Revista Iberoamericana Ambiente & Sustentabilidad
ISSN: 2697-3510 I e-ISSN: 2697-3529 I Vol. 7, 2024
DOI: https://doi.org/10.46380/rias.v7.e384

GESTIÓN SUSTENTABLE DE RECURSOS HÍDRICOS

Hidden costs of water retained for avocado production in Mexico.

Costos ocultos del agua retenida para producción de aguacate en México.

Custos ocultos da água retida para produção de abacate no México.

Carlos Francisco Ortiz-Paniagua, Gerardo Ruiz-Sevilla
Universidad Michoacana de San Nicolás de Hidalgo, México
carlos.ortiz@umich.mx

Artículo científico

Recibido: 25/04/2024
Aceptado: 01/11/2024
Publicado: 18/11/2024

ABSTRACT

Tancítaro accounts for 15% of the total avocado production in Michoacán, Mexico, establishing it as the municipality that produces and exports the highest quantity of avocados globally. However, the construction of water dams (pots), fed by precipitation, rivers, springs, and wells predominantly for the irrigation of avocado orchards, significantly influences local ecosystems. Given that this water-primarily originates from rainfall, it is considered freely accessible and is thus excluded from the production costs. Nonetheless, in a hypothetical scenario where this water is not to be quantified, the question arises regarding the financial implications of the retained water. This study aimed to estimate the volume of water retained and ascertain its associated cost. The methodology employed Geographic Information Systems and the development of a script in RStudio to compute the water volume and then estimate its economic value through opportunity cost scenarios. The results indicated that the cost of water constitutes approximately 50% of the total income generated from the cultivation of the irrigated area. These costs, however, remain hidden, as the price competitiveness of avocado cultivation may be jeopardized when such factors are considered.

Keywords: agricultural exports, economic valuation of water, Geographic Information Systems, water dams

RESUMEN

Tancítaro aporta el 15% de la producción total de aguacate del estado de Michoacán (México), esto lo convierte en el municipio que más produce y exporta aguacate del mundo. Sin embargo, la construcción de represas de agua (hoyas de agua), que son llenadas a partir de precipitaciones, ríos, manantiales y pozos; cuyo propósito es el regadío de los huertos de aguacate impactan significativamente en los ecosistemas locales. Por ser agua proveniente principalmente de la lluvia, se considera como de libre acceso. Por lo tanto, no se incorpora en los costos de producción, sin embargo, en caso hipotético de que se cuantificara ¿Cuál sería el costo del agua retenida? El objetivo de la presente investigación fue estimar el volumen de agua que se retiene y estimar su costo. La metodología consideró los Sistemas de Información Geográfica y la confección de un "script" en RStudio para calcular el volumen de agua y posterior a ello, se estimó el valor económico a través de escenarios de costo de oportunidad. Los resultados revelaron que el costo del agua representa cerca de 50% de los ingresos totales del cultivo de la superficie de riego, de manera que estos costos se ocultan, ya que de tomarse en cuenta la competitividad por precio del cultivo de aguacate podría verse afectada.

Palabras clave: exportaciones agrícolas, hoyas de agua, Sistemas de Información Geográfica, valoración económica del agua

RESUMO

Tancítaro contribui com 15% da produção total de abacate do estado de Michoacán (México), o que o torna o município que mais produz e exporta abacate no mundo. Porém, a construção de barragens de água (bacias hidrográficas) que são abastecidas a partir de: precipitações, rios, nascentes e poços. Seu objetivo é irrigar pomares de abacate, o que impacta significativamente os ecossistemas locais. Como a água provém principalmente da chuva, é considerada de livre acesso. Portanto, não está incorporado aos custos de produção, porém, no caso hipotético de que fosse quantificado, qual seria o custo da água retida? O objetivo deste estudo foi estimar o volume de água retido e estimar seu custo. A metodologia utilizou Sistemas de Informação Geográfica e a elaboração de um “roteiro” no RStudio, para calcular o volume de água e, em seguida, estimou-se o valor econômico através de cenários de custos de oportunidade. Os resultados revelaram que o custo da água representa perto de 50% do rendimento total do cultivo superficial de irrigação, pelo que estes custos ficam ocultos, pois se for tida em conta a competitividade de preços da cultura do abacate, esta poderá ser afetada.

Palavras chave: exportações agrícolas, potes de água, Sistemas de Informação Geográfica, valorização económica da água

INTRODUCTION

Approximately 46% of the planet's livable land is dedicated to the agriculture Food and Agriculture Organization (2023), this activity contributes to the economy by generating jobs in society, as well as to human life and food. However, it also generates impacts on the natural environment and ecosystems (Arisoy, 2020). The market system promotes the competitiveness of the global agricultural sector, resulting in the practice of different strategies from differentiation, organic production, comparative advantages, and competitive advantages to maintain and increase its market (Ueasangkomsate et al., 2018). However, some factors are driving the competitiveness of organic agriculture, such as subsidies (Kujala et al., 2022). This situation has reconfigured production systems, focusing supply on external markets and seeking greater profitability, while supply focuses on highly productive regions (Badgley et al., 2007).

This has led to a growing and intense global competitiveness, which in most cases is detrimental to the well-being of the population and the deterioration of ecosystems; this is the hidden face of competitiveness, which is not only seen in the primary sector but also other sectors, such as textile production (Wardhani and Nugraheni, 2019). Some studies found that avocados have a water footprint estimated at 849 m^3 of water consumption per ton (Sommaruga and Eldridge, 2021). Although there are economic benefits to the avocado industry, there are negative impacts on biodiversity, hydrological systems, and forest fragmentation due to the expansion of avocado production frontiers and the virtual water from countries with chronic water stress toward more water-rich regions (Caro et al., 2021; Denvir et al., 2021). In this sense, agriculture has been encouraged by the growing world population, the efficiency of transport systems, and the connectivity of supply chains (Sánchez et al., 2021). The crops of high demand and price stand out, including the Mexican avocado (Persea americana var. Hass) (Sibulali, 2020).

Since the end of 2022, a significant decrease in the price of the avocado began due to the increase in world production (Chaparro and Janzen, 2022) and the characteristics of the value chain, such as modular and hierarchical governance in imitation learning between participants (Reyes-Gómez et al., 2023) maintaining an organization, institutional articulation, and cooperation that has been consolidated over 20 years, in this regard, Mexico stands as the foremost producer of avocados, contributing up to 45% of the global market and The avocado from Michoacan contributes 90% of national exports. (Cruz-López et al., 2022; Olivares-Martínez et al., 2023). In the year 2022, the cultivated area accounted for 70.6% of the national total, yielding a production of 672,149 tons, which constitutes 88% of the national total. SIAP, [Servicio de Información Agroalimentaria y Pesquera] 2022. The fruit is produced under intensive production systems, which use large amounts of water, agrochemicals, and expansion of cultivation to forest areas through deforestation, which is unsustainable (Denvir et al., 2021; Cho et al., 2021). Of avocado agriculture in Michoacán, 63% of the surface is temporary, and 37% has irrigation (SIAP, 2023).

Of the total area that Michoacán allocates to avocado, Tancítaro represents 19% (SIAP, 2023). The irrigation area is 15%, and the rest is temporary (85%) (SIAP, 2022); however, these data do not report irrigation with dams; it is assumed there is a larger irrigation area, as demonstrated in this article. Avocado growers have significantly increased their use of dams to retain rainwater, a freely available resource without ownership boundaries. One of the transcendent aspects of damming water is that, in the last ten years, they have altered the hydrogeographic system of the basin (Ruíz-Sevilla and Ortiz-Paniagua, 2021). There is a lack of understanding regarding how water is retained in dams, the ecological processes involved, and the significance of this retention. The importance of this study lies in estimating the volume of water and its economic value under specific assumptions. However, the ecological implications of this process still require further research.

Avocado production has been associated with significant water conflicts and negative environmental and socio-economic impacts on local communities in the main production areas. Authorities, policymakers, and small producers must project future water scarcity to evaluate the critical capacity and optimal levels of avocado production (Sommaruga and Eldridge, 2021). So, ignoring the amount of water that is used and will be used in the future for avocado exports constitutes a risk for the regional economy (Caro et al., 2021). Water, an indispensable resource for ecological and socio-economic systems, provides ecosystem services based on its different uses and can be classified into intermediate or final services (Fisher & Turner, 2008; Gain et al., 2021). The efficient management of water is crucial for achieving water security. Ecosystems' well-being depends on how water is managed for agriculture, presenting a significant social challenge across various scales (Mishra, et al., 2021).

Conceiving water from this perspective, there are elements to attribute an economic value, which would otherwise remain hidden when considering it as a free input, as well as to decide the appropriate policies to achieve this objective and monitor the available indicators (Labandeira et al., 2007). So, it seeks to integrate a scheme with a vision of supply and demand, quantity and quality that considers these ecosystem services' economic and social valuation to design incentives that promote regional sustainability based on information (Escobar and Gómez, 2007). Economic valuation identifies whether the prices in the market are subsidized or covered by the producers (Martínez-Luna et al., 2021). This reveals the existence of hidden costs, which do not incentivize the farmer’s competitiveness.

Implications of Avocado Production

Water is, in many regions of the world, a scarce and precious resource; efficient management and allocation must be incorporated into the study of rational decisions to promote efficient use both physically and economically because there is rarely clarity in this relationship in agricultural irrigation systems (Cai et al., 2003) At the same time, a correlation between farming areas and water reduction in China has been discovered a redistribution of water attributable to agricultural management (Zhongwei et al., 2024). In this way, the cost of water as an input is not part of the production cost structure. Therefore, market signals are incomplete; knowing this water cost requires indirect estimates (Pulido-Velázquez et al., 2014). In addition, the estimated cost does not necessarily consider the opportunity costs of use; even ignoring deficit irrigation can lead to a significant underestimation of crop profitability and water rates and incentives for savings. Some studies do not incorporate deficit irrigation, demonstrating a more inelastic demand for water for irrigation (Sapino et al., 2022). Pots used for irrigation in the study region would have an analogous effect.

In Tancítaro and the avocado-producing region, the socioeconomic, physical, and ecological effects of avocado production can be appreciated. On the one hand, land use change has advanced significantly, and with it, erosion, landscape modification, reduction of biodiversity and soil chemical properties (Denvir et al., 2021; Pérez-Solache et al., 2023; Vega-Agavo et al., 2021), illegal logging, conflicts in land ownership, deforestation to inadequate and socially marginalized areas, undermining livelihoods and increasing their vulnerability to climatic events (Ramírez-Mejía et al., 2022) and crop changeover (Bachmann-Fuentes, 2021). It has also increased the use of agrochemicals for cultivation, eliminating beneficial organisms for the soil and the plant itself (Pérez-Solache et al., 2023; Gutierrez et al., 2015) in addition to increasing the pollution and eutrophication of water bodies and increasing diseases in communities that depend on water that has been contaminated (Hernández-Morales et al., 2014).

The production of avocados involves a water footprint, which represents the volume of water used per unit of product and has a significant environmental impact on the water sector (Hoekstra et al., 2011). In the area near Tancítaro, specifically in Ziracuaretiro, the water footprint for rainfed avocado cultivation has been estimated at 839.03 m³ per ton. At the same time, irrigation increases to 2,355.80 m³ per ton, resulting in an average of 1,597.41 m³ per ton. These figures indicate that the water usage in this region is 1.5 times higher than the global average water footprint (Fuerte-Velázquez and Gómez-Tagle, 2024).

Regarding socioeconomic aspects, avocado cultivation in the Tancítaro region has promoted the growth of criminal cells that provide "protection" in the illegal logging of the forest, forcing the session of land rights and burning large tracts of forest (Ávila, 2014) as well as rent seekers who extort avocado producers or sellers (Aguirre and Gómez, 2020). This is reflected in social conflicts and insecurity that are mainly due to the economic diversification of the drug cartels, which have found avocado production a permanent and secure source of income. This situation has increased violence because the purpose is to control the avocado zone (Linthicum, 2019). If this is not paid attention to, the water balance can lead to a lack of guarantee for the water supply in the future, which can be exacerbated by climate change (Figueroa et al., 2023).

In Michoacán, notable examples of forest governance emerge, which, owing to the active participation of the community, have effectively mitigated the encroachment of external groups. This has facilitated a more sustainable management of the forest. Although there is potential for avocado cultivation, the community continues to prioritize forest management, partly due to the recognition that a transition from forest to avocado production may engender internal divisions within the community (Rosales et al., 2023; Castro et al., 2012; Juarez, 2024). Concurrently, the region is becoming increasingly vulnerable due to its significant dependence on revenue generated by the avocado industry. Consequently, there is an urgent need for economic diversification, and alterations in agro-industrial avocado production should be earnestly contemplated by both regional and federal governments, as well as by society at large (De la Vega-Rivera and Merino-Pérez, 2021).

Regarding socioeconomic aspects, avocado cultivation in the Tancítaro region has promoted the growth of criminal cells that provide "protection" in the illegal logging of the forest, forcing the session of land rights and burning large tracts of forest (Ávila, 2014) As well as rent seekers who extort avocado producers or sellers (Aguirre and Gómez, 2020). This is reflected in social conflicts and insecurity that are mainly due to the economic diversification of the drug cartels, which have found avocado production a permanent and secure source of income. This situation has increased violence because the purpose is to control the avocado zone (Linthicum, 2019). Michoacán represents a distinct case; however, the production of avocados has resulted in social conflicts and considerable environmental consequences in Salamina, Colombia. Although it has emerged as a substantial economic driver, it has simultaneously intensified social grievances and inequalities within local communities (Suárez, 2024). Likewise, comparable outcomes are observed in the hyper-arid coastal regions of Peru; however, the situation is more critical concerning water availability and the extension of avocado agriculture. (Esteve-Llorens et al., 2022).

The expansion of avocado cultivation has implied greater water consumption, and the strategy followed by producers is to dam it. How much water is dammed for irrigation of avocado production in Tancítaro, Michoacan? What is the competitive advantage in terms of production costs granted by damming such water? Knowing this volume is crucial because it allows us to measure the phenomenon, its possible ecological implications (water scarcity for the environment), and social (latent conflicts). At the same time, it allows us to identify the hidden costs of water as an input and its contribution to competitiveness by estimating hidden costs. The estimation and internalization of hidden costs (social and ecological) are fundamental processes to promote sustainable agriculture (He et al., 2021).

The uneven water storage has caused tension within the communities, leading to conflicts between residents and the growers. During the last dry season, organized community members dismantled multiple water reservoirs constructed to irrigate avocado orchards in the Salvador Escalante and Villa Madero municipalities. This was in response to the severe water scarcity experienced in the region (Solís, 2024).

Water for irrigation represents 72% of world freshwater extractions and constitutes an ecosystem service, and the allocation of economic value to this depends on five factors: quality, location, reliability of access, time of availability, and quantity (Koo-Oshima et al., 2024). Externalities on use must also be considered (Labandeira et al., 2007) and its taxonomy as scale, assignability, enforceability, and tradeability of property rights (Paniagua and Rayamajhee, 2020). This sense of water for the ecosystem or environment is not contemplated when the flow is diverted or hoarded in cisterns. Posing any of these circumstances as a problem, the economic value of the water ecosystem service offers a perspective to design management strategies and instruments as incentives for rational and efficient use in the agricultural sector. Water offers several ecosystem services and constitutes a drill to total services. An important study by Costanza et al., (1997) estimated the annual value of ecosystem services at US $54 trillion (10^12).

The present research has two sequential objectives: 1) to estimate the volume of water retained for avocado irrigation and, from the results, 2) to assess the cost of this water as an input. The hypothesis is that the water retained by not being considered in the costs of avocado production as an input gives a competitive advantage reflected in the gross income and is significant for the producers of Tancítaro. The article is organized as follows: first, it addresses physiographic aspects and characteristics of the study area, then continues with theoretical elements and the state of the art in water, environmental economics, and competitiveness. Next, the methodology to achieve the objectives is addressed to show the study's results, discussion, and conclusions.

METHODS, TECHNIQUES, AND INSTRUMENTS

Geographical delimitation of the study area

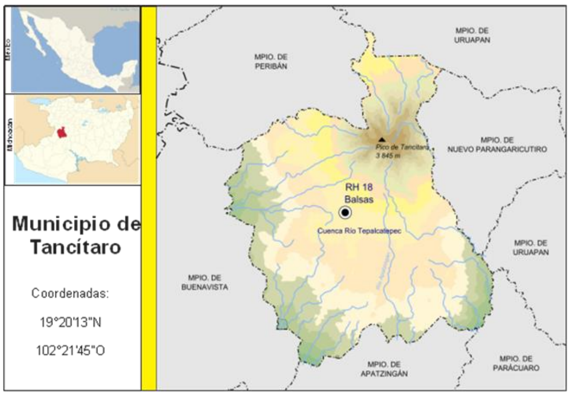
The environmental characteristics of the municipality make the cultivation of avocado in this region one of the most successful crops, being the combination of physical and environmental factors that determine the potentiality of an area for a given plant species so that the agroclimatic characterizations that play a determining role in planning activities and decision-making for the implementation of agricultural programs (Garrido-Ramírez, 2018). Tancítaro is part of the well-known "avocado strip, " an agroecological zoning with similar characteristics related to its suitability and potential to produce hass avocado covering other municipalities.

Tancítaro is supplied by 16 basins that make up the Pico de Tancítaro, and these depend on the population, see Figure 1 (Fuentes-Junco, 2011, p. 33). This municipality is located between the minimum UTM coordinates: X = 762557.59 and Y = 2122112.02 and maximum: X = 795089.85 and Y = 2162107.23, has a minimum altitude of 820 MAMSL and a maximum of 3,840 MAMSL. It comprises an area of 715,056 km² (71,505.68 ha), representing 1.22% of the state's total and a population of 29,414 inhabitants (Instituto Nacional de Estadística y Geografía [INEGI], 2015).

At the highest municipal elevation lies the Tancítaro Peak, established as Flora and Fauna Protection Area, (forward FFPA), recognized as an area of importance for the conservation of birds (AICA number C05) and Priority Terrestrial Region number 114 (RTP-114). A place where there are forests of high-altitude pine, oyamels, oaks, pines of various species, and pastures, as well as temporary agriculture in the low areas. It is also considered the most critical avocado-producing area in the country. It is part of the so-called "Avocado Strip," whose forms of agricultural production demand a large amount of water (Fuentes-Junco, 2011).

This FFPA covers the municipalities of Tancítaro, Periban de Ramos, Nuevo Parangaricutiro, and Uruapan, decreed as national parks on July 27, 1940. It is currently under the category of "Flora and Fauna Protection Area (FFPA)”, since august 19, 2009, management to the National Commission of Protected Natural Areas (CONANP Spanish abbreviature) Region: West and Central Pacific and has a total area of 23,405.92 ha (234.0592 km^2) (DOF [Diario Oficial de la Federación], 2013). Various pines, oaks, cedars, and firs represent the vegetation. At the same time, several mammals, birds, amphibians, and various endemic species are in the fauna (CONANP, 2022). The agro-climatic and physical characteristics of the study area have supported the successful production of avocados in this important area.

Figure 1. *Geographic location of Tancítaro, Mexico.*



Source: Own elaboration based on INEGI (2014 and 2015).

The combination of these environmental factors has resulted in the capture of water, which, as an ecosystem service in the region, has generated the conditions that have allowed for enhanced avocado production. Avocado cultivation is one of the most successful in the world because of its high profitability.

Construction of dam map to store water in Tancítaro

A base map was built in UTM coordinates with a Transverse Mercer Projection located in zone thirteen, WGS_1984_UTM_Zone_13N, to count the dams that dam water in the municipality. From the vector data, the primary inputs were formed: a TIN (Irregular Networks of Triangles) and a Digital Elevation Model (DEM) that used altimetric information, scale 1:50,000, with a resolution of 10x10m/ cell (Cell Size X, Y).

To determine the number of dams, a base map was made with the location and dimensions of the dams (dams) by visual interpretation of satellite images initially using Google Earth Pro *V. 7.3.3.7721 (64-bit) software that uses* Google Earth Image images [Google Earth Pro (2021) CNES/Airbus 2020 and Maxar Technologies 2020] before coupling of the municipal boundary and digitized under a grid of 1 x 1 km, This was done at an eye height of between 65.61 km to 500 m to obtain the highest possible resolution. The reservoirs detected for surface and rainwater collection (dams or pots) were digitized with these elements. This program allows the 3D visualization of physical features in the territory and provides advanced tools for measuring distances and areas. It also allows you to couple and visualize your data with base cartography, supporting three-dimensional geospatial data through files with *kml* extension.

The vector data that were used to couple to the satellite image were obtained from the charts E13B28, E13B29, E13B38, E13B39, E13B48, and E13B49 of the (INEGI, 2014) scale 1:50,000 representing the main features such as localities, springs, primary runoff, and altitudinal data. This procedure allowed locating the most significant number of dams up to 3.5m x 3.5m (12.25 m^2) near the localities and communication routes, in addition to the better observance of them and thus their subsequent export to ArcGIS 10.5 (McGwire et al., 1996; Haynes, 2020). Then, a new project was carried out within the ArcGIS 10.5 software, configured with the coordinates of the area, and the native Google Earth file (*.kml) was imported. With it, attributes were assigned to the tables, providing information on areas, perimeters, and centroids for use (Alonso, 2015).

Once digitized, they were classified according to the surface, considering the construction specifications of water dams referred to in the technical sheets of Ministry of Agriculture, Livestock, Rural Development, Fisheries and Food (Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación [SAGARPA]) (SAGARPA, 2017a and SAGARPA, 2017b). In this way, the volume estimation was carried out according to the formula presented by the (United States Department of Agriculture, 1997) and the script formulation described in the software. "RStudio"[1]; using next formula: V=(A+B+C) *D (1).

Where:
V = Excavation volume
A = Excavation area at surface level
B = Excavation area at half the depth
C = Excavation area at maximum depth
D = Maximum depth

Once the surfaces and sizes were identified, a classification was made by ranges in six classes ranging from 12 m^2 to more than 10 000 m^2.

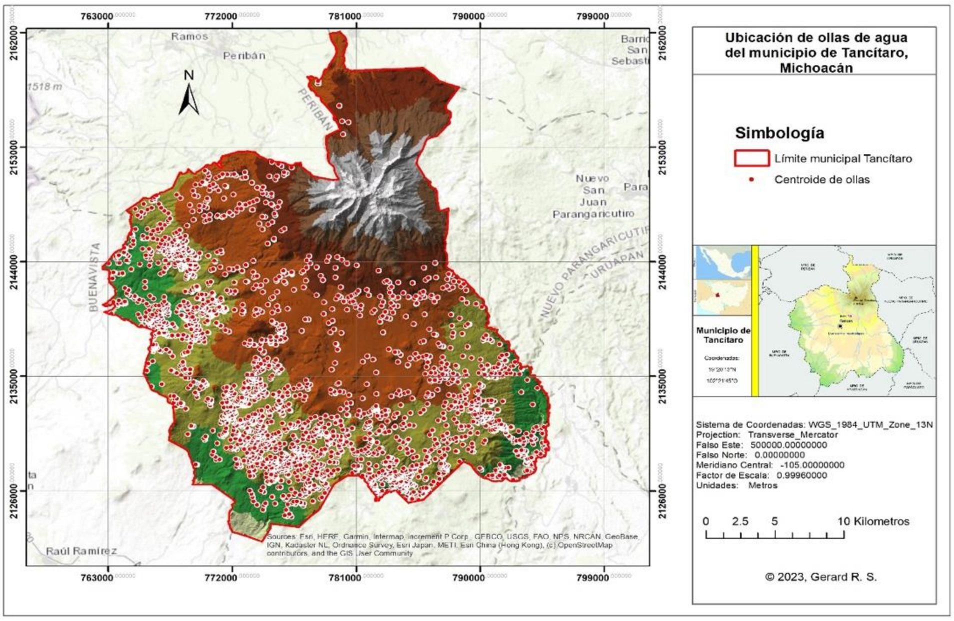
[1] *Details about script: RStudio 2024.04.2+764 "Chocolate Cosmos" Release (e4392fc9ddc21961fd1d0efd47484b43f07a4177, 2024-06-05) for Windows. zilla/5.0 (Windows NT 10.0; Win64; x64) AppleWebKit/537.36 (KHTML, like Gecko) RStudio/2024.04.2+764 Chrome/120.0.6099.291 Electron/28.3.1 Safari/537.36, Quarto 1.4. 555.RS.*

RESULTS AND DISCUSSION

Estimation of the amount of water dammed in Tancítaro

Figure 2 represents the record of 2,900 water dams located and distributed in the municipality of Tancítaro, which have different dimensions and capacities. With this classification by surface (m^2), it was more affordable to determine the depth allowing us to estimate the volume (m^3). *Figure 3* shows that taking advantage of a cineritic cone, it is coated with a geomembrane for water storage as one of the liquid collection techniques. The most common is excavating the surface well lined with plastic geomembrane. Based on satellite imagery and field visits, dam sizes were classified.

Figure 2. *Distribution of rainwater catchment dams in Tancítaro, 2021.*



Source: Own elaboration, based on INEGI (2014) and Google Earth Pro (2021).

The dams were classified into six different sizes (Table 2) in which the "tiny" dams of between 12 m^2 and 163 m^2 are the ones that most dominate the territory, being those of 1,626 m^2 and up to more than 10,000 m^2 the ones with the lowest frequency of appearance and that have been built taking advantage of the geomorphology of the terrain. The total area is 163.45 hectares, where approximately 9,757,054.01 m^3 (9,757.05 hm^3) of water are collected, which can be compared to 650,470.27 water tankers with a capacity of 15 000 liters each. For example, see Figure 3, the angles and scales of a dam of water waterproofed with geomembrane taking advantage of the geomorphology of the land, whose size reaches 1.51 ha, and its approximate volume is 121,202.58 m^3.

Figure 3. *Angles and scales of a waterproofed water dam.*

Source: Google Earth Pro (2023) and Ruíz-Sevilla and Ortiz-Paniagua (2021).

Table 1. *Classification of dams according to surface area.*

Class	Classification Tuition (m^2)	Water dams (dams) quantity	Class	Water volume (m^3)
A	12 – 163	779	Very small	156,362.032
B	163.1 – 325.0	713	Small	507,216.108
C	325.1 – 652.0	717	Medium	1,655,920.056
D	652.1 – 1626.0	510	Large	3,053,930.352
E	1,626 and more	181	Very large	4,383,625.464
	TOTAL	**2,900**		**9,757,054.013**

Source: Own elaboration.

Estimation of the economic value of water dammed in Tancítaro

Lake Cuitzeo contains 920 hm^3, Lake Patzcuaro contains 220 hm^3, and Lake Zirahuén 208.22 hm^3 (Secretaría de Medio Ambiente y Recursos Naturales, 2023). The volume of water dammed in the municipality of Tancítaro would be equivalent to approximately 4.68% of the volume of water from Lake Zirahuén to have the perspective in magnitude. As shown in table 2 and taking as an example of estimation, only Class A (very small) would need 10,424.14 water tankers (pipes) with a capacity of 15 thousand liters per unit to store the water contained in the total dams used for irrigation in the dry season (February, March, April, and May). If water were acquired at a market price of USD 118.00) per five m^3, size of a tanker truck o cistern truck, it would reach a cost of $20,848,270.93 (Twenty million eight hundred forty-eight thousand two hundred and seventy and ninety-three cents) (Mexican pesos equivalent to USD $1,158,237.2) renting the transport of this water to irrigate the orchards during the dry season.

By 2022, there was a planted area of 24,805 hectares in the municipality of Tancítaro (SIAP, 2023), and of these, 3,815 hectares corresponded to irrigation. With this information and considering that an average cultivated hectare consumes around 9,717.90 liters per hectare per day (Gómez-Tagle and Morales, 2018) would imply the use of 37,073,788.50 liters of water (37,073.788 m^3) for a total production of 41,437 tons equivalent to a production value of 950,954.58 thousand pesos; (USD $52,830,810.0).

Assuming a four-month dry season, from February to May, using weekly irrigation would require 44,889 tanker trucks, costing 2,000 pesos (USD 118) each. So, the simulated expenditure on water of 9.36% of the total value of avocado production is equivalent to 455 million pesos (USD $26.7 million) of the value of irrigation avocado production and 1.8% (88.9 million pesos). It refers to the value of the production of 2021, which amounted to 4,863,531,060.00 Mexican pesos ($286 million USD).

Therefore, considering the cost of water at market price would reduce 9.36% of the total income of Tancítaro avocado producers, specifically 48% (455/950) of the income of avocado producers who use irrigation. So, the conditions of competitiveness would change significantly if the costs were not considered or hidden costs for irrigation with water damming were contemplated.

The production model used in Michoacan, known as primary export, is based on utilizing its natural resources as a competitive advantage (McKay *et al.,* 2021). The agricultural export sector heavily relies on water and soil, taking advantage of favorable environmental conditions. With an intense concentration and reconfiguration in terms of its specialization, Michoacán is highly specialized (Vargas-Canales *et al.,* 2020).

The specific type of market entry represented by this form of engagement in international markets has proven successful in exporting various crops in different regions of Mexico (Vargas-Canales *et al.,* 2020). However, with the paramount importance of water as an input, the proliferation of water reservoirs for retention has grown significantly. This growth shows signs of disturbances in the hydrological cycle, leading to an increased focus on avocado cultivation and consequently resulting in monoculture in the region. This monoculture negatively affects water retention, biodiversity, and the regional microclimate (Ruíz-Sevilla and Ortiz-Paniagua, 2021).

The specialization has led to increased regional wealth, but it has not translated into improved regional welfare levels due to unequal distribution. There has been a significant impact on water extraction, with virtual water trade growing rapidly and a notable increase in international avocado trade. Specifically, the global virtual water trade of avocados increased from 408 mm^3 to 2238 mm^3 between 2000 and 2016, in line with the rise in international trade volume from 0.4 Mt to 1.9 Mt over the same period (Caro et al*.,* 2021).

Understanding the quantity of retained water used to irrigate avocado crops is an essential factor for effectively managing growth, water allocation, and identifying environmentally friendly alternatives. Additionally, it provides valuable insight into the economic impact on the competitiveness of the crop. The availability and management of water are crucial for economic and social development, especially in regions where agriculture is a significant industry. One such example is the municipality of Tancítaro in Michoacán, Mexico. The estimations reveal a significant volume of 9,757,054.01 m^3 of dammed water in Tancítaro, a vital resource for agricultural production, particularly avocado farming. This region is known for its abundant water supply, with 30 million m^3 available annually. This plentiful water supply supports agricultural activities and domestic use by the municipality's inhabitants (Fuentes and Bocco, 2003).

Despite Mexico's seemingly plentiful water resources, the water poverty index (HPI) analysis shows that the country faces significant challenges compared to other nations. Mexico's HPI is the lowest, indicating a high-water poverty level. This index comprises five indicators: resources, Use, Access, Capacity, and Environment. It reflects the limitations in equitable and sustainable access to water (Olivas and Camberos, 2021).

Please note the study's limitations: 1) The study did not account for other costs such as water use or storage. 2) Field verification of the depth and size of a representative dam sample was impossible due to the region's security conditions. 3) More field verification with producers is needed to determine the cost of water for a representative sample of producers, as well as the cost of the tanker truck at different points of the basin.

The paradox of Tancítaro is evident in its abundant water resources, yet its population still grapples with poverty. This underscores the challenges of managing and distributing resources equitably. While the water available in the region could support agricultural production and spur economic growth, its potential is limited due to ineffective water management policies and inadequate infrastructure. Furthermore, the significant cost of water in the market and its impact on the competitiveness of local producers must be addressed. Economic analysis indicates that if hidden water costs are reflected in market prices, the profitability of avocado cultivation could be severely affected.

Other studies indicate that more efficient irrigation practices can be implemented for avocados. However, this may result in specific effects, such as reduced yield, in exchange for alleviating water stress. Consequently, the authors refer to deficit irrigation as a potential alternative for conserving water and achieving environmental benefits in avocado cultivation, albeit with acceptable yield reductions (Cárceles *et al.*, 2023). This suggests that there are alternatives to minimize water retention in pots. Nevertheless, these techniques must be widely disseminated. These actions could be feasible due to some studies showing that a reduction in the growth of avocado fruit was observed with induced water deficit. Still, the isohydric stomatal behavior of the leaves helped to minimize negative changes in water balance. Also, there was substantial recovery after re-watering; hence, the short-term water stress did not decrease avocado fruit size. Negative impacts might appear if the drought treatment were prolonged (Teruko *et al.,* 2024).

The findings highlight the significance of comprehensive water management that considers not just agricultural requirements but also ecological and social considerations. Unequal access and the uneven distribution of benefits across sectors can exacerbate environmental and social tensions, particularly in neighboring areas that rely on the same water sources, especially for those communities residing at lower elevations (Olivas and Camberos, 2021). It's important to highlight that this study is pioneering in its use of techniques, including the implementation of geographic information systems and the script for measuring the depth of the dams. The study's approach and comparison methods for estimating the monetary value of retained water are also noteworthy.

Meanwhile, a study examined the water footprint of avocado production in Michoacán. The study emphasized the substantial water usage in agriculture, significantly contributing to Mexico's overall water footprint. The research highlighted the significant water footprint of avocado production, underscoring its challenge to water sustainability in the region (Fuerte-Velázquez and Gómez-Tagle, 2024). It is essential to recognize that specific community production models have demonstrated relative success in mitigating the negative environmental and social impacts associated with the crop without necessitating land use changes and with sufficient economic support for implementing appropriate practices. Furthermore, these models have fostered forest conservation (Ramírez *et al*., 2024).

Addressing the challenges of water scarcity requires attention to the water footprint of avocado production and implementing policies promoting sustainable water management. Essential steps include improving infrastructure, enhancing water use efficiency in agriculture, and advocating for sustainable agricultural practices. Collaborative efforts among the government, local communities, and the private sector are crucial for equitable and efficient water resource management (Olivas and Camberos, 2021; Fuerte-Velázquez and Gómez-Tagle, 2024). Emphasizing a holistic approach to water management that considers human and environmental needs is vital for ensuring sustainable development in Mexico.

The issue of ecological degradation and its ramifications on water resources, alongside the societal impacts stemming from avocado production in the region, ought to be regarded as a broader concern that adheres to the dynamics of demand and international markets. Consequently, consumers must also accept responsibility for internalizing externalities (De la Vega-Rivera and Merino-Pérez, 2021) while simultaneously assessing the region's carrying capacities and optimal production levels of avocados.

CONCLUSIONS

In avocado production, water is a fundamental element of social development, and to give continuity and permanence to this activity, it is necessary to guarantee a constant flow and quality of water. However, today, the construction of water dams is a factor that is affecting the ecosystem significantly, which has implications on the hydrological cycle (Ruíz-Sevilla and Ortiz-Paniagua, 2021), climate, aquifer recharge, water stress, and water for other sectors, ecosystems, or domestic use for human populations. That is why studying the implications of water dams is relevant to understanding the magnitude of the phenomenon.

This study estimated the amount of dammed water at 9,757,054,013 m^3, equivalent to approximately 4.68% of the water in Lake Zirahuén. In terms of extension and stored water, this Lake is the third most crucial lake in Michoacan. This estimate used geographic information systems and satellite imagery.

The present study aimed to estimate the volume of water retained in dams for irrigation of avocado orchards, allowing us to know the hidden costs and assign price to water as an input. The main finding of the work reveals that the cost of water as input is equivalent to 48% of the value of irrigation production and 9.36% of the total output (irrigation and temporary) of the municipality of Tancítaro. So, the competitiveness of avocados in this municipality (the largest producer in the world) is based on the availability of water resources. Given its reliance on price elasticity, if a value were placed on water and factored into market prices, it could impact competitiveness. The study implies the need to implement measures for regulating water retention. These measures should encompass a comprehensive framework for ecological considerations and the importance of preventing degradation to safeguard the productive capacities of the ecosystem. Additionally, it is crucial to explore actions aimed at redistributing the gains from exports and averting conflicts related to water usage in the region.

In the social aspect, water disputes can intensify, especially with the lower altitude municipalities that have significant agriculture production and are located at the border to Tancítaro (Buena Vista Tomatlán, Tepalcatepec, Apatzingán, and Parácuaro), giving rise to socio-ecological conflicts that imply the defense or privilege of the resource. The production of avocado in the municipality of Tancítaro is not sustainable because incorporating the water element as one of the inputs to be paid, as is done with light or the salary of day laborers and agrochemicals, among others, it would be observed that it would not be profitable, becoming a product of high economic value that few could pay or have access to generating local and focused wealth.

Water scarcity is a priority situation today that must be addressed through public policies that raise awareness and regulate water use among users. It is, therefore, essential to observe the laws and make the necessary reform proposals to include this type of work that significantly impacts the ecosystem and hydrological cycle. If there is not the organized will and intention of all users to achieve harmony with the environment and thus obtain better goods and services (healthier food, clean water, abundant resources, better use), simply the tendency to impoverishment, social inequality, and a deteriorated ecosystem will be part of the life of the new generations. The extension of avocado cultivation is causing changes in the ecological environment, hydrological balance, and modifications in the use of soil. Authorities and avocado producers must attend to the issue and prevent the consequences as possible from social conflicts regarding access to water.

In Tancítaro, the benefits of successful avocado cultivation have not been distributed equitably, which can be seen in a high percentage of the population living in poverty and organized crime (Aguirre and Gómez, 2020). In the case of water for ecosystems, this is a distant issue in the minds of producers, who are more concerned with short-term profitability, ignoring possible alterations to the hydrological cycle (Ruíz-Sevilla and Ortiz-Paniagua, 2021) because of water retention. Water expenditure indicates avocado water use, as demonstrated (Sommaruga and Eldridge, 2021; Caro *et al.*, 2021). However, when this is put in economic terms, the idea of the magnitude of the savings that producers present and that are not compensated, for example, for ecological restoration and improving the capture of water from ecosystems, becomes more apparent.

BIBLIOGRAPHIC REFERENCES

Aguirre, J. and Gómez, M. (2020). Competitive strategies in contexts of organized crime: the case of the avocado industry in Mexico. *International Journal of Criminal Justice Sciences, 15*(1), 114-126. https://doi:10.5281/zenodo.3822110

Alonso, D. (2015). How to extract kml in Google Earth Pro and import it into QGIS as a shape. *MappingGis.* https://acortar.link/9ci26e

Arisoy, H. (2020). Impact of agricultural supports on the competitiveness of agricultural products. *Agricultural Economics–Czech*, *66*, 286–295. https://doi:10.17221/416/2019-AGRICECON

Ávila, G. P. (2014). Evaluación social regional. Sistema de microcuencas prioritarias Pátzcuaro-Zirahuén. En *Proyecto de bosques y cambio climático.* SEMARNAT-UNAM. https://acortar.link/MumBFw

Badgley, C., Moghtader, J., Quintero, E., Zakem, E., Chappell, M. J., Avilés-Vázquez, K., Samulon, A. and Perfecto, I. (2007). Organic agriculture and the global food supply. *Renewable Agriculture and Food Systems*, *22*(2), 86–108. https://doi:10.1017/s1742170507001640

Bachmann-Fuentes, R. I. (2021). La inseguridad alimentaria y la tragedia del campo en México: consecuencias de las políticas agrícolas neoliberales. *Espacio Regional. Revista de Estudios Sociales*, *1*(11), 89-108. https://acortar.link/7080Ej

Cai, X. M., Rosegrant, M. W., and Ringler, C. (2003). Physical and economic efficiency of water use in the river basin: Implications for efficient water management. Water *Resources Research*, *39*(1), 1-12. https://doi.org/10.1029/2001WR000748

Cárceles R. B., Durán Z. V. H., Franco T. D., Cuadros T. S., Sacristan P. C., García-Tejero I. F. (2023). Irrigation Alternatives for Avocado (Persea americana Mill.) in the Mediterranean Subtropical Region in the Context of Climate Change: A Review. *Agriculture, 13*(5), 1049. https://doi.org/10.3390/agriculture13051049

Caro, D. A., Alessandrini, F., Sporchia and Borghesi, S. (2021). Global virtual water trade of avocado. *Journal of Cleaner Production*, *285*, e124917. https://doi.org/10.1016/j.jclepro.2020.124917

Chaparro, G. N., and Janzen, J. (2022) Guacamole is Back: Seasonal Production from South America Lowered Avocado Prices. *Farmdoc Daily,* (12), 196. https://acortar.link/bK0k51

Cho, K., Goldstein, B., Gounaridis, D., Newell, J. P. (2021). Where does your guacamole come from? Detecting deforestation associated with the export of avocados from Mexico to the United States. *Journal of Environmental Management*, 278(1), 111482. https://doi.org/10.1016/j.jenvman.2020.111482

Comisión Nacional de Áreas Naturales Protegidas. (2022). *Área Natural Protegida, Pico de Tancítaro. Sistema de Información, Monitoreo y Evaluación*. https://acortar.link/jHs63g

Costanza, R., d'Arge R., de Groot, R., Farber S., Grasso M., y Hannon, B. (1997). The value of the world's ecosystem services and natural capital. *Nature*, 387, 253–260. https://doi.org/10.1038/387253a0

Cruz-López, D. F., Caamal-Cauich, I., Pat-Fernández, V. G., and Reza Salgado, J. (2022). Competitiveness of Mexico's Hass avocado exports in the world market. *Revista Mexicana de Ciencias Agrícolas*, *13*(2), 355–362. https://doi.org/nqcm

De la Vega-Rivera A., and Merino-Pérez, L. (2021). Socio-Environmental Impacts of the Avocado Boom in the Meseta Purépecha, Michoacán, México. *Sustainability, 13*(13), 7247. https://doi.org/10.3390/su13137247

Denvir, A., Arima, E. Y., González-Rodríguez, A., and Young, K. R. (2021). Ecological and human dimensions of avocado expansion in México: Towards supply-chain sustainability. *Ambio*, *51*(1), 152-166. https://doi:10.1007/s13280-021-01538-6

Diario Oficial de la Federación. (2013). *Programa de Manejo del Área de Protección de Flora y Fauna Pico de Tancítaro*. Secretaría de Gobernación. https://acortar.link/18fhXh

Escobar, L. A., and Gómez, A. P. (2007). El valor económico del agua para riego un estudio de valoración contingente. *Ingeniería de Recursos Naturales y del Ambiente*, (6), 16-32. https://acortar.link/1ePKEN

Esteve-Llorens, X., Ita-Nagy, D., Parodi, E., González-García, S., Moreira, M. T., Feijoo, G., and Vázquez-Rowe, I., (2022). The environmental footprint of critical agro-export products in the Peruvian hyper-arid coast is a case study for green asparagus and avocado. *Science of The Total Environment*, *818*, e151686. https://doi.org/10.1016/j.scitotenv.2021.151686

Figueroa, E. J. R., Rentería, E. R., and Martín, P. (2023). La gestión de los recursos hídricos en el municipio de Culiacán, Sinaloa, México. *Estudios Regionales en Economía, Población y Desarrollo, 13*(73). https://doi.org/10.20983/epd.2023.73.1

Fisher, B., and Turner, K. (2008). Ecosystem services: Classification for valuation. *Biological Conservation*, *141*(5), 1167–1169. https://doi.org/10.1016/j.biocon.2008.02.019

Food and Agriculture Organization. (2023). *World food and agriculture. Statistical Yearbook* 2023. https://doi.org/10.4060/cc8166en

Fuentes, J. J., and Bocco, G. (2003). El Agua: dinámica y análisis regional. En A. Velásquez, A. Torres y G. Bocco (Comps.). *Las Enseñanzas de San Juan. Investigación participativa para el manejo integral de recursos naturales* (I Ed., pp. 95-126). Instituto Nacional de Ecología. https://acortar.link/mKua97

Fuentes-Junco, J. J. A. (2011). *Estimación del Recurso Hídrico Superficial en el Pico de Tancítaro, Michoacán: Oferta, Demanda y Escenarios de* Disponibilidad [Tesis de Doctorado, Universidad Nacional Autónoma de México]. https://acortar.link/L2rphR

Fuerte-Velázquez, D. J. and Gómez-Tagle, A. (2024). Water Footprint and Water Sustainability of Agroindustrial Avocado Production in a Warm Tropical Climate Municipality: A Case Study in the Michoacan Avocado Belt in Central México. *Water,* *16*(12), 1719. https://doi.org/10.3390/w16121719

Gain, A. K., Hossain, S., Benson, D., Di Baldassarre, G., Giupponi, C., and Huq, N. (2021). Social-ecological system approaches for water resources management. International Journal of Sustainable Development y World Ecology, *28*(2), 109–124. https://doi.org/gjpsrz

Garrido-Ramírez, E. (2018). Áreas potenciales para el cultivo de Aguacate (Persea americana L.) cultivas "Hass" en el Estado de Guerrero, México. *Agro Productividad*, *6*(5), 52-57. https://acortar.link/ztunSH

Gómez-Tagle, A. and Morales, Ch. R. (November 2018). *Hydrological impact of the green gold (avocado culture) in central Mexico; rainfall partition and water use comparison with native forests*. [Conferece]. Conferencia conjunta de bosques y agua, Valdivia, Chile. https://doi.org.10.13140/RG.2.2.18644.65921

Gutiérrez, G. D. F., Ruíz, M. R. and Xoconoxtle, C. B. (2015). *El estado actual de los cultivos genéticamente modificados en México y su contexto internacional*. Centro de Investigación y de Estudios Avanzados del Instituto Politécnico Nacional. Pp. 190. https://acortar.link/PSv1au

Haynes, K. B. (2020). *The Urban Morphology of Hyderabad, India: A Historical Geographic Analysis* [Theses Masters, Western Michigan University]. https://acortar.link/f5acgt

He, D. C., Ma, Y. L., Li, Z. Z., Zhong, C. S., Cheng, Z.B., and Zhan, J. (2021). Crop Rotation Enhances Agricultural Sustainability: From an Empirical Evaluation of Eco-Economic Benefits in Rice Production. *Agriculture, 11*(2), e91. https://doi.org/10.3390/agriculture11020091

Hernández-Morales, R., Hidalgo-Anguiano, M., Murillo, M. D. R. O., and Ríos, M. S. A. (2014). Factores abióticos que rigen la presencia y permanencia del género Microcystis Kützing ex Lemmermann en un lago tropical profundo. *Biológicas*, *16*(1), 33-42. https://acortar.link/ey0SXD

Hoekstra, A.Y., Chapagain, A.K., Aldaya, M.M., and Mekonnen, M.M. (2011). *The Water Footprint Assessment Manual. Setting the Global Standard.* Earthscan. https://acortar.link/VF7RHO

Instituto Nacional de Estadística y Geografía. (2014). *Conjunto de datos vectoriales de información topográfica. Cartas: E13B28, E13B29, E13B38, E13B39, E13B48 y E13B49 escala 1:50.000 serie III.* https://acortar.link/K8c3rs

Instituto Nacional de Estadística y Geografía. (2015). *Catálogo de claves de entidades federativas, municipios y localidades.* https://acortar.link/1SCdRw

Juarez S., I. (2024). Green Gold: *The Political Ecology of the Avocado Agribusiness in Mexico.* [Thesis Degree of Bachelor, Middlebury College] https://acortar.link/rRR4yK

Koo-Oshima, S., Mejías-Moreno, P., Khazal, K. and Kiersh, B. (2024). Agricultura y desarrollo rural. En: Informe Mundial de las Naciones Unidas sobre el Desarrollo de los Recursos Hídricos 2024. Pp. 31-46. https://doi.org/10.18356/9789233002296c009

Kujala, S., Hakala, O., and Viitaharju, L. (2022). Factors affecting the regional distribution of organic farming, *Journal of Rural Studies, 92*(226-236). https://doi.org/gqk5h4

Labandeira X., J. Carmelo L., and M. X. Vázquez (2007). *Economía Ambiental.* Pearson Educación.

Linthicum, K. (November 2019). Inside the Bloody Cartel War for Mexico's Multibillion-Dollar Avocado Industry. *Los Angeles Times*. https://acortar.link/7irBex

Martínez-Luna, D. Mora-Flores, J., Exebio-García, A., Arana-Coronado,O., and Arjona-Suárez, E. (2021). Valor económico del agua en el Distrito de Riego 100, Alfajayucan, Hidalgo. *Terra Latinoamericana*, *39*. https://doi.org/10.28940/terra.v39i0.544

McGwire, K. C., Estes, J. E., and Star, J. L. (1996). A comparison of maximum likelihood-based supervised classification strategies. *Geocarto International*, *11*(2), 3–13. https://doi.org/crzcjt

McKay, B. M., Fradejas, A. A., and Ezquerro-Cañete, A. (Eds.). (2021). *Agrarian Extractivism in Latin America*. Routledge.

Mishra, B.K., Kumar, P., Saraswat, C., Chakraborty, S., Gautam, A. (2021). Water Security in a Changing Environment: Concept, Challenges and Solutions. *Water* 2021, *13*, 490. https://doi.org/10.3390/w13040490

Olivas, M. J., and Camberos, M. (2021). El índice de pobreza hídrica para México: una comparación con países de la OECD. *Entre Ciencia e Ingeniería*, *15*(29), 54-62. https://doi.org/nqj6

Olivares-Martinez, L.D., Gomez-Tagle, A., Pérez-Salicrup, D.R. (2023). Regional Drivers behind the Burning of Remanent Forests in Michoacán Avocado Belt, Central Mexico. *Fire,* 6, 81. https://doi.org/10.3390/fire6030081

Paniagua, P., Rayamajhee, V. (2023). On the nature and structure of externalities. *Public Choice.* https://doi.org/10.1007/s11127-023-01098-1

Pérez-Solache, A., Vaca-Sánchez, M.S., Maldonado-López, Y., De Faria, M.L., Borges, M.A.Z., Fagundes, M., and Cuevas-Reyes P. (2023). Changes in land use of temperate forests associated to avocado production in Mexico: Impacts on soil properties, plant traits, and insect-plant interactions. *Agricultural Systems,* 204, e103556. https://doi.org/nqj9

Pulido-Velázquez, M., Cabrera, E., and Garrido C., A. (2014). *Economía del agua y gestión de recursos hídricos*. *Ingeniería del Agua*, *18*(1), 99–110. https://doi.org/3qd

Ramírez-Mejía, D., Levers, C. and Mas, J. F. (2022). Spatial patterns and determinants of avocado frontier dynamics in Mexico. *Regional Environmental Change,* 22, (28). https://doi.org/10.1007/s10113-022-01883-6

Ramírez, M. I., Špirić, J., and Orozco-Meléndez, F. (2024). Sustainability of the community model of avocado production in the Monarch Butterfly Biosphere Reserve, Michoacán, México. *GeoJournal, 89*(189). https://doi.org/10.1007/s10708-024-11195-3

Reyes-Gómez, H., Martínez-González, E. G., Aguilar-Ávila, J., and Aguilar Gallegos, N. (2023). Gobernanza de la cadena global de valor del aguacate en México. *Ciencia y Tecnología Agropecuaria*, *24*(2). https://doi.org/10.21930/rcta.vol24_num2_art:3120

Rosales, A. G., León, V. C. I. and Ortiz-Paniagua C. F. (2023). Gobernanza forestal en México desde la perspectiva del análisis estructural. *Regions and Cohesion*, *13*(1), 52-73. https://doi.org/10.3167/reco.2023.130104

Ruíz-Sevilla, G. and Ortiz-Paniagua, C. F. (2021). Implicaciones de la Producción de Aguacate en el Balance Hídrico desde una Perspectiva de los Sistemas de Información Geográfica (SIG), 2011-2019 (2021). *Revista de Investigaciones CIMEXUS, 17*(2), 11-27. https://acortar.link/Dqy7Yy

Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación. (2017a). *Diseño y construcción de ollas de agua* (Segunda Edición).

Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación. (2017b). Diseño y construcción de jagueyes (Segunda Edición).

Sánchez, S. Y., Pérez, C. J. A., Sangroni, L. N., Cruz B. C., and Medina N., Y. E. (2021). Retos actuales de la logística y la cadena de suministro. *Ingeniería Industrial*, *42*(1), 169-184. https://acortar.link/04TQgl

Sapino, F., C. D. Pérez-Blanco, C. Gutiérrez-Martín, A. García-Prats, and M. Pulido-Velázquez. (2022). Influence of crop-water production functions on the expected performance of water pricing policies in irrigated agriculture. *Agricultural Water Management,* 259, e107248. https://doi.org/10.1016/j.agwat.2021.107248

Servicio de Información Agroalimentaria y Pesquera. (2022). *Escenario mensual de productos agroalimentarios (2022)*. https://nube.siap.gob.mx/cierreagricola

Secretaría de Medio Ambiente y Recursos Naturales. (2023). *Área y volumen de almacenamiento de lagos principales.* Recuperado en agosto de 2023 de https://acortar.link/JIdczy

Servicio de Información Agroalimentaria y Pesquera. (2023). *Escenario mensual de productos agroalimentarios (2023)*. https://nube.siap.gob.mx/cierreagricola

Sibulali, A. (2020). *Avocado: Market Intelligence report.* Western Cape Goverment. https://acortar.link/AHtz7z

Solís, A. (2024). Angry farmers in a once-lush Mexican state target avocado orchards that suck up too much water. *Associated Press*. https://acortar.link/L6QoYZ

Sommaruga, R. and Eldridge, H.M. (2021). Avocado Production: Water Footprint and Socio-economic Implications. *EuroChoices*, *20*(2), 48-53. https://doi.org/h3nf

Suárez, A. (2024). Critical overview of the expansion of Hass avocado plantations in Salamina, northern Caldas, Colombia. *Journal of Land Use Science*, *19*(1), 230-238. https://doi.org/nqr9

Teruko, K., Gould, N., Campbell, D. and Clearwater, M. J. (2024). Clearwater, Isohydric stomatal behaviour alters fruit vascular flows and minimizes fruit size reductions in drought-stressed 'Hass' avocado (*Persea americana* Mill.). *Annals of Botany*, *133*(7), 969-982. https://doi.org/gt4j5c

Ueasangkomsate, P., Suthiwartnarueput, K., and Chaveesuk, R. (2018). Understanding Competitive Advantage of Organic Agriculture through the Natural-Resource-Based View: Case Studies of Three Organic Rice Producer Networks. *Thammasat Review*, *21*(2), 179-200. https://acortar.link/XxOlLj

United States Department of Agriculture. (1997). *Ponds planning, design, construction.* https://acortar.link/S5TCmA

Vargas-Canales, J. M., Carbajal-Flores, G., Bustamante-Lara, T. I., Camacho-Vera, J. H., Fresnedo-Ramírez, J., Palacios-Rangel, M. I., and Rodríguez-Haros, B. (2020). Impact of the Market on the Specialization and Competitiveness of Avocado Production in Mexico. *International Journal of Fruit Science*, *20*(sup3), S1942-S1958. https://doi.org/nqsd

Vega-Agavo, M. I., Suazo-Ortuño, I., Lopez-Toledo, L., Gómez-Tagle, A., Sillero, N., Pineda-López, R., and Alvarado-Díaz, J. (2021). Influence of avocado orchard landscapes on amphibians and reptiles in the trans-Mexican volcanic belt. *Biotropica, 53*(6), 1631-1645. https://doi.org/10.1111/btp.13011

Wardhani, E. and Nugraheni, S. (2019). Competitiveness with (out) sacrificing environment: Estimating economic cost of groundwater pollution. In A. G. Abdullah, I. Widiaty and C. Abdullah (Eds), *Global Competitiveness: Business Transformation in the Digital Era (pp. 81-84).* Taylor and Francis Group. https://doi.org/nqsk

Zhongwei, H., Xing, Y., Peng, J., Siao S., and Leng, G. (2024). Shifts in trends and correlation of water scarcity and productivity over China. *Journal of Hydrology*, 635, e131187. https://doi.org/10.1016/j.jhydrol.2024.131187