Momani et al., 2010). These studies indicate that shifts in production standards among Avocado farmers through lower usage of pesticides can contribute to improvements in Mexico's surface water quality.

In practice, the amendment strengthened monitoring, certification, and sanitation requirements for export-eligible orchards. These changes plausibly reduced agrochemical loads through three channels.

First, enhanced record-keeping and APHIS-verified pesticide documentation are designed to reduce unnecessary or repeated applications. Export certification requires detailed spray logs, adherence to pre-harvest intervals, and traceability from orchard to packinghouse. These requirements naturally encourage more precise timing of applications and discourage redundant or poorly timed sprays that increase runoff risk.

Second, expanded monitoring substitutes for chemical insurance spraying. The amendment increased fruit-fly trapping grids, orchard-level surveillance, and pest-free area certification. When pest pressure is measured scientifically, growers can target sprays more precisely and rely more on integrated pest management, reducing total chemical load.

Third, stricter sanitation requirements lower pest pressure without chemicals. Orchard sanitation, packinghouse safeguards, and traceback labeling reduce pest populations directly and strengthen enforcement against illegal or excessive pesticide use. Lower pest pressure reduces the need for broad-spectrum insecticides and repeated applications.

Together, these channels provide a coherent explanation for the observed improvements in surface water quality. Export-oriented orchards often adopt drip irrigation, micro-sprinklers, and improved soil-moisture management to meet certification standards, further reducing runoff and chemical transport into waterways.

5.3.2 Quantitative Evidence: Fertilizers

Because pesticides and fertilizers are complementary inputs in avocado production (Huang et al., 2024), reduced pesticide use, in turn, lowers the marginal productivity of fertilizers, leading farmers to apply less nitrogen and phosphorus fertilizer. While we do not have access to micro-level data on fertilizer applications in Mexico, we are able to make use of nitrogen-nitrate and phosphorus contaminants that are both directly linked to avocado production (Yates et al., 1992; Bender and Faber, 2004). To the extent that the 2016 Program led to lower applications of nitrogen fertilizers, we expect to see improvements in surface water quality through reduction in fertilizer run-off and nitrogen pollutants. This is precisely because a 10% decrease in the use of nitrogen and phosphorus fertilizers leads to a 1.52% decrease in the concentration of nitrogen and a 1.37% decrease in the concentration of phosphorus across watersheds (Paudel and Crago, 2021).

We implement our baseline empirical specification using log-transformed nitrate and phosphorus as outcome variables of interest in Table 4. In the first step of nitrification, ammonia-oxidizing bacteria oxidize ammonia to nitrite (EPA, 2000). In the second step of the nitrification process, nitrite-oxidizing bacteria oxidize nitrite to nitrate (EPA, 2000). Columns (1) and (3) include controls for nitrite and ammonia, temperature, precipitation, and population. The results in column (1) indicate that the 2016 Mexican Hass Avocado Import Program amendment is correlated to approximately a 10 percent decrease in nitrates, suggesting a decline in nitrogen pollutants. Column (2) also shows that the policy is associated with a 6.5 percent decrease in phosphorus levels when comparing avocado-producing and non-avocado-producing municipalities. Column (3) shows that the results for nitrate are highly robust and significant when measuring treatment with the avocado suitability index (AvoSuitability) instead of the Treat dummy. However, the results are not robust for phosphorus in column (4). For columns (3) and (4), the sample is reduced to Jalisco and all of its contiguous states (except

Michoacán). In addition, all of the results for nitrogen-nitrate are robust when applying robust Conley standard errors with 50 km spatial buffers. These results are in Table A17. Overall, these findings indicate that the 2016 Mexican Hass Avocado Import Program improved surface water quality through reduction in fertilizer runoff.

Table 4: Impact of the 2016 Mexican Hass Avocado Import Program on Nitrogen-Nitrate and Phosphorus Contaminants in Water

	Dependent Variable:			
	Nitrate	Phosphorus	Nitrate	Phosphorus
	(1)	(2)	(3)	(4)
Post*Treat	-0.1012**	-0.0651**	-	-
	(0.0469)	(0.0326)	-	-
Post*AvoSuitability	-	-	-0.1236***	-0.0424
	-	-	(0.0356)	(0.0264)
Month and Year Fixed Effects	Yes	Yes	Yes	Yes
Monitor Fixed Effects	Yes	Yes	Yes	Yes
Controls	Yes	Yes	Yes	Yes
Observations	42,341	42,341	9,732	9,732
R^2	0.5345	0.6156	0.6795	0.7417

Note: All robust standard errors are clustered at the monitor level. Data for this table spans from 2013 to 2019. The coefficient of interest is Post*Treat. Post equals 1 if the observation took place after 2015, 0 otherwise. Treat equals 1 if a monitor is in a municipality that grew avocados between 2003 to 2013. The response variable in columns 1 and two are log(nitrate) and log(phosphorous), respectively. Columns 3 and 4 test the robustness of the results in Columns 1 and 2 by replacing the Treat dummy with the municipal level avocado suitability index labeled "AvoSuitability." All regressions with the AvoSuitability index have a reduced sample consisting of all municipalities in Jalisco and Jalisco's contiguous states. Right-hand controls include logged total population, logged temperature at the monitor level, and municipal precipitation by taking the log(precipitation+1) value of the monthly average precipitation from 1980-2010. Each column includes month, year, and monitor fixed effects. Only column 1 includes controls for ammonia and nitrite because of the nitrogen cycle (which phosphorous is not a part of). *** is significant at the 1 percent level, ** is significant at the 5 percent level, and * is significant at the 10 percent level.

5.4 Robustness checks

We carry out several robustness checks that support our main findings. First, several states in the main analysis do not have any rural municipalities that are in the treatment group, including Baja California, Chihuahua, Coahuila, San Luis Potosi, Yucatan, and Quintana Roo. Table A3 in the Appendix presents results replicating the analysis in Table 2, but omitting these states. Point estimates and statistical significance do not change substantively.

Second, we repeat our main specification in a balanced panel sample at the monitor and year level; in the main sample, monitors often have several readings throughout the year during different months. Table A4 in the Appendix displays these results. In columns (1) and (2), we average the BOD (COD) records for each monitor-year. The *Post*Treat* coefficient values are -0.115 and -0.099 for BOD and COD, respectively - nearly identical to the values presented in Table 2 - and still strongly statistically significant for both. Columns (3) and (4) present the results of including only the maximum reading for each monitor per year. Here, the *Post*Treat* coefficient is not statistically significant for either BOD or COD, suggesting that heavily polluted surface water bodies remained heavily polluted after the 2016 amendment. Columns (5) and (6) present the results of including only the minimum reading for each monitor-year. This time the coefficient values for BOD and COD are -0.170 and -0.154, respectively – slightly more negative than the results in Table 2 – and both are statistically significant. This suggests that the minimum water quality monitor readings improved after the policy. In short, Table A4 indicates that the most polluted surface water sources did not improve substantially, but the average and less-polluted ones did.

Third, Tables A5 - A7 in the Appendix display robustness checks of the main surface water results when we replace the BOD inequality values with 1.25, 1.5, and 1.75. Likewise, the tables show the results of replacing the COD inequality values with 1, 3, and 7. These tables show that the results are not sensitive to the original replacement values of BOD and COD being 1 and 5, respectively.

Fourth, we test two-way fixed effects for monitor by month and year fixed effects to control for time-varying factors specific to each monitor in each month-year combination. The results are presented in Table A8 of the Appendix. The results remain robust, regardless of whether we use a two-way fixed effect for monitor by month and monitor fixed effects or just a one-way monitor by month fixed effect.[20] We also rerun the analysis

[20]Table A8 in the Appendix also shows that the results are robust when using monitor by municipality

clustering at the watershed level for both BOD and COD, rather than at the monitor level ((Keiser and Shapiro, 2019a,b) Results are available in Table A9 of the Appendix. The BOD and COD results remain statistically significant and similar to the main results presented in Table 2.[21]

Fifth, we run placebo tests to address concerns about whether the results of Table 2 are random or if the rest of the country experienced a major shift in water quality due to other reasons/policies. To construct the placebo tests for BOD and COD, we omit all treatment municipalities from the original sample for Table 2. The placebo sample only includes municipalities that were in the original control group. The original sample includes 125 treatment municipalities and 471 control municipalities, so for this test we randomly select 125 municipalities to be in the treatment group. The placebo tests – displayed in Figures A3 and A4 in the Appendix – provide evidence that shifts in water quality improvement were not present throughout all of Mexico, and the results from Table 2 are not random. Both figures show no statistical difference between the random treatment groups and control groups for BOD and COD for pre-treatment and post-treatment years. This test is strongly robust for randomly selecting 125 treatment municipalities numerous times; when we randomly choose different treatment municipalities, the results remain heavily consistent.[22] There are further placebo tests that randomly select 100 and 75 treatment municipalities instead of 125. The results are consistent in each case and are shown in Figures A5 - A8

Sixth, we evaluate the sensitivity of the cutoff used. For example, in our analysis, the cut off for time treatment is January 2016. We choose this cutoff to account for farmers having up to the following annual year to make agricultural practice adjustments to work toward becoming avocado certified. Table A11 shows the results of applying 4 different

fixed effects or monitor by municipality and year fixed effects.

[21]We do not run a robustness check for clustering at the municipality level because several separate water sources exist in municipalities.

[22]Results of several randomly selected treatment municipalities are available upon request.

cutoff periods. In Figure 1, avocado production appears to increase in between 2015 - 2016. When the time treatment begins in January 2015, the results remain robust. In addition, when the cutoff is February 2016 (a full year after the policy announcement), July 2016 (the enactment of the policy), or January 2017, the results are robust. February 2016 gives the strongest and most consistent result for both BOD and COD among these alternative treatment time cutoffs. This suggests that after one full year of the policy's announcement, avocado farmers adapted their agricultural practices.

Seventh, autocorrelation may be a concern with clustering robust standard errors at the monitor level. We note that the main results of Table 2 are robust when incorporating Conley standard errors with 25 km, 50 km, and 75 km buffers and are shown in Table A14. In addition, Tables A17, A18, and A20 show that the results of Tables 3 - 4 in this paper are robust when applying Conley standard errors with spatial buffers. When running Winsorization robustness tests that either omit observations above the 90th or 95th percentile of BOD and COD values, the results are robust as shown in Tables A12 and A13.

Furthermore, Tables A15 and A16 separate the main results of Table 2 for each month to leverage the granularity of the data at the monthly level. Avocado trees in Mexico can bloom throughout the entire calendar year, depending on the tree's maturity. The strongest and most consistent results for BOD and COD are in March and April. Both these months show that the 2016 policy is associated with decreased BOD and COD. The tables also show statistically significant decreases in BOD or COD in May, June, July, August, and September.[23]

An additional concern is the potential endogeneity of the original dummy specification of Treat in equation (1). Using an agro-climatic suitability measure for avocados in Mexico would provide a strong argument that the main results are driven by changes in

[23]The only individual month results not included is December due to multicollinearity issues when only regressing results for this month.

avocado production. Using detailed information on soil composition and local microclimates, we develop a novel municipality-level avocado suitability index applying methods from agricultural science (Dubrovina and Bautista, 2014). The avocado suitability index focuses on two components: soil and climate. FAO produces agricultural suitability indices for many crops, but not for avocados. In general, no well-recognized avocado suitability index exists. Figures A9 and A10 display decision trees that break down how to determine how suitable a municipality's soil and climate are for avocado tree growth, using a 4-point ranking (3 = very suitable, 2 = suitable, 1 = low suitability, and 0 = no suitability).[24] Both Soil and Climate suitability measures range from 0 to 3 based on the categories previously mentioned. For the primary analysis, we calculate the avocado suitability index as the geometric mean of the soil and climate values to account for the interactive nature soil and climate have on avocado tree growth suitability. The geometric mean of the suitability index is $AvoSuitability_i = \sqrt{Soil_i * Climate_i}$.

Even if cleaner practices are adopted, it is possible that the increase in avocado production could result in an increased application of fertilizers and pesticides, which would be contradictory to improved water quality. We present the results of our DID model that employ logged areas of total agriculture sown and harvested at the municipal level as the outcome variable in Table A29. However, the results yield no statistical significance that helps us rule out this possibility. In addition, Figures A11 and A12 display comparisons in avocado and total agriculture growth across treated and control groups. For most of the years, the treatment group has higher growth rates than the control group. This indicates that despite the treatment group having higher agricultural growth rates, it still experienced improved water quality compared to the control group.

Figures A15 and A16 provide monthly BOD and COD aggregates for both the treatment and control groups. To complement the analysis at the monthly level, Figures A13 and A14 illustrate the seasonality of pollution based on the mean pollution levels for each month. In

[24] A more detailed description of the index construction is in Appendix Section A.2.

Table 5: Impact of the 2016 Mexican Hass Avocado Import Program on Water Quality using Avocado Suitability Index

	BOD			COD		
	(1)	(2)	(3)	(4)	(5)	(6)
Post*AvoSuitability	-0.158***	-0.158***	-0.152***	-0.115***	-0.115***	-0.116***
	(0.042)	(0.042)	(0.041)	(0.031)	(0.031)	(0.031)
Month and Year Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Monitor Fixed Effects	Yes	Yes	Yes	Yes	Yes	Yes
Temperature Control	No	Yes	Yes	No	Yes	Yes
Municipal level controls	No	No	Yes	No	No	Yes
N	8,638	8,638	8,638	8,638	8,638	8,638
R^2	0.559	0.559	0.560	0.508	0.508	0.509

Note: All robust standard errors are clustered at the water monitor level. Data for the table spans from 2013 to 2019. The analysis in this table is identical to Table 2, with the exception that the coefficient of interest is Post**AvoSuitability*. AvoSuitability is an avocado suitability index I construct using agricultural methods based on Dubrovina and Bautista (2014). *** is significant at the 1 percent level, ** is significant at the 5 percent level, and * is significant at the 10 percent level.

addition, we filtered the data to match monitors that had monitor readings each month of each year of the data. Tables A24 and A25 show no statistical significance when applying this method, likely because of the limited data to do this and the significant reduction of observations that take place (Each regression only had 99 to 751 observations as opposed to over 36,000 observations in the main analysis).

Finally, we note that Jalisco is the only state to successfully gain avocado export certification after the 2016 policy amendment. We next reduce the sample data to Jalisco and its contiguous states (except Michoacán). We further replace Treat with the avocado index, AvoSuitability, in equation (1) and present in Table 5. The results for Post*Avosuitability are highly robust and strongly significant across all specifications. These results provide strong evidence that the water quality improvement is driven by avocado production.[25]

[25]The results of Table 5 are robust when $AvoSuitability_i = Climate_i * Soil_i + Climate_i + Soil_i + 2$. The results are in Table A19.

6 Conclusion

This paper empirically evaluates the impact of agricultural trade regulation on surface water quality. We estimate the effects of the 2016 Mexican Hass Avocado Import Program amendment on local water pollution. In particular, our analysis shows that the policy shift led to a decrease in BOD and COD of approximately 12 percent and 11 percent, respectively. We further offer supportive evidence that the 2016 amendment incentivized avocado farmers to utilize cleaner avocado production methods, in the form of cleaner agrochemical practices, which led to reduced nitrogen runoff. These findings introduce norms on imported products as a way to mitigate the pollution haven effect. In the case of this particular policy, granting all other Mexican states avocado-exporting rights to the U.S. (in addition to Michoacán), provided a strong enough incentive for Mexican farmers to make significant changes in their agricultural practices.

The story of this paper's findings is straightforward: incentives matter. For decades, Mexico has struggled to improve its water quality. Our findings indicate how policies around international trade of agricultural products can lead to water quality improvements when a developed country monitors a developing country's production. This can be the case when a developing country has a strong enough economic incentive to apply more efficient and environmentally safe production methods. We believe that future research can benefit from studying how international agricultural trade policy and regulation among different countries impact both water quality and quantity. Newer knowledge on trade and water quality can greatly improve policymakers' decisions regarding what laws to enact or amend that could potentially mitigate the pollution haven effect.

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A Appendix

Online Appendix: Supplementary Figures and Tables

Supplementary appendix for "Agricultural Trade Policy and Water Quality

Evidence from the Mexican Hass Avocado Import Program"

follows:

A.1 Nitrogen Cycle

Equations A.1 - A.3 display the nitrification and denitrification process. Table 4 regresses nitrogen nitrite and ammonia onto nitrogen nitrate. This method may raise concerns of simultaneity and reverse causality. Equations A.1 and A.2 show through the chemistry literature that there are natural chemical reactions that result in different nitrogen types forming into other nitrogens. These equations argue that it is important, for better measuring accuracy, to include the nitrogen right-hand controls for nitrate in Table 4. Equations A.1 and A.2 depict the nitrification process. The aerobic ammonia oxidations proceed by the following stoichiometry [26] (Ward, 2013) :

$$NH_3 + 1.5O_2 \rightarrow NO_2^- + H_2O + H^+ \tag{A.1}$$

In short, equation A.1 shows the chemical process of how ammonia turns into nitrite. Equation A.2 depicts that through oxidization, nitrite can turn into nitrate [27] (Ward, 2013):

$$NO_2^- + 0.5O_2 \rightarrow NO_3^- \tag{A.2}$$

Denitrification is the dissimilatory reduction of one or both nitrate and nitrite to the gaseous oxides such as nitric oxide and nitrous oxide due to aerobic bacteria. The following is the flow of the denitrification process (Knowles, 1982): $NO_3^- \rightarrow NO_2^- \rightarrow (NO) \rightarrow N_2O \rightarrow N_2$. Equation A.3 shows one of the intermediary steps of denitrification known as nitrate reductase. This is when nitrate forms into nitrite [28] (Marschner, 2011; Bernhard, 2010):

$$NO_3^- + 2H^+ + 2e^- \rightarrow NO_2^- + H_2O \tag{A.3}$$

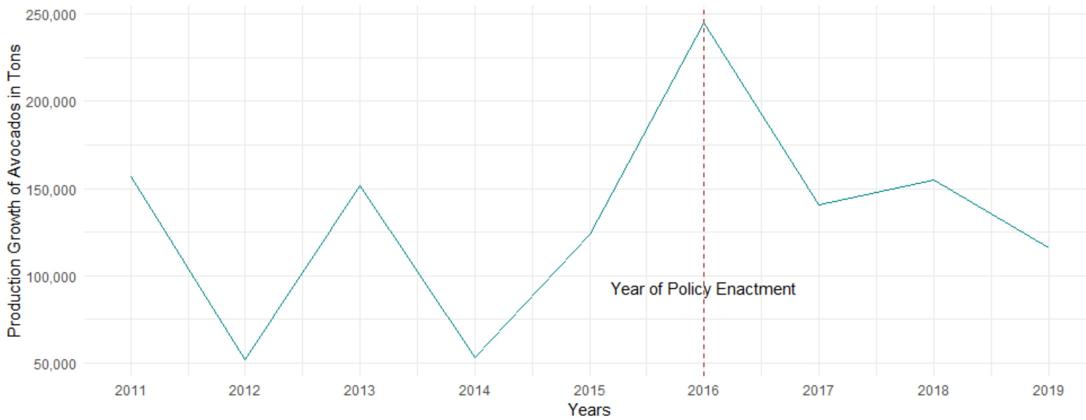
[26] Equations A.1 - A.2 represent standard chemistry symbols. NH_3 and O_2 represent ammonia and oxygen, respectively. Symbols for nitrite, water, and hydrogen ion are NO_2^-, H_2O, and H^+, respectively

[27] NO_3^- stands for nitrate.

[28] e^- is the symbol for an electron.

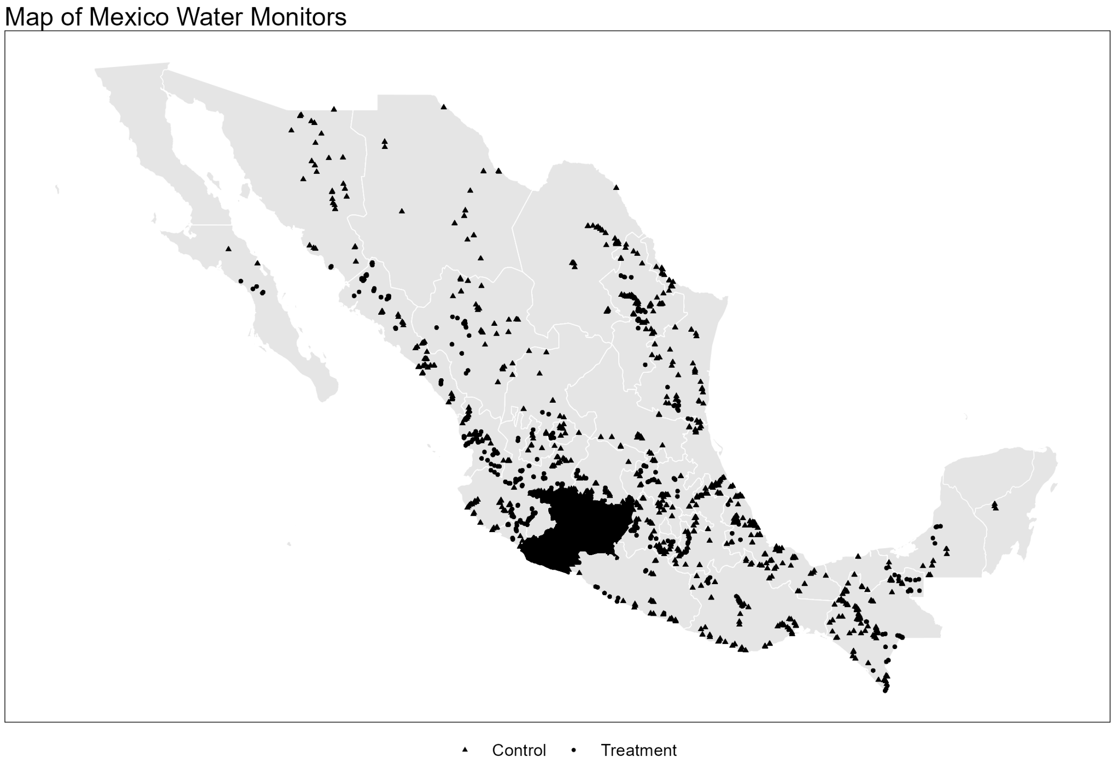
A.2 Additional Figures and Tables

Figure A1: Mexico's National Avocado Production Growth in Tons



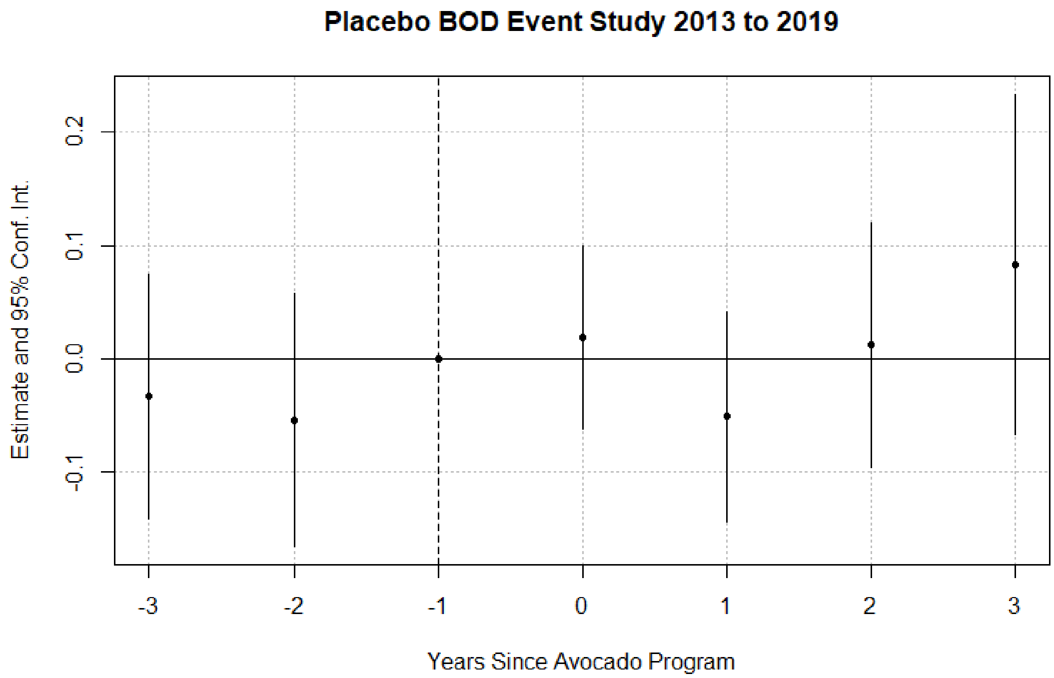
The data for this figure comes from El Gobierno de México's Servicio de Información Agroalimentaria y Pesquera (SIAP). The image shows the difference of the current year's avocado production from the previous year at Mexico's national level. The dashed vertical line on 2016 represents when the 2016 Mexican Hass Avocado Import Program amendment was enacted. The image includes national results for the years 2011 to 2019.

Figure A2: Surface Water Quality Monitors in Mexico from 2013 to 2019



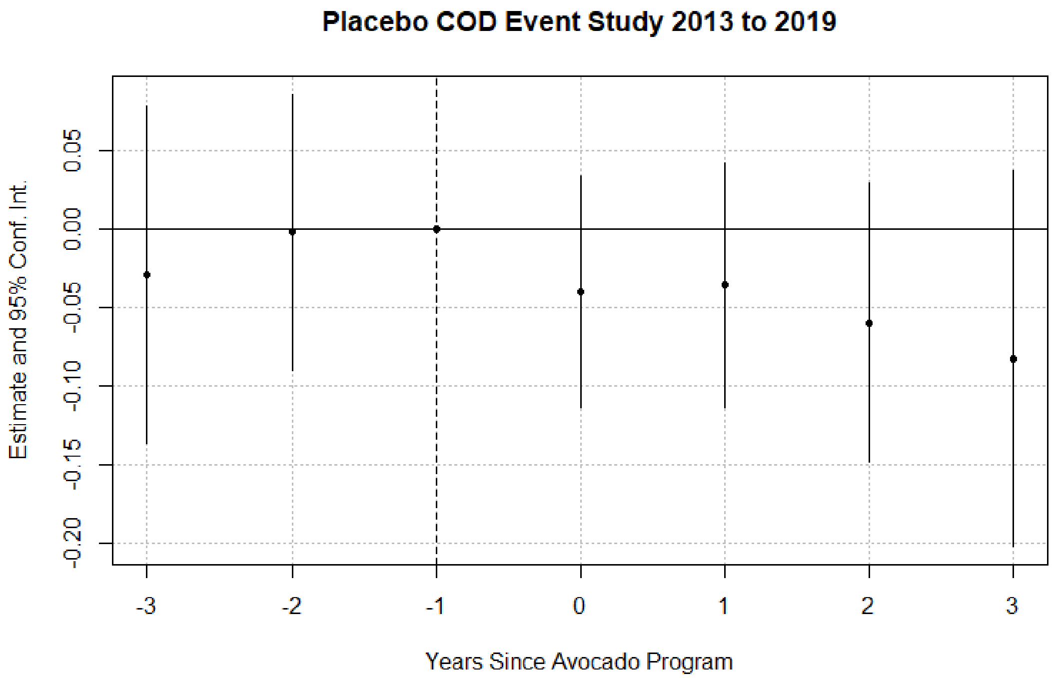
This map shows the geographic locations of the monitors in the surface water monitor sample. The circles represent monitors that are in the treatment group while the triangles symbolize the monitors in the control group. The blackened out state is Michoacán. We do not include monitors from Michoacán in the analysis because it was the only state that could export avocados before the 2016 Mexican Hass Avocado Import Program amendment.

Figure A3: Placebo Biochemical Oxygen Demand Event Study 2013 to 2019



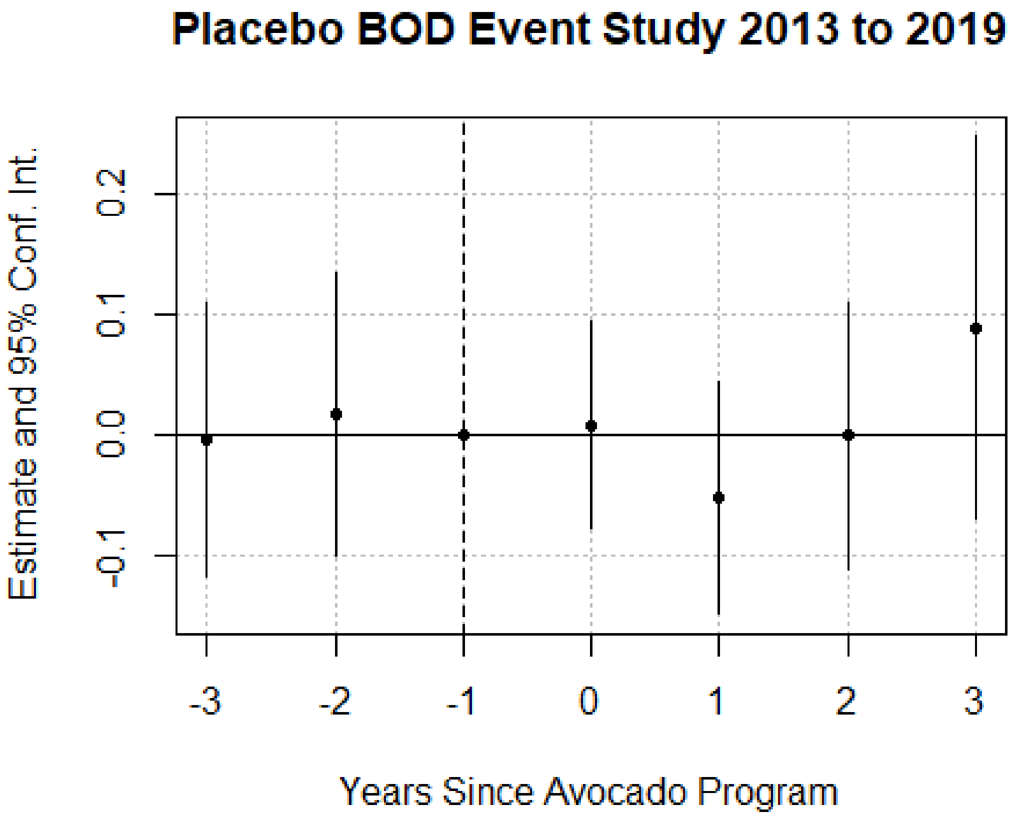
For this figure, we omit the study's original treatment group and only include monitors in control municipalities. 125 out of 471 municipalities are in the treatment group of the original sample. To run a placebo test for BOD, we randomly select 125 municipalities to include in as the new treatment group. The event study includes fixed effects at the month and year level and monitor location as well as municipality controls and controls for temperature at the monitor level. In addition, we control for municipal precipitation by taking the log(precipitation+1) value of the monthly average precipitation from 1980-2010. All robust standard errors are clustered at the monitor level.

Figure A4: Placebo Chemical Oxygen Demand Event Study 2013 to 2019



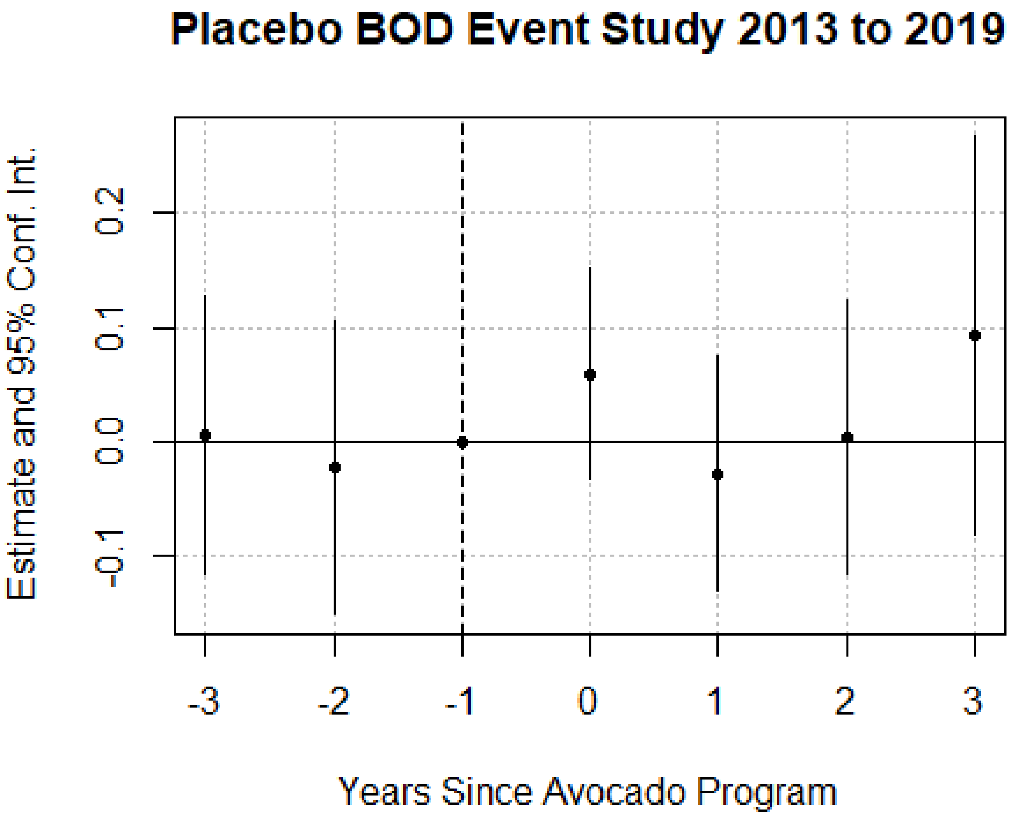
For this figure, we omit the study's original treatment group and only include monitors in control municipalities. 125 out of 471 municipalities are in the treatment group of the original sample. To run a placebo test for COD, we randomly select 125 municipalities to include in as the new treatment group. The event study includes fixed effects at the month and year level and monitor location as well as municipality controls and controls for temperature at the monitor level. In addition, we control for municipal precipitation by taking the log(precipitation+1) value of the monthly average precipitation from 1980-2010. All robust standard errors are clustered at the monitor level.

Figure A5: Placebo Biochemical Oxygen Demand Event Study with 100 Randomly Selected Treatments



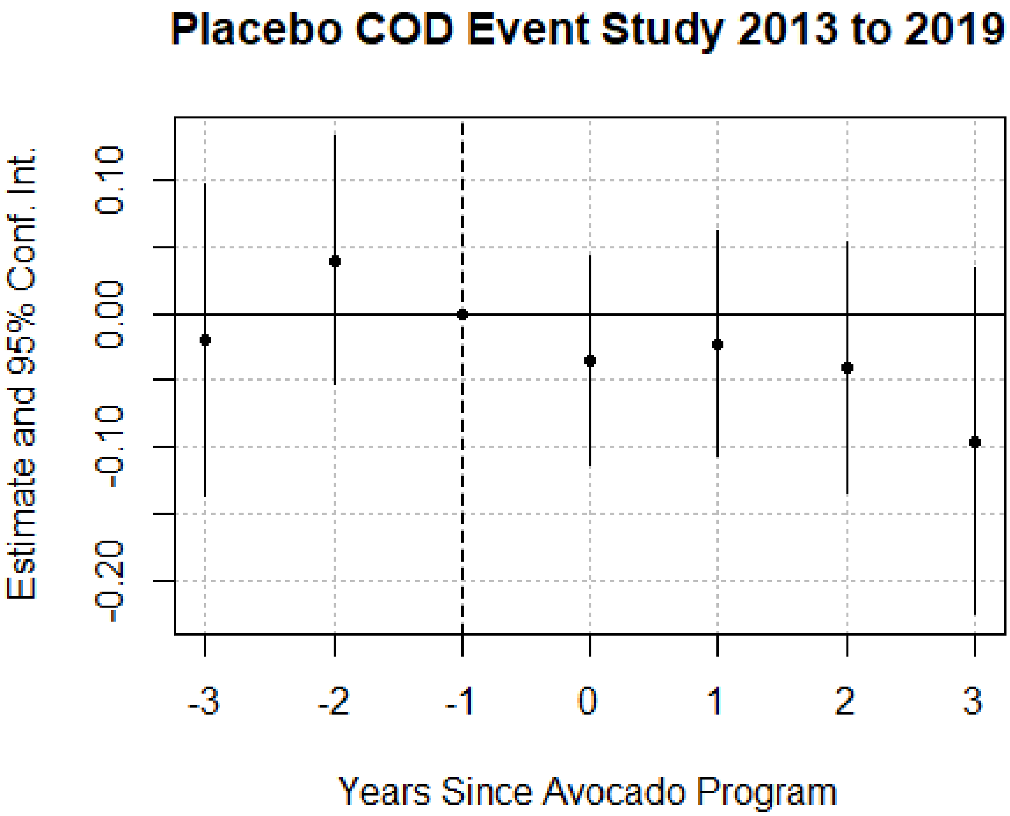
For this figure, we omit the study's original treatment group and only include monitors in control municipalities. To run a placebo test for COD, we randomly select 100 municipalities to include in as the new treatment group. The event study includes fixed effects at the month and year level and monitor location as well as municipality controls and controls for temperature at the monitor level. In addition, we control for municipal precipitation by taking the log(precipitation+1) value of the monthly average precipitation from 1980-2010. All robust standard errors are clustered at the monitor level.

Figure A6: Placebo Biochemical Oxygen Demand Event Study with 75 Randomly Selected Treatments



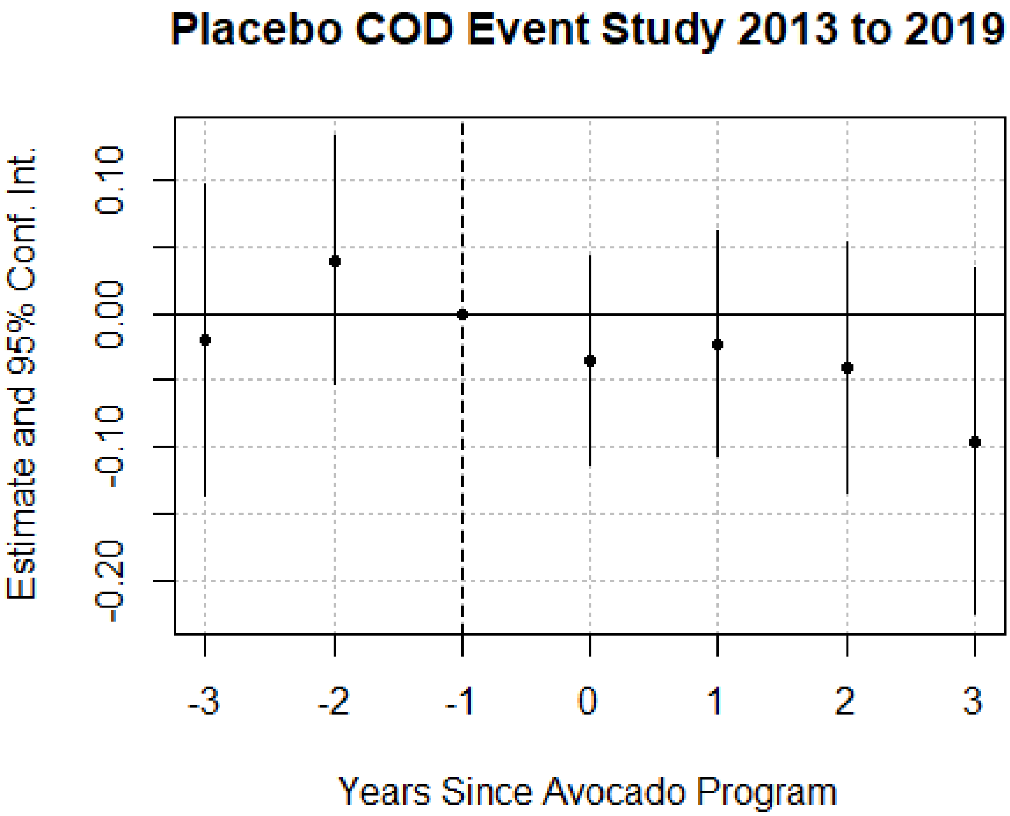
For this figure, we omit the study's original treatment group and only include monitors in control municipalities. To run a placebo test for COD, we randomly select 75 municipalities to include in as the new treatment group. The event study includes fixed effects at the month and year level and monitor location as well as municipality controls and controls for temperature at the monitor level. In addition, we control for municipal precipitation by taking the log(precipitation+1) value of the monthly average precipitation from 1980-2010. All robust standard errors are clustered at the monitor level.

Figure A7: Placebo Chemical Oxygen Demand Event Study with 100 Randomly Selected Treatments



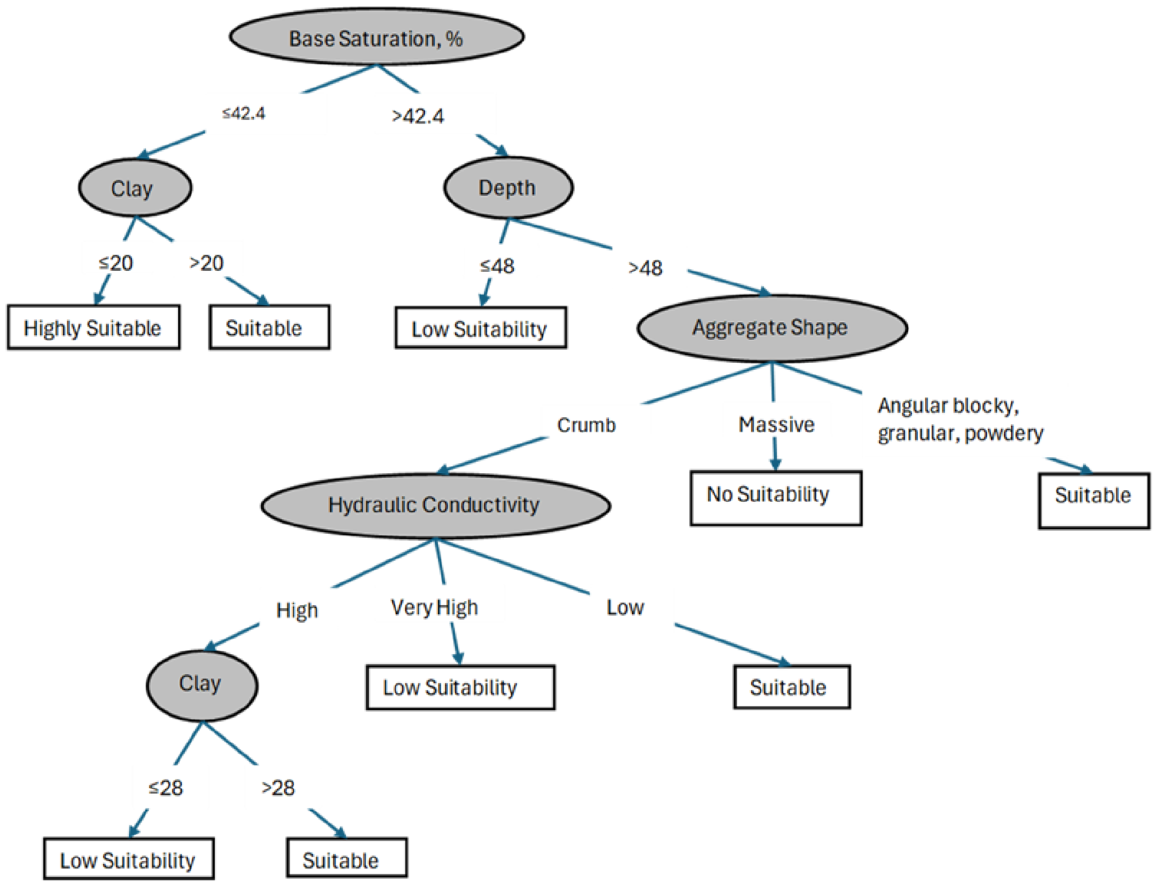
For this figure, we omit the study's original treatment group and only include monitors in control municipalities. To run a placebo test for COD, we randomly select 100 municipalities to include in as the new treatment group. The event study includes fixed effects at the month and year level and monitor location as well as municipality controls and controls for temperature at the monitor level. In addition, we control for municipal precipitation by taking the log(precipitation+1) value of the monthly average precipitation from 1980-2010. All robust standard errors are clustered at the monitor level.

Figure A8: Placebo Chemical Oxygen Demand Event Study with 75 Randomly Selected Treatments



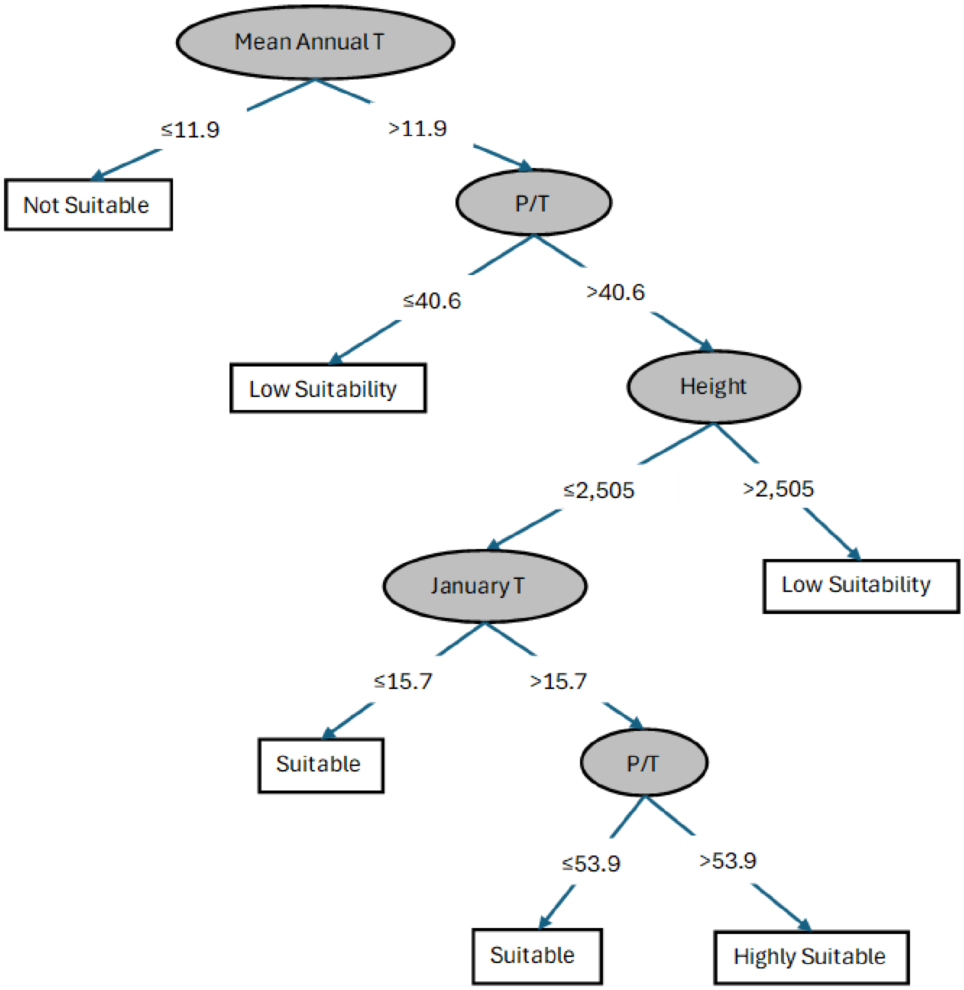
For this figure, we omit the study's original treatment group and only include monitors in control municipalities. To run a placebo test for COD, we randomly select 75 municipalities to include in as the new treatment group. The event study includes fixed effects at the month and year level and monitor location as well as municipality controls and controls for temperature at the monitor level. In addition, we control for municipal precipitation by taking the log(precipitation+1) value of the monthly average precipitation from 1980-2010. All robust standard errors are clustered at the monitor level.

Figure A9: Avocado Soil Suitability Tree



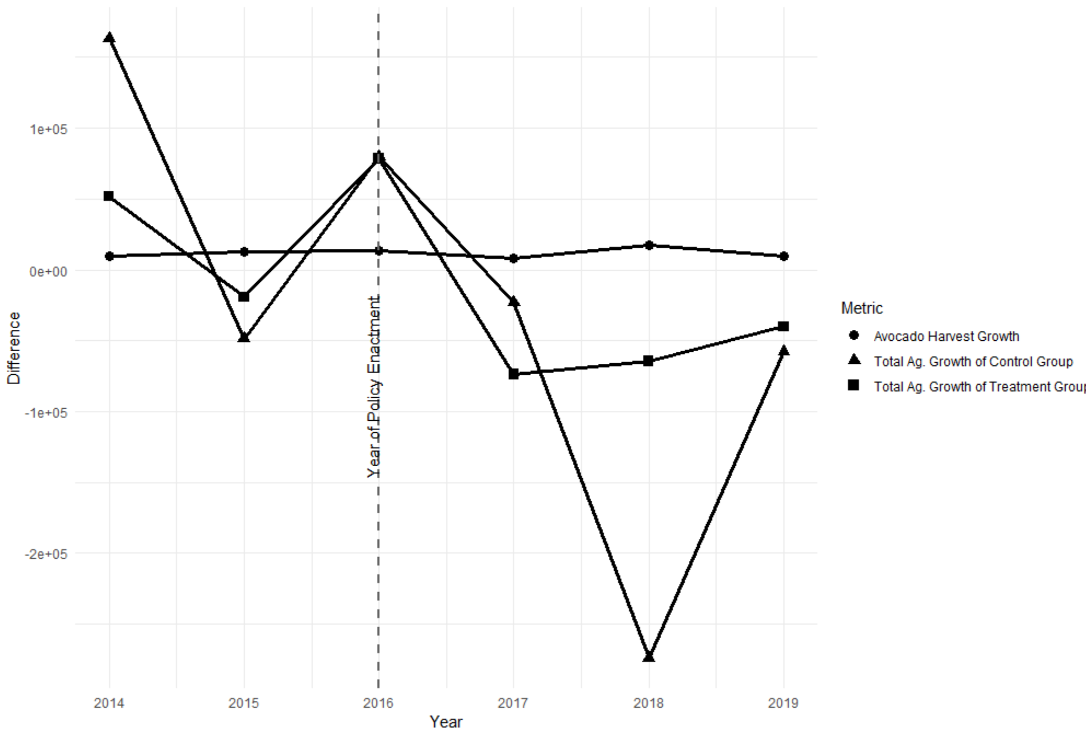
Note: This image represents the avocado soil suitability methodology from Dubrovina and Bautista (2014). Base saturation and clay are in percentage terms, and depth is in centimeters.

Figure A10: Avocado Climate Suitability Tree



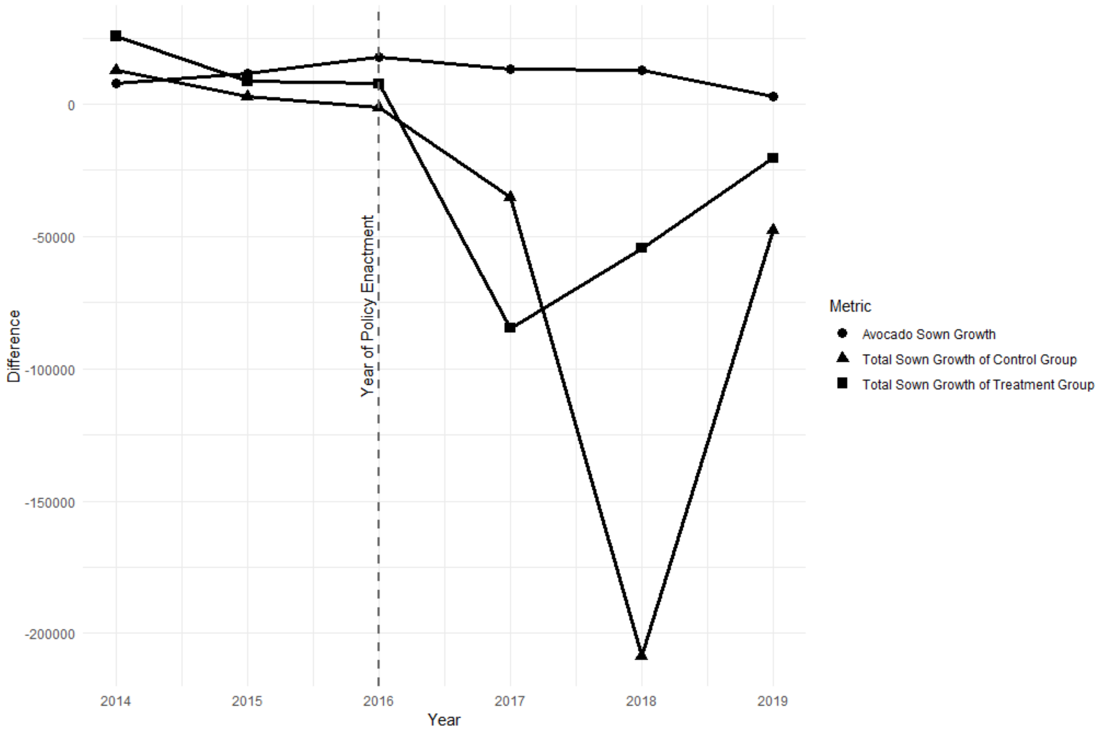
Note: This image represents the avocado soil suitability methodology from Dubrovina and Bautista (2014). Mean annual t is in Celsius, P/T is the ratio of precipitation in inches divided by mean annual temperature, height represents altitude in meters, and January stands for the average temperature in January in Celsius.

Figure A11: Avocado and Total Agriculture Growth Comparisons



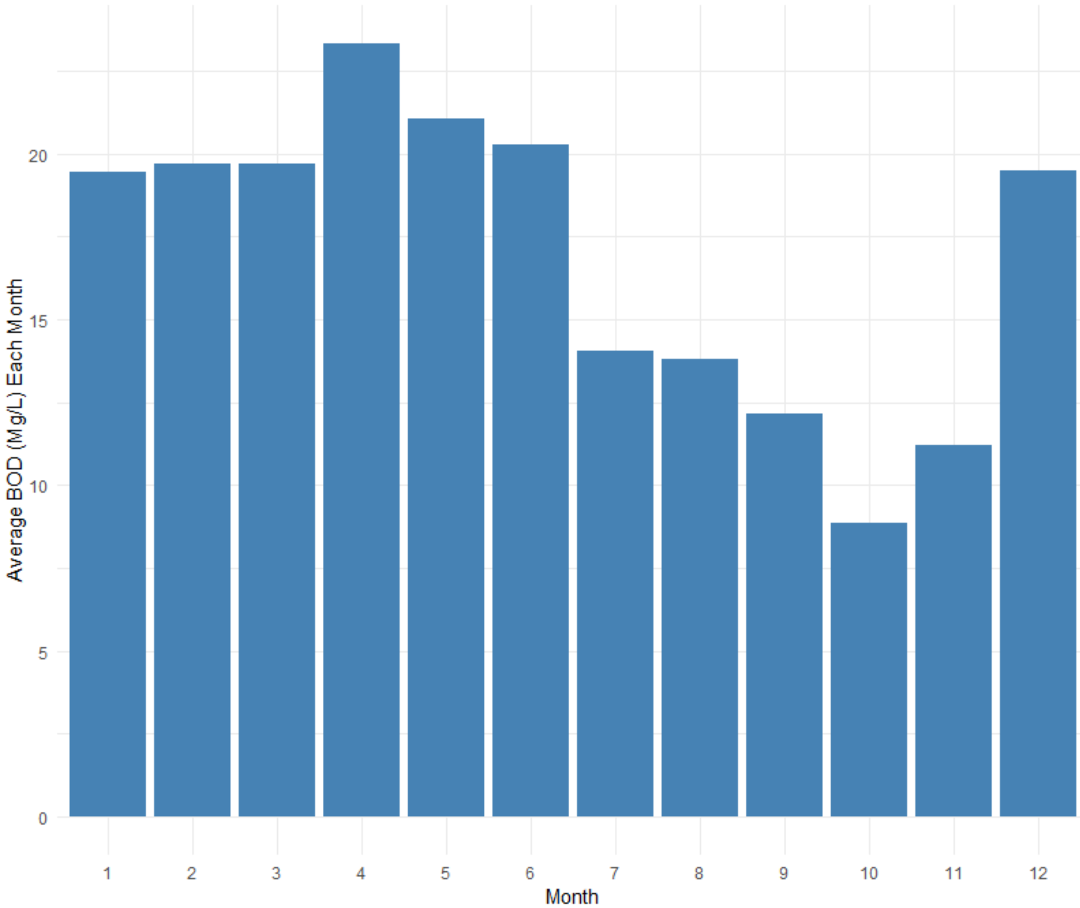
The data for this figure comes from El Gobierno de México's Servicio de Información Agroalimentaria y Pesquera (SIAP). The image shows the difference of the current year's avocado harvest from the previous year at Mexico's national level in hectares. The image also shows the difference of the current year's total agriculture harvested in hectares from the previous year at Mexico's national level for the treatment and control group of the main analysis. The dashed vertical line on 2016 represents when the 2016 Mexican Hass Avocado Import Program amendment was enacted. The image includes national results for the years 2014 to 2019.

Figure A12: Avocado and Total Agriculture Growth Comparisons



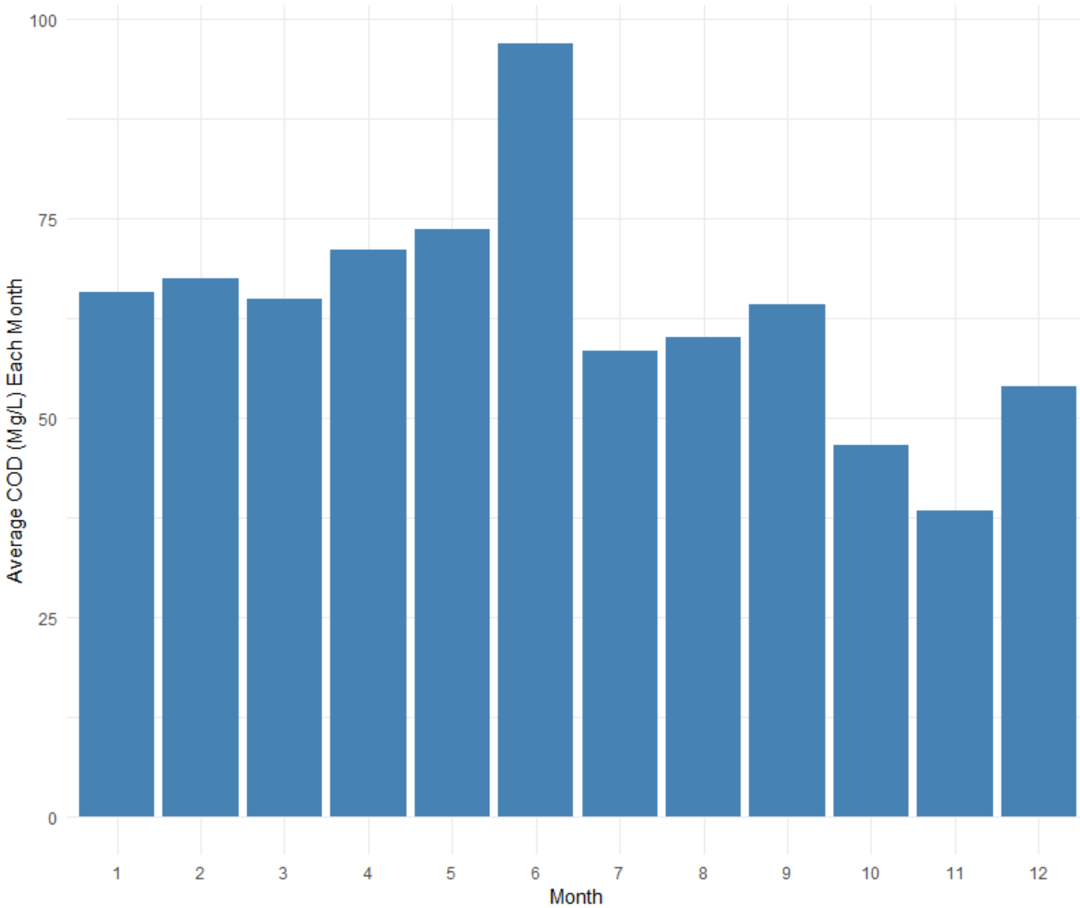
The data for this figure comes from El Gobierno de México's Servicio de Información Agroalimentaria y Pesquera (SIAP). The image shows the difference of the current year's avocado sown from the previous year at Mexico's national level in hectares. The image also shows the difference of the current year's total agriculture sown in hectares from the previous year at Mexico's national level for both the treatment and control group of the main analysis. The dashed vertical line on 2016 represents when the 2016 Mexican Hass Avocado Import Program amendment was enacted. The image includes national results for the years 2014 to 2019.

Figure A13: Average Monthly BOD (Mg/L) Levels



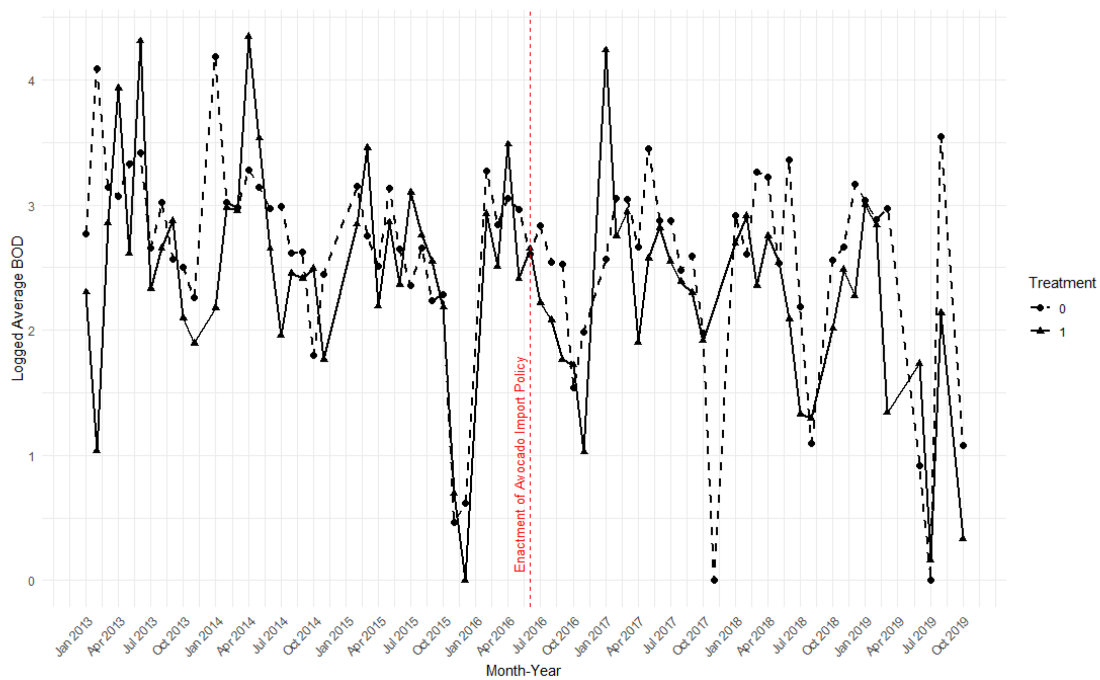
The data shows the average monthly BOD pollution levels (Mg/L) of the analysis in Table 2. It takes the average monthly results across the years 2013 to 2019. On the x-axis, 1 represents January, 2 represents February, 3 represents March, 4 is April, 5 is May, 6 is June, 7 is July, 8 is August, 9 is September, 10 is October, 11 is November, and 12 is December.

Figure A14: Average Monthly COD (Mg/L) Levels



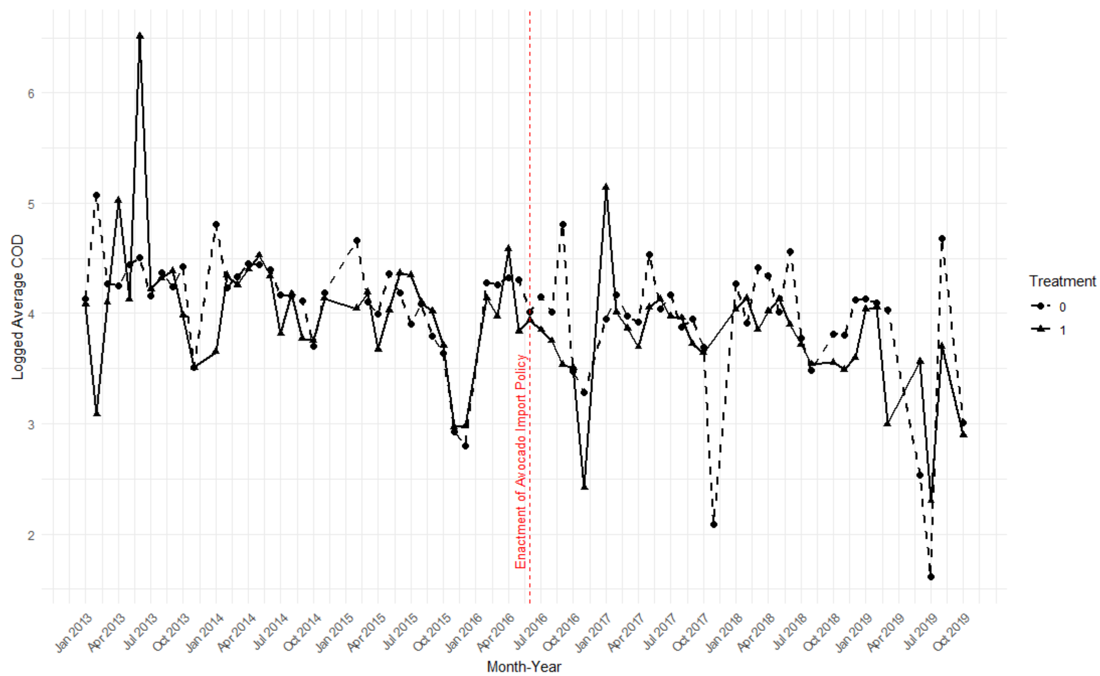
The data shows the average monthly COD pollution levels (Mg/L) of the analysis in Table 2. It takes the average monthly results across the years 2013 to 2019. On the x-axis, 1 represents January, 2 represents February, 3 represents March, 4 is April, 5 is May, 6 is June, 7 is July, 8 is August, 9 is September, 10 is October, 11 is November, and 12 is December.

Figure A15: Average Monthly BOD (Mg/L) Aggregates



This figure shows the monthly aggregate average of logged biochemical oxygen demand for all surface water monitors in the treatment group (solid line) and control group (dashed line). The figure covers the years 2013 to 2019. The dashed vertical lines emphasize that the USDA announced the policy to the public in February 2015 and enacted the policy in June 2016.

Figure A16: Average Monthly COD (Mg/L) Aggregates



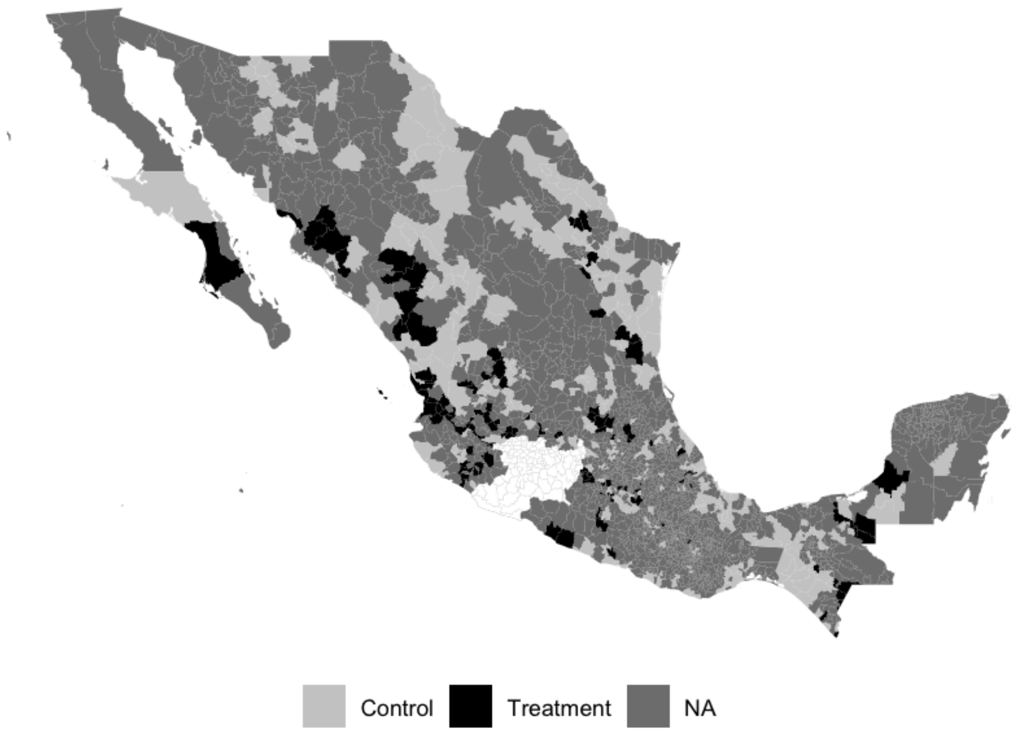
This figure shows the monthly aggregate average of logged chemical oxygen demand for all surface water monitors in the treatment group (solid line) and control group (dashed line). The figure covers the years 2013 to 2019. The dashed vertical lines emphasize that the USDA announced the policy to the public in February 2015 and enacted the policy in June 2016.

Table A1: Summary Statistics of BOD and COD Analysis 2013-2019

Variable	**Observations**	**Mean**	**Std. Dev.**	**Min.**	**25th**	**75th**	**Max.**
BOD (mg/L)	36,705	16.93	100.85	1	1	7.75	9,000
COD (mg/L)	36,705	65.73	585.81	3.12	11	50	99,200
Temperature (Celsius)	36,705	27.47	5.31	0.1	24	31.1	48.6
Precipitation (Inches)	3,445	93.99	99.93	0	14.8	150.23	828.8
Agriculture Sown (Hectares)	3,297	16,510.85	21,384.59	3.9	4,709.7	20,714	227,538
Agriculture Harvested (Hectares)	3,297	15,681.63	20,284.45	3.9	4,374	19,623	225,758
Population	471	38,557.41	27,600.70	399	16,120	58,960	99,590
Education (Percent)	471	21.68	4.79	10.3	18.2	24.6	44.2

Note: See data section for definitions of variables.

Figure A17: Treatment and Control Municipalities



The figure show's the municipalities that are in the treatment and control group for Table 2. The Treatment and control municipalities are in black and light gray, respectively. The dark gray municipalities are not in the sample and are denoted NA. The state that is whited out is Michoacán. Gray municipalities represent areas not included in the sample because they did not have water quality monitors with consistent readings from 2013-2019.

Table A2: Summary Statistics of Mechanism Analysis 2013-2019

Variable	**Observations**	**Mean**	**Std. Dev.**	**Min**	**25th**	**75th**	**Max**
Nitrate (mg/L)	42,342	0.71	1.56	0.00043	0.048	0.667	43.325
Nitrite (mg/L)	42,342	0.07	0.27	0.00074	0.0025	0.028	13.172
Nitrogen Ammonium (mg/L)	42,342	2.23	8.95	0.0015	0.055	0.340	198.875
Phosphorous (mg/L)	42,342	0.86	2.67	0.0005	0.055	0.512	87.453
Temperature (Celsius)	42,342	27.65	5.24	0	24.3	31.4	48.6
Precipitation (Inches)	3,536	93.53	101.20	0	14.07	150.03	828.8
Population	488	40,540.51	27,725.25	399	18,480	59,114	99,590

Note: See data section for definitions of variables.

Table A3: DID Results for Only States with Monitors in Treatment Group

	BOD			COD		
	(1)	(2)	(3)	(4)	(5)	(6)
Post*Treat	-0.121***	-0.118**	-0.121***	-0.115***	-0.115***	-0.114***
	(0.047)	(0.047)	(0.033)	(0.031)	(0.033)	(0.033)
Month and Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Monitor FE	Yes	Yes	Yes	Yes	Yes	Yes
Temperature Control	No	Yes	Yes	No	Yes	Yes
Municipal level controls	No	No	Yes	No	No	Yes
N	33,423	33,423	33,423	33,423	33,423	33,423
R^2	0.5614	0.5616	0.5618	0.4987	0.4987	0.5002

Note: This table is the same as Table 2, but we omit monitors from the states of Chihuahua, Coahuila, San Luis Potosi, Yucatan, and Quintana Roo. These states did not have any monitors in the treatment group among the sample. All robust standard errors are clustered at the surface water monitor level. *** is significant at the 1 percent level, ** is significant at the 5 percent level, and * is significant at the 10 percent level.

Table A4: DID Results for Balanced Panel of Mean, Max, and Min

	(1)	(2)	(3)	(4)	(5)	(6)
	BOD	COD	BOD	COD	BOD	COD
	Mean	Mean	Max	Max	Min	Min
Treat*Post	-0.115**	-0.099**	-0.045	-0.008	-0.170***	-0.154***
	(0.049)	(0.033)	(0.060)	(0.040)	(0.048)	(0.039)
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Monitor FE	Yes	Yes	Yes	Yes	Yes	Yes
Temperature Control	Yes	Yes	No	No	No	No
N	8,799	8,799	8,799	8,799	8,799	8,799
R^2	0.749	0.761	0.699	0.699	0.63	0.61

Note: All robust standard errors are clustered at the water monitor level. Data for this table spans from 2013 to 2019. The coefficient of interest is Post*Treat. Post equals 1 if the observation took place after 2015, 0 otherwise. Treat equals 1 if a monitor is in a municipality that grew avocados between 2003 to 2013. The sample consists of an even panel at the monitor and year level. Values for BOD and COD are logged. Each column includes year and monitor fixed effects. Columns 1 and 2 measure the average reading of a monitor in a year, columns 3 and 4 measure the highest reading of a monitor in a year, and columns 5 and 6 measure the lowest reading of a monitor in a year. The analysis includes 8,799 observations. *** is significant at the 1 percent level, ** is significant at the 5 percent level, and * is significant at the 10 percent level.

Table A5: DID Results for BOD and COD When Inequality Values Equal 1.5 and 7, Respectively

	BOD			COD		
	(1)	(2)	(3)	(4)	(5)	(6)
Post*Treat	-0.097**	-0.095**	-0.097**	-0.092***	-0.092***	-0.091***
	(0.038)	(0.038)	(0.038)	(0.028)	(0.028)	(0.028)
Month and Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Monitor FE	Yes	Yes	Yes	Yes	Yes	Yes
Temperature Control	No	Yes	Yes	No	Yes	Yes
Municipal level controls	No	No	Yes	No	No	Yes
N	36,705	36,705	36,705	36,705	36,705	36,705
R^2	0.610	0.610	0.610	0.544	0.544	0.545

Note: All robust standard errors are clustered at the surface water monitor level. Data for the table spans from 2013 to 2019. The coefficient of interest is Post*Treat. Post equals 1 if the observation took place after 2015, 0 otherwise. Treat equals 1 if a monitor is in a municipality that grew avocados between 2003 to 2013. The response variable in columns 1-3 is the logged value of BOD. For columns 4-6, the response variable is logged COD. Each column includes year and monitor fixed effects and controls for what month the monitor's reading took place. The temperature control is at the monitor station location at the time of the BOD or COD reading. The municipal level controls include the 8.2 magnitude earthquake that hit Oaxaca in 2017, logged hectares of agriculture sown and harvested at the municipal level, the percent of the population that has at least a secondary level of education, and the logged population. In addition, we control for municipal precipitation by taking the log(precipitation+1) value of the monthly average precipitation from 1980-2010. *** is significant at the 1 percent level, ** is significant at the 5 percent level, and * is significant at the 10 percent level.

Table A6: DID Results for BOD and COD When Inequality Values Equal 1.25 and 3, Respectively

	BOD			COD		
	(1)	(2)	(3)	(4)	(5)	(6)
Post*Treat	-0.107***	-0.105***	-0.108***	-0.138***	-0.138***	-0.138***
	(0.041)	(0.041)	(0.041)	(0.037)	(0.037)	(0.037)
Month and Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Monitor FE	Yes	Yes	Yes	Yes	Yes	Yes
Temperature Control	No	Yes	Yes	No	Yes	Yes
Municipal level controls	No	No	Yes	No	No	Yes
N	36,705	36,705	36,705	36,705	36,705	36,705
R^2	0.601	0.601	0.601	0.505	0.505	0.506

Note: All robust standard errors are clustered at the surface water monitor level. Data for the table spans from 2013 to 2019. The coefficient of interest is Post*Treat. Post equals 1 if the observation took place after 2015, 0 otherwise. Treat equals 1 if a monitor is in a municipality that grew avocados between 2003 to 2013. The response variable in columns 1-3 is the logged value of BOD. For columns 4-6, the response variable is logged COD. Each column includes year and monitor fixed effects and controls for what month the monitor's reading took place. The temperature control is at the monitor station location at the time of the BOD or COD reading. The municipal level controls include the 8.2 magnitude earthquake that hit Oaxaca in 2017, logged hectares of agriculture sown and harvested at the municipal level, the percent of the population that has at least a secondary level of education, and the logged population. In addition, we control for municipal precipitation by taking the log(precipitation+1) value of the monthly average precipitation from 1980-2010. *** is significant at the 1 percent level, ** is significant at the 5 percent level, and * is significant at the 10 percent level.

Table A7: DID Results for BOD and COD When Inequality Values Equal 1.75 and 1, Respectively

	BOD			COD		
	(1)	(2)	(3)	(4)	(5)	(6)
Post*Treat	-0.088**	-0.087**	-0.089**	-0.198***	-0.198***	-0.198***
	(0.036)	(0.036)	(0.036)	(0.050)	(0.050)	(0.050)
Month and Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Monitor FE	Yes	Yes	Yes	Yes	Yes	Yes
Temperature Control	No	Yes	Yes	No	Yes	Yes
Municipal level controls	No	No	Yes	No	No	Yes
N	36,705	36,705	36,705	36,705	36,705	36,705
R^2	0.617	0.617	0.617	0.460	0.460	0.462

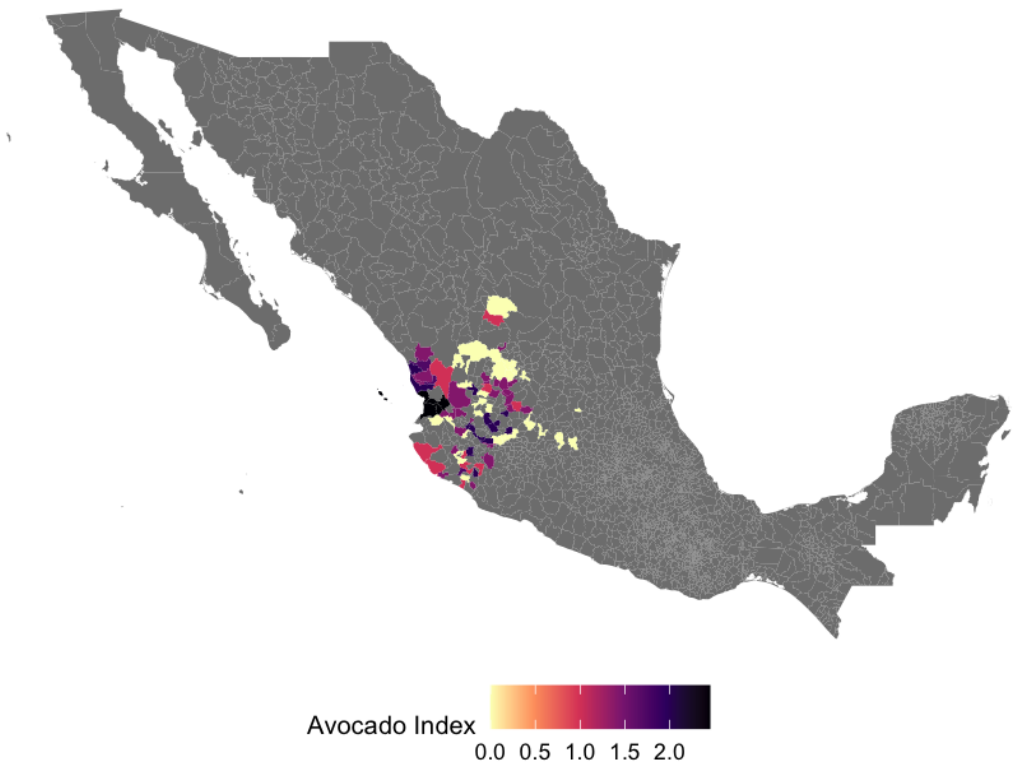
Note: All robust standard errors are clustered at the surface water monitor level. Data for the table spans from 2013 to 2019. The coefficient of interest is Post*Treat. Post equals 1 if the observation took place after 2015, 0 otherwise. Treat equals 1 if a monitor is in a municipality that grew avocados between 2003 to 2013. The response variable in columns 1-3 is the logged value of BOD. For columns 4-6, the response variable is logged COD. Each column includes year and monitor fixed effects and controls for what month the monitor's reading took place. The temperature control is at the monitor station location at the time of the BOD or COD reading. The municipal level controls include the 8.2 magnitude earthquake that hit Oaxaca in 2017, logged hectares of agriculture sown and harvested at the municipal level, the percent of the population that has at least a secondary level of education, and the logged population. In addition, we control for municipal precipitation by taking the log(precipitation+1) value of the monthly average precipitation from 1980-2010. *** is significant at the 1 percent level, ** is significant at the 5 percent level, and * is significant at the 10 percent level.

Table A8: Robustness Results with Varying Fixed Effects

	BOD				COD			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post*Treat	-0.375***	-0.129**	-0.369***	-0.122***	-0.293***	-0.124**	-0.285**	-0.111***
	(0.047)	(0.055)	(0.038)	(0.044)	(0.035)	(0.040)	(0.027)	(0.032)
Month by Monitor FE	Yes	Yes	No	No	Yes	Yes	No	No
Year FE	No	Yes	No	Yes	No	Yes	No	Yes
Monitor by Municipality FE	No	No	Yes	Yes	No	No	Yes	Yes
Right Hand Controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	36,705	36,705	36,705	36,705	36,705	36,705	36,705	36,705
R^2	0.547	0.577	0.566	0.589	0.523	0.523	0.515	0.530

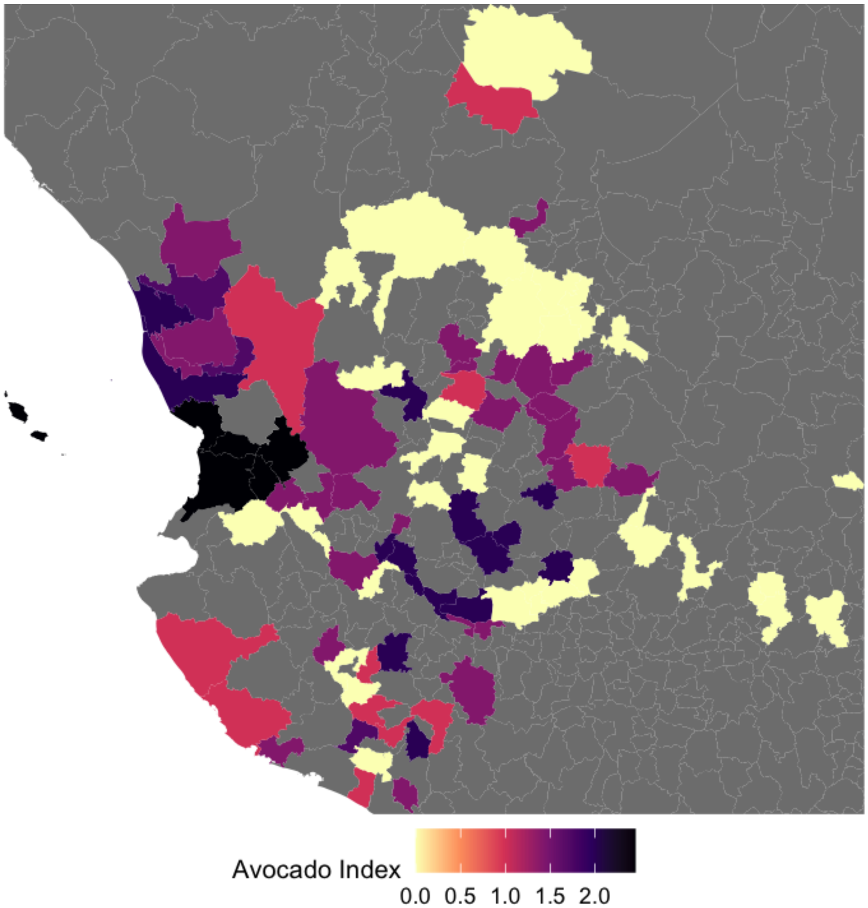
Note: All robust standard errors are clustered at the surface water monitor level. Data for the table spans from 2013 to 2019. The coefficient of interest is Post*Treat. Post equals 1 if the observation took place after 2015, 0 otherwise. Treat equals 1 if a monitor is in a municipality that grew avocados between 2003 to 2013. The response variable in columns 1-3 is the logged value of BOD. For columns 4-6, the response variable is logged COD. Each column includes year and monitor fixed effects and controls for what month the monitor's reading took place. The temperature control is at the monitor station location at the time of the BOD or COD reading. The municipal level controls include the 8.2 magnitude earthquake that hit Oaxaca in 2017, logged hectares of agriculture sown and harvested at the municipal level, the percent of the population that has at least a secondary level of education, and the logged population. In addition, we control for municipal precipitation by taking the log(precipitation+1) value of the monthly average precipitation from 1980-2010. *** is significant at the 1 percent level, ** is significant at the 5 percent level, and * is significant at the 10 percent level.

Figure A18: Avocado Suitability

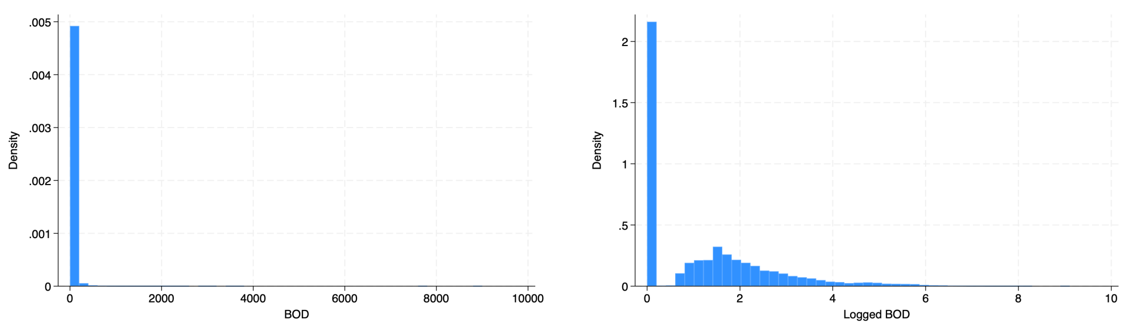


The figure displays the avocado suitability index based on the methods of Dubrovina and Bautista (2014). Gray municipalities represent areas not included in the sample because they did not have water quality monitors with consistent readings from 2013-2019.

Figure A19: Avocado Suitability Index Zoomed In



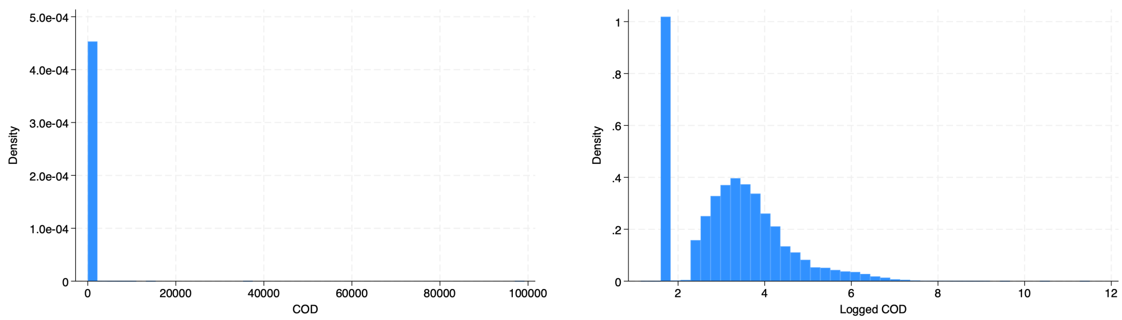
The figure displays the avocado suitability index sample based on the methods of Dubrovina and Bautista (2014). Gray municipalities represent areas not included in the sample because they did not have water quality monitors with consistent readings from 2013-2019.



(a) (b)

Figure A20: BOD Distribution

Notes: Images a and b show the distribution for Biochemical Oxygen Demand (BOD) and logged Biochemical Oxygen Demand, respectively. The Y-axis represents the probability distribution while the X-axis represents the BOD values.



(a) (b)

Figure A21: COD Distribution

Notes: Images a and b show the distribution for Chemical Oxygen Demand (COD) and logged Chemical Oxygen Demand, respectively. The Y-axis represents the probability distribution while the X-axis represents the COD values.

Table A9: Main Results with Clustering at the Watershed Level

	(1) BOD	(2) COD
Post*Treat	-0.122*	-0.111**
	(0.073)	(0.048)
Month and Year FE	Yes	Yes
Monitor FE	Yes	Yes
Controls	Yes	Yes
N	36,705	36,705
R^2	0.589	0.530

Note: All robust standard errors are clustered at the watershed level. Data for this table spans from 2013 to 2019. The left-hand variables are logged BOD and COD for columns 1 and 2, respectively. The coefficient of interest is Post*Treat. Post equals 1 if the observation took place after 2015, 0 otherwise. Treat equals 1 if a monitor is in a municipality that grew avocados between 2003 to 2013. All columns include logged total population, percent of municipality population with at least a secondary education, the 8.2 magnitude Oaxaca earthquake in 2017, logged temperature at the monitor level, and amount of total agriculture sown and harvested in hectares at the municipality level. In addition, both columns control for municipal precipitation by taking the log(precipitation+1) value of the monthly average precipitation from 1980-2010. Each column includes year and monitor fixed effects and controls for what month the monitor's reading took place. *** is significant at the 1 percent level, ** is significant at the 5 percent level, and * is significant at the 10 percent level.

Table A10: Results for Groundwater Nitrite Contamination

	(1) Nitrite	(2) Nitrite
Post*Treat	0.1331***	0.1394***
	(0.0349)	(0.0329)
Month and Year FE	Yes	Yes
Monitor FE	Yes	Yes
Nitrate	No	Yes
Ammonia	No	Yes
Controls	No	Yes
N	42,342	42,342
R^2	0.5195	0.5814

Note: All robust standard errors are clustered at the watershed level. Data for this table spans from 2013 to 2019. The left-hand variable is log(nitrite).The coefficient of interest is Post*Treat. Post equals 1 if the observation took place after 2015, 0 otherwise. Treat equals 1 if a monitor is in a municipality that grew avocados between 2003 to 2013. All columns include logged total population, logged temperature at the monitor level, and municipal precipitation by taking the log(precipitation+1) value of the monthly average precipitation from 1980-2010. Each column includes year and monitor fixed effects and controls for what month the monitor's reading took place. *** is significant at the 1 percent level, ** is significant at the 5 percent level, and * is significant at the 10 percent level.

Table A11: Main Results in Table 2 with Different Time Treatment Cutoffs

	BOD				COD			
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Post*Treat	-0.103**	-0.075*	-0.120***	-0.089**	-0.108***	-0.077**	-0.110***	-0.053*
	(0.051)	(0.044)	(0.045)	(0.042)	(0.038)	(0.031)	(0.032)	(0.028)
Month and Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Monitor FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Temperature Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Municipal level controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Time Treatment Start Year	2015	2017	2016	2016	2015	2017	2016	2016
Time Treatment Start Month	January	January	February	July	January	January	February	July
N	36,705	36,705	36,705	36,705	36,705	36,705	36,705	36,705
R^2	0.589	0.589	0.589	0.589	0.530	0.530	0.530	0.530

Note: All robust standard errors are clustered at the water monitor level. Data for the table spans from 2013 to 2019. The methods are the same as Table 2 with all the monitor and municipal controls. The outcome variable for columns 1-4 is biochemical oxygen demand and for columns 5-8 it is chemical oxygen demand. Columns 1 and 5 begin treatment in January 2015. Columns 2 and 6 begin treatment in January 2017. Columns 3 and 7 begin treatment in February 2016. Columns 4 and 8 begin treatment in July 2016. *** is significant at the 1 percent level, ** is significant at the 5 percent level, and * is significant at the 10 percent level.

Table A12: Main Results in Table 2 with Winsorization (Omission Above 95th Percentile)

	BOD			COD		
	(1)	(2)	(3)	(4)	(5)	(6)
Post*Treat	-0.113***	-0.111***	-0.116***	-0.109***	-0.114***	-0.120***
	(0.042)	(0.042)	(0.042)	(0.042)	(0.042)	(0.043)
Month and Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Monitor FE	Yes	Yes	Yes	Yes	Yes	Yes
Temperature Control	No	Yes	Yes	No	Yes	Yes
Municipal level controls	No	No	Yes	No	No	Yes
N	34,870	34,870	34,870	34,870	34,870	34,870
R^2	0.448	0.448	0.448	0.424	0.471	0.471

Note: All robust standard errors are clustered at the water monitor level. Data for the table spans from 2013 to 2019. The methods for columns 1-6 are the same as Table 2, but this table applies a Winsorization of maximum values robustness check. All BOD and COD values above the 95th percentile of the original sample values are omitted in this robustness check (BOD and COD values above 56.67 mg/L and 225.50 mg/L, respectively). *** is significant at the 1 percent level, ** is significant at the 5 percent level, and * is significant at the 10 percent level.

Table A13: Main Results in Table 2 with Winsorization (Omission Above 90th Percentile)

	BOD			COD		
	(1)	(2)	(3)	(4)	(5)	(6)
Post*Treat	-0.120***	-0.118***	-0.123***	-0.123***	-0.122***	-0.122***
	(0.041)	(0.041)	(0.041)	(0.030)	(0.030)	(0.030)
Month and Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Monitor FE	Yes	Yes	Yes	Yes	Yes	Yes
Temperature Control	No	Yes	Yes	No	Yes	Yes
Municipal level controls	No	No	Yes	No	No	Yes
N	33,035	33,035	33,035	33,034	33,034	33,034
R^2	0.359	0.359	0.360	0.375	0.375	0.377

Note: All robust standard errors are clustered at the water monitor level. Data for the table spans from 2013 to 2019. The methods for columns 1-6 are the same as Table 2, but this table applies a Winsorization of maximum values robustness check. All BOD and COD values above the 90th percentile of the original sample values are omitted in this robustness check (BOD and COD above 23.99 mg/L and 111.80 mg/L, respectively). *** is significant at the 1 percent level, ** is significant at the 5 percent level, and * is significant at the 10 percent level.

Table A14: Main Results with Conley Standard Errors

	BOD			COD		
	(1)	(2)	(3)	(4)	(5)	(6)
Post*Treat	-0.118***	-0.118***	-0.118***	-0.110***	-0.110***	-0.110***
	(0.039)	(0.042)	(0.045)	(0.030)	(0.032)	(0.034)
Month and Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Monitor FE	Yes	Yes	Yes	Yes	Yes	Yes
Temperature Control	Yes	Yes	Yes	Yes	Yes	Yes
Buffer Zone in KM	25	50	75	25	50	75
N	36,705	36,705	36,705	36,705	36,705	36,705
R^2	0.589	0.589	0.589	0.529	0.529	0.529

Note: The columns in this table use the same methods as Table 2 with monitor level temperature controls. Instead of reporting robust standard errors clustered at the monitor level, the table reports robust Conley standard errors with 25km, 50km, and 75 km buffers. *** is significant at the 1 percent level, ** is significant at the 5 percent level, and * is significant at the 10 percent level.

Table A15: DID Results for BOD for Each Month

	BOD										
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Post*Treat	0.466**	0.160	-0.205**	-0.305***	-0.221**	-0.061	-0.180*	-0.050	-0.160*	-0.672	-0.514
	(0.221)	(0.128)	(0.098)	(0.104)	(0.101)	(0.102)	(0.096)	(0.092)	(0.092)	(0.084)	(0.509)
Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Monitor FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Temperature Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Municipal level controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1,735	3,405	4,423	3,514	3,576	3,640	3,592	3,713	3,604	3,972	1,003
R^2	0.818	0.776	0.726	0.753	0.740	0.679	0.681	0.695	0.690	0.672	0.933

Note: All robust standard errors are clustered at the water monitor level. Data for the table spans from 2013 to 2019. This table splits the BOD results of Table 2 by each individual month. December is not included due to issues of multicollinearity when only running observations for that single month. *** is significant at the 1 percent level, ** is significant at the 5 percent level, and * is significant at the 10 percent level.

Table A16: DID Results for COD for Each Month

	COD										
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)
Post*Treat	0.144	0.055	-0.213***	-0.341***	-0.103	-0.170*	-0.257***	0.093	-0.067	0.024	-0.366
	(0.179)	(0.098)	(0.079)	(0.086)	(0.086)	(0.093)	(0.089)	(0.077)	(0.075)	(0.076)	(0.526)
Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.
Year FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Monitor FE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Temperature Control	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Municipal level controls	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
N	1,735	3,405	4,423	3,514	3,576	3,640	3,592	3,713	3,604	3,972	1,003
R^2	0.819	0.770	0.707	0.755	0.712	0.660	0.656	0.654	0.652	0.626	0.907

Note: All robust standard errors are clustered at the water monitor level. Data for the table spans from 2013 to 2019. This table splits the COD results of Table 2 by each individual month. December is not included due to issues of multicollinearity when only running observations for that single month. *** is significant at the 1 percent level, ** is significant at the 5 percent level, and * is significant at the 10 percent level.

Table A17: Mechanism - DID Results for Nitrogen and Phosphorus Contaminants with Conley Standard Errors

	(1) Nitrate	(2) Phosphorus	(3) Nitrate	(4) Phosphorus
Post*Treat	-0.101*	-0.065	-	-
	(0.060)	(0.043)	-	-
	-	-	0.1236***	-0.0424
	-	-	(0.039)	(0.0315)
Month and Year FE	Yes	Yes	Yes	Yes
Monitor FE	Yes	Yes	Yes	Yes
Right Hand Controls	Yes	Yes	Yes	Yes
Ammonia Control	Yes	No	Yes	No
Nitrite Control	Yes	No	Yes	No
Buffer in KM	50	50	50	50
N	42,341	42,341	9,732	9,732
R^2	0.5345	0.6009	0.6795	0.7417

Note: All robust Conley standard errors have 50 km buffers. Data for this table spans from 2013 to 2019. The coefficient of interest is Post*Treat. Post equals 1 if the observation took place after 2015, 0 otherwise. Treat equals 1 if a monitor is in a municipality that grew avocados between 2003 to 2013. The response variable in columns 1 and two are log(nitrate) and log(phosphorous), respectively. Right-hand controls include logged total population, logged temperature at the monitor level, and municipal precipitation by taking the log(precipitation+1) value of the monthly average precipitation from 1980-2010. Each column includes month, year and monitor fixed effects. Only column 1 includes controls for ammonia and nitrite because of the nitrogen cycle (which phosphorous is not a part of). *** is significant at the 1 percent level, ** is significant at the 5 percent level, and * is significant at the 10 percent level.

Table A18: Index 1 Results with Conley Standard Errors with 50 KM Buffer

	(1) BOD	(2) COD
Post*AvoSuitability	-0.152***	-0.116***
	(0.049)	(0.034)
Month and Year FE	Yes	Yes
Monitor FE	Yes	Yes
Controls	Yes	Yes
N	8,638	8,638
R^2	0.560	0.509

Note: All robust Conley standard errors are clustered with a 50 km buffer. Data for this table spans from 2013 to 2019. The left-hand variables are logged BOD and COD for columns 1 and 2, respectively. The coefficient of interest is Post*AvoSuitability. Post equals 1 if the observation took place after 2015, 0 otherwise. The index is calculated applying methods from Dubrovina and Bautista (2014). $AvoSuitability_i = \sqrt{Climate_i * Soil_i}$. All columns include logged total population, percent of municipality population with at least a secondary education, the 8.2 magnitude Oaxaca earthquake in 2017, logged temperature at the monitor level, and amount of total agriculture sown and harvested in hectares at the municipality level. In addition, both columns control for municipal precipitation by taking the log(precipitation+1) value of the monthly average precipitation from 1980-2010. Each column includes year and monitor fixed effects and controls for what month the monitor's reading took place. *** is significant at the 1 percent level, ** is significant at the 5 percent level, and * is significant at the 10 percent level.

Table A19: Index 2 Results

	(1) BOD	(2) COD
Post*AvoSuitability	-0.033***	-0.027***
Clustered SE	(0.011)	(0.009)
Conley SE 50 KM Buffer	(0.013)	(0.010)
Month and Year FE	Yes	Yes
Monitor FE	Yes	Yes
Controls	Yes	Yes
N	8,638	8,638
R^2	0.560	0.509

Note: All robust Conley standard errors are clustered with 50 km buffers. Data for this table spans from 2013 to 2019. The left-hand variables are logged BOD and COD for columns 1 and 2, respectively. The coefficient of interest is Post*AvoSuitability. Post equals 1 if the observation took place after 2015, 0 otherwise. The index is calculated by applying methods from Dubrovina and Bautista (2014). $AvoSuitability_i = Climate_i * Soil_i + Climate_i + Soil_i + 2$. All columns include logged total population, percent of municipality population with at least a secondary education, the 8.2 magnitude Oaxaca earthquake in 2017, logged temperature at the monitor level, and amount of total agriculture sown and harvested in hectares at the municipality level. In addition, both columns control for municipal precipitation by taking the log(precipitation+1) value of the monthly average precipitation from 1980-2010. Each column includes year and monitor fixed effects and controls for what month the monitor's reading took place. *** is significant at the 1 percent level, ** is significant at the 5 percent level, and * is significant at the 10 percent level.

Table A20: Binary OLS Results with Conley SE

	(1) BOD	(2) BOD	(3) COD	(4) COD
Post*Treat	-0.053***	-0.052***	-0.050***	-0.022**
	(0.020)	(0.020)	(0.014)	(0.010)
Threshold (mg/L)	2	10	10	50
Month and Year FE	Yes	Yes	Yes	Yes
Monitor FE	Yes	Yes	Yes	Yes
Temp. Control	Yes	Yes	Yes	Yes
N	36,705	36,705	36,705	36,705
R^2	0.349	0.351	0.299	0.143

Note: All robust Conley standard errors have a 50 KM buffer. Data for this table spans from 2013 to 2019. TBOD and COD are dummies equal to 1 if above the "Threshold", and 0 otherwise. The coefficient of interest is Post*Treat. Post equals 1 if the observation took place after 2015, 0 otherwise. Treat equals 1 if a monitor is in a municipality that grew avocados between 2003 to 2013. All columns include logged total population, percent of municipality population with at least a secondary education, the 8.2 magnitude Oaxaca earthquake in 2017, logged temperature at the monitor level, and amount of total agriculture sown and harvested in hectares at the municipality level. In addition, both columns control for municipal precipitation by taking the log(precipitation+1) value of the monthly average precipitation from 1980-2010. Each column includes year and monitor fixed effects and controls for what month the monitor's reading took place. *** is significant at the 1 percent level, ** is significant at the 5 percent level, and * is significant at the 10 percent level.

Table A21: Soil Characteristics

Variable	Classification	Value	Value Description
Andosol	Highly Suitable	3	7.7 percent organic matter, formed in volcanic tephra
Luvisol	Suitable	2	Favorable textural and structural characteristics for good water physical properties
Phaeozems	Suitable	2	Favorable textural and structural characteristics for good water physical properties
Kastanozem	Suitable	2	High Base Saturation and granular structure
Gleysol	Suitable	2	High base saturation, good depth, crumb shape, low hydraulic conductivity
Solonchak	Suitable	2	High base saturation, deep depth, crum to blocky shape, low hydraulic conductivity
Calcisol	Suitable	2	High base saturation, depth within 100 cm, blocky
Chernozem	Suitable	2	High base saturation, deep depth, blocky
Cambisol	Low Suitability	1	2.3 percent organic matter
Regosol	Low Suitability	1	Low cation exchange capacity
Arenosol	Low Suitability	1	Low base saturation, varying depth, $<$ 15 percent clay content
Histosol	Low Suitability	1	Varying base saturation, varying aggregate shape, varying depth, very low hydraulic conductivity
Fluvisol	Low Suitability	1	Varying vase saturation, depth $>$ 50 cm, low hydraulic conductivity
Vertisol	No Suitability	0	Clayey texture and Massive Structure
Leptosol	No Suitability	0	Shallow depth profile ($<$ 25 cm)
Planosol	No Suitability	0	Varying base saturation, varying depth, massive shape, low hydraulic conductivity, high clay texture
Durisol	No Suitability	0	Base saturation $>$ 50 percent, within 100 cm depth, typically massive shape

Note: Soil information comes from Dubrovina and Bautista (2014) and ISRIC World Soil Information.

Table A22: Summary Statistics of BOD and COD Analysis 2013-2019

Variable	Mean	Std. Dev.	Min.	Max.
BOD (mg/L)	18.73	104.73	1	3,060.99
COD (mg/L)	69.81	255.77	5	9,109.5
AvoSuitability	1.14	0.77	0	2.45
AvoSuitability 2	6.56	2.80	3	13
Temperature (Celsius)	27.05	4.63	6.8	42.5
Precipitation (Inches)	893.46	271.60	381.9	1,455.3
Population	37,201.12	26,030.51	2,082	99,590
Education (Percent)	21.81	3.64	11.54	32.98
Agriculture Sown (Hectares)	20,393.84	17,269.2	1,108	83,508
Agriculture Harvested (Hectares)	19,631.57	16,740.35	888	82,973

Note: Variables are the same as Table A1. $AvoSuitability = \sqrt{Climate * Soil}$ and $AvoSuitability2 = Climate * Soil + Climate + Soil + 2$

Table A23: DID Results with Interaction of Treatment with Avocado Hectares Sown or Harvested

	BOD		COD	
	(1)	(2)	(3)	(4)
Post*log(AvocadoSown)	-0.009	-	-0.007	-
	(0.013)	-	(0.009)	-
Post*log(AvocadoHarvest)	-	-0.011	-	-0.005
	-	(0.014)	-	(0.009)
Month and Year FE	Yes	Yes	Yes	Yes
Monitor FE	Yes	Yes	Yes	Yes
N	36,705	36,705	36,705	36,705
R^2	0.589	0.589	0.528	0.528

Note: All robust standard errors are clustered at the municipality level. Data for the table spans from 2013 to 2019. All columns control for municipality population and monitor location ambient temperature. *** is significant at the 1 percent level, ** is significant at the 5 percent level, and * is significant at the 10 percent level.

Table A24: BOD Balanced Monthly Analysis

	BOD					
	(1)	(2)	(3)	(4)	(5)	(6)
Post*Treat	-0.362	-0.249	-0.010	0.500	0.012	-0.034
	(0.330)	(0.228)	(0.246)	(0.487)	(0.475)	(0.261)
Month	March	April	May	June	July	October
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Monitor FE	Yes	Yes	Yes	Yes	Yes	Yes
Temperature Control	No	Yes	Yes	No	Yes	Yes
Municipal level controls	No	No	Yes	No	No	Yes
N	751	354	276	270	99	428
R^2	0.750	0.684	0.773	0.578	0.587	0.609

Note: The data spans from 2013 to 2018. This table uses the same regressions as Table 2 and includes controls for population, education, agriculture sown and harvested, the 8.2 magnitude earthquake that hit Oaxaca in 2017, ambient temperature, and monthly precipitation. Each column filters the data to only include balanced data for monitors that had 1 reading for a specific month each year (March, April, May, June, July, October). Only balanced data observations in each specific month are included in each respective regression. The response variable is biochemical oxygen demand. *** is significant at the 1 percent level, ** is significant at the 5 percent level, and * is significant at the 10 percent level.

Table A25: COD Balanced Monthly Analysis

	COD					
	(1)	(2)	(3)	(4)	(5)	(6)
Post*Treat	-0.572**	0.004	-0.171	-0.502	-0.094	0.056
	(0.271)	(0.179)	(0.364)	(0.390)	(0.524)	(0.201)
Month	March	April	May	June	July	October
Year FE	Yes	Yes	Yes	Yes	Yes	Yes
Monitor FE	Yes	Yes	Yes	Yes	Yes	Yes
Temperature Control	No	Yes	Yes	No	Yes	Yes
Municipal level controls	No	No	Yes	No	No	Yes
N	751	354	276	270	99	428
R^2	0.750	0.728	0.687	0.584	0.558	0.559

Note: The data spans from 2013 to 2018. This table uses the same regressions as Table 2 and includes controls for population, education, agriculture sown and harvested, the 8.2 magnitude earthquake that hit Oaxaca in 2017, ambient temperature, and monthly precipitation. Each column filters the data to only include balanced data for monitors that had 1 reading for a specific month each year (March, April, May, June, July, October). Only balanced data observations in each specific month are included in each respective regression. The response variable is chemical oxygen demand. *** is significant at the 1 percent level, ** is significant at the 5 percent level, and * is significant at the 10 percent level.

Table A26: Main Table with Levels of BOD and Nitrate

	BOD	Nitrate
	(1)	(2)
Post × Treat	-6.710*	-0.076*
	(3.467)	(0.040)
Month FE	Yes	Yes
Year FE	Yes	Yes
Monitor FE	Yes	Yes
Temperature Control	Yes	Yes
Municipal Controls	Yes	Yes
N	36,705	42,341
Adj. R^2	0.241	0.574

Note: Column 1 is identical to column 3 in Table 2 except that BOD is not logged in this table. Column 2 is identical to column 1 in Table 4 except that nitrate is not logged in this table. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Table A27: Results with No Upstream Municipalities

	BOD	COD	Nitrate	Phosphorous
	(1)	(2)	(3)	(4)
Post × Treat	-0.124***	-0.116***	-0.102**	-0.082**
	(0.047)	(0.033)	(0.050)	(0.040)
Monitor FE	Yes	Yes	Yes	Yes
Month FE	Yes	Yes	Yes	Yes
Year FE	Yes	Yes	Yes	Yes
Temperature Control	Yes	Yes	Yes	Yes
Municipal Controls	Yes	Yes	Yes	Yes
N	30,091	30,091	35,437	35,437
Adj. R^2	0.600	0.537	0.530	0.583

Note: This table runs the same analysis as Table 2 and 4 but omits all upstream municipalities from the sample. Columns 1 and 2 use the same specification as columns 3 and 6 of Table 2. Columns 3 and 4 apply the same specifications as columns 1 and 2 of Table 4. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Table A28: Results with Upstream Controls

	BOD		COD	
	(1)	(2)	(3)	(4)
Post × Treat	-0.120***	-0.135***	-0.110***	-0.122***
	(0.045)	(0.045)	(0.317)	(0.032)
Upstream Drainage Area	Yes	Yes	Yes	Yes
River Basin Fixed Effects	Yes	Yes	Yes	Yes
Monitor Fixed Effects	Yes	No	Yes	No
Month Fixed Effects	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes
Temperature Control	Yes	Yes	Yes	Yes
Municipal Controls	Yes	Yes	Yes	Yes
N	36,705	36,705	36,705	36,705
Adj. R^2	0.589	0.173	0.530	0.173

Note: This table runs the same regressions as columns 3 and 6 of Table 2, but includes river basin fixed effects and a control for upstream drainage area. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.

Table A29: DID Results with Total Agriculture Sown and Harvested in Hectares as Response Variables

	Logged Sown		Logged Harvested	
	(1)	(2)	(3)	(4)
Post × Treat	0.007	0.015	0.015	0.023
	(0.025)	(0.026)	(0.029)	(0.029)
Municipality Fixed Effects	Yes	Yes	Yes	Yes
Month Fixed Effects	Yes	Yes	Yes	Yes
Year Fixed Effects	Yes	Yes	Yes	Yes
Municipal Level Controls	Yes	No	Yes	No
N	36,705	36,705	36,705	36,705
Adj. R^2	0.594	0.394	0.593	0.393

Note: This table runs the DID specification of Table 2, but shows the results of logged total agriculture sown or harvested in hectares as the response variables instead of proxies for water quality/pollutants. In addition, the regressions use municipality fixed effects instead of monitor fixed effects and clusters the robust standard errors at the municipality level instead of the monitor level sense the data's sown and harvest data are at the municipal level as opposed to a water quality monitor level. *** $p < 0.01$, ** $p < 0.05$, * $p < 0.10$.