Agroforestry as an approach to reduce the water footprint in a profitable way in the Maule Region, Chile

Study from an agroforestry case study to measure the potential for water savings in the watersheds of the Maule Region

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Abstract

The food system is strongly related to the pressure of our planetary boundaries, being responsible for a significant amount of greenhouse gas emissions, land use change, biodiversity loss, biochemical flows, and freshwater use. The dominant system in food production is monoculture, using agrochemicals and motorized equipment. However, monocultures are not the only way to produce food. Agroforestry can reach similar production levels but with environmental benefits such as enhancing biodiversity, reducing erosion, increasing soil carbon sequestration, and reducing agrochemicals pollution. Agroforestry also has a water saving potential, by reduction of runoff and improvement in water infiltration in the soil. The deep roots of trees can access deeper water and redistribute it to the upper layers. Additionally, the increase of shade in the system increases soil moisture and decreases soil evaporation and crop transpiration.

In the Maule Region, Chile, agriculture is strongly focused on fruit monocultures and is the region that consumes most of the fresh water in the country. The region has been affected by a prolonged drought, with an uninterrupted sequence of dry years since 2010. Climate projections estimate that it will get worse in the future, with an increase in temperature and a reduction in precipitation. To address this complex scenario of water scarcity in agriculture, a solution could be to move from conventional agriculture to agroforestry. This study seeks to answer the research question: What is the potential for water savings in the Maule watersheds, moving from conventional agriculture to agroforestry without affecting economic returns?

The study uses the agroforestry project "Huertas A Deo" (HAD) as a case study to analyze the productivity of the agroforestry system, calculate the water footprint, and perform economic and spatial analyses. The results show that the agroforestry system could be highly productive and have a lower water consumption per hectare compared to conventional monocultures. Also, it is economically competitive with the highest profit among the crops analyzed. The spatial analysis shows a five time reduction in the water footprint if all fruit monocultures are transformed to agroforestry. We conclude that the agroforestry system is a powerful tool to face water scarcity in the Maule region while still being competitive against monocultures.

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1. Introduction

1.1 Water scarcity in the Maule Region of Chile

Chile has a high agricultural production specialized in fruits. The country stands out for being within the top five in the world in the production of cherry and cranberry. Furthermore, Chile is within the world's ten largest producers of apple, grape, kiwi, hazelnut, and plum (FAO, 2018). Most of the agriculture is found in the country's central zone due to its Mediterranean climate (Valdés-Pineda et al., 2014). According to the Köppen's climate classification, the Mediterranean climate considers dry-warm summer (Csb) and dry-hot summer (Csa) (Figure 1). The agricultural sector is highly related to water consumption, using more than 70% of the freshwater in the country, well above human consumption (11.8%), industry (6.7%), and mining (3.7%); (MOP, 2020) (Figure 2).

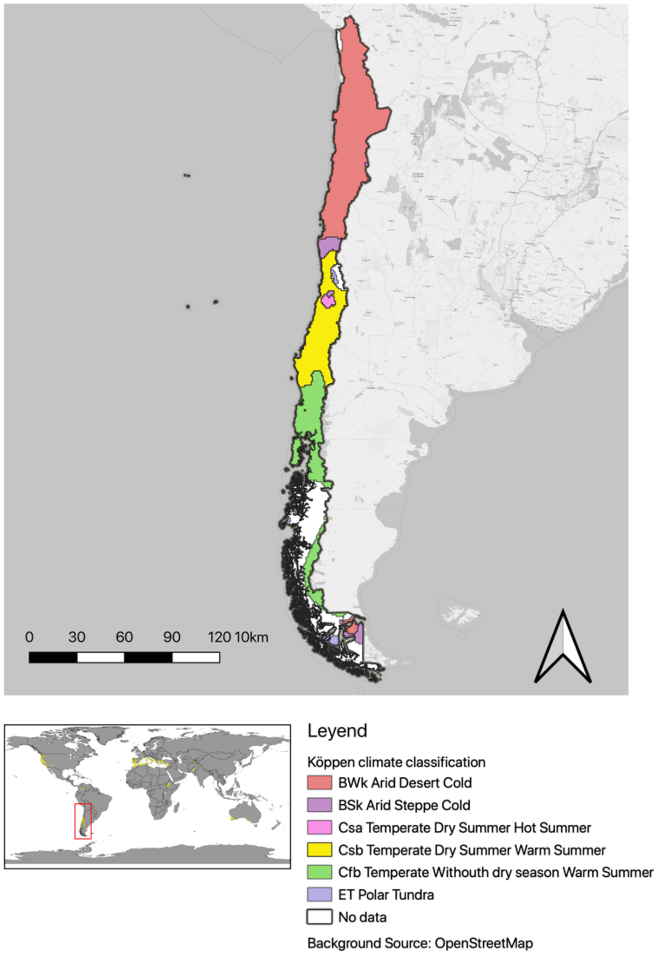

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Figure 1. Köppen's climate classification in Chile. Most of the agriculture is located in the central zone of the country corresponding to a Mediterranean climate, classified as dry-warm summer (Csb) and dry-hot summer (Csa).

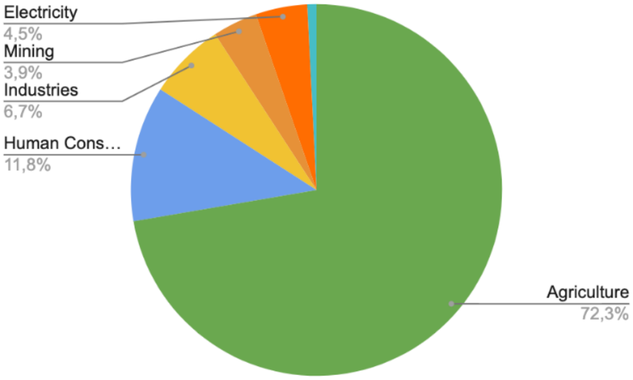


Figure 2. Water consumption by sector (MOP, 2020). The agricultural sector consumes the most amount of water (72,3%).

The central zone, specialized in agriculture and, therefore, highly dependent on water, has experienced a prolonged drought, with an uninterrupted sequence of dry years since 2010 and mean rainfall deficits of 20–40%. It is the longest drought event on record and has been called "Mega Drought" (MD) (Garreaud et al., 2020) (Figure 3).

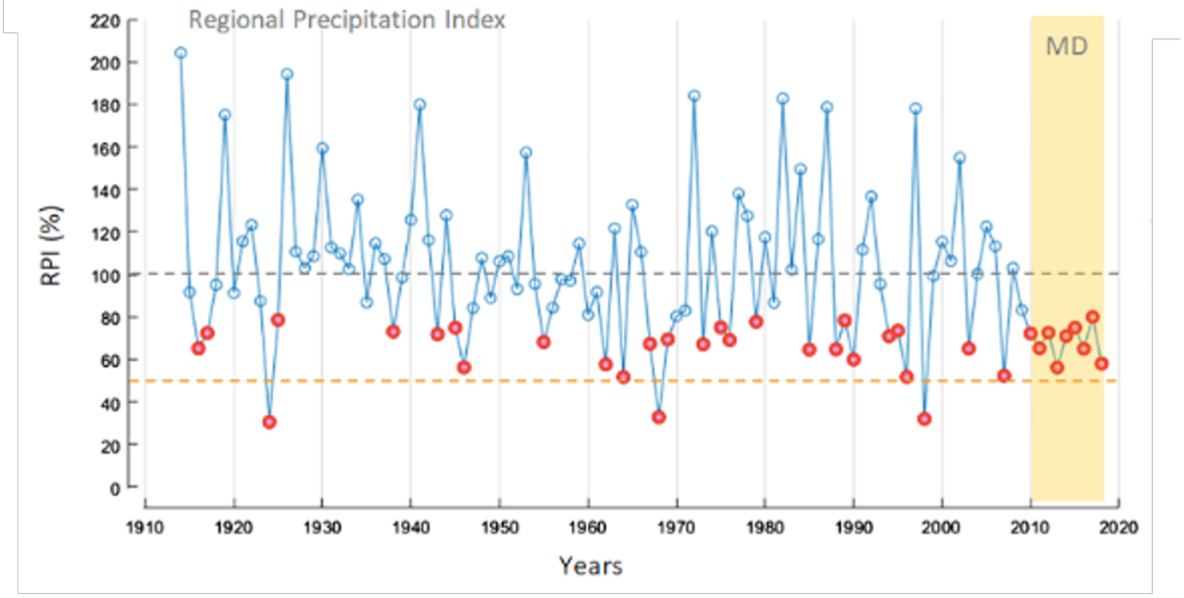


Figure 3. Mega drought (MD) in the Central Chile (Garreaud et al., 2020). Annual series of Central Chile regional precipitation index (RPI). Droughts, defined as years with RPI < 80%, are identified by the red circles.

The central zone affected by mega-drought is located from 30º-38ºS and includes the regions of Valparaiso, Metropolitana, O'Higgins, Maule, Ñuble, and Biobío, that are all characterized by a Mediterranean climate (Garreaud et al., 2020) (Figure 4). The territories' administrative divisions use fictional boundaries, such as regions, provinces, and communities. In developing agricultural policy, sometimes the administrative division does not fit the geographic outlay. That is why the government defined Environmental Homogeneous Areas, considering geographic variables such as landscape relief, climate, and water availability (Sotomayor et al., 2000). The Maule Region is the second largest region in the country in terms of fruit production (Ramirez et al., 2021) and most of the agriculture is in the "Intermediate Depression" area (Apey, 2020) (Figure 5).

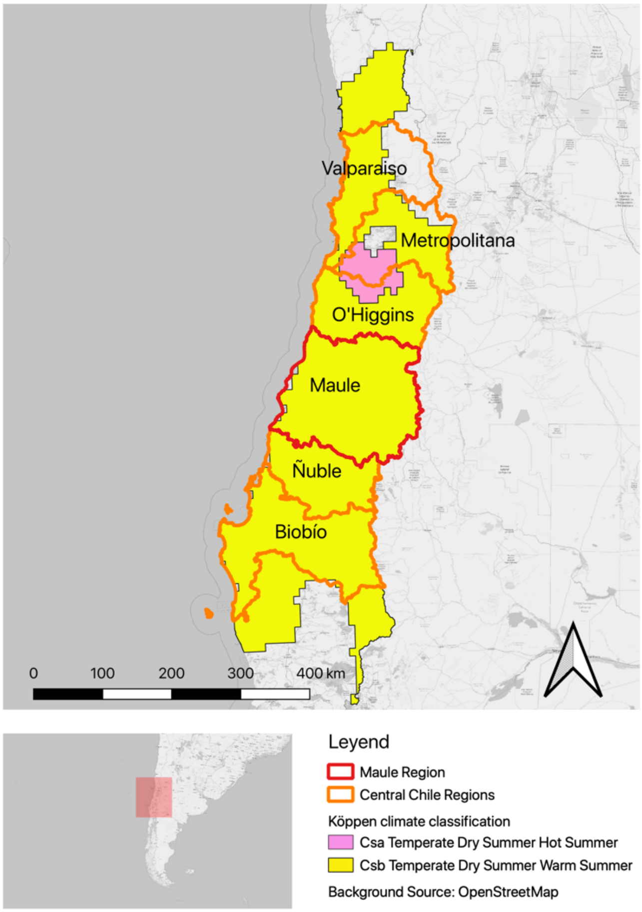


Figure 4. Regions of Central Chile affected by the mega-drought. Among them is the Maule Region.

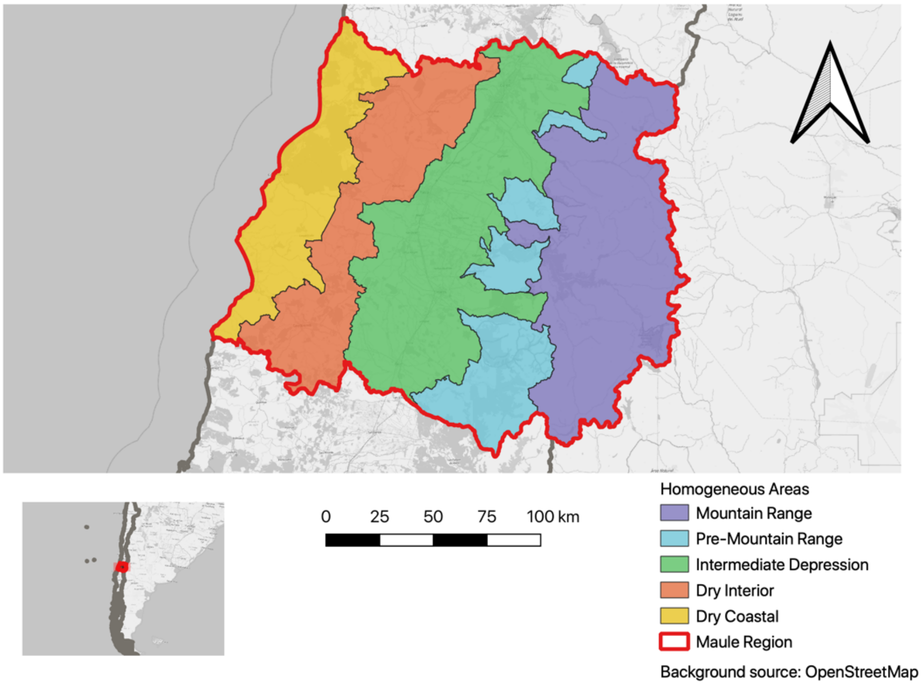


Figure 5. Environmental Homogeneous Areas in the Maule Region. Most of the fruit monocultures are in the Intermediate Depression area.

The Maule region has the highest water use in Chile (Valdés-Pineda et al., 2014). It is also the region with the largest blue water footprint in the country (Donoso et al., 2012). To understand the water use in the region, it is recommended to complement the environmental homogeneous areas classification with the watersheds in the region (Apey, 2020). The Maule region has five main watersheds. The main one is the Maule River, which contains 13.4% of the area of fruit plantations in the country (Apey, 2020). According to the General Water Directorate of the Ministry of Public Works (DGA-MOP), the region has 20 sub-watersheds and 96 subsub-watersheds (Figure 6).

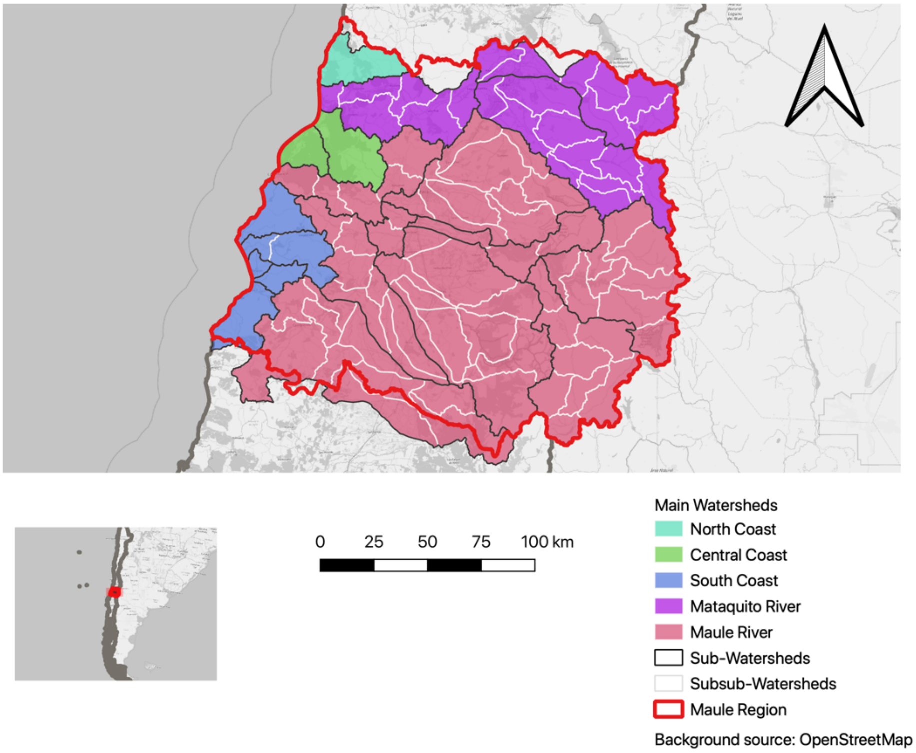


Figure 6. Watersheds in the Maule region, divided into main watershed, sub-watersheds, and subsub-watersheds. The Maule River is the largest watershed in the region, in which most of the fruit production are concentrated.

The watersheds of the Maule region are affected by the prolonged drought, and the government expects the drought effects to intensify even more in the future (ARClim, 2020). The Chilean Ministry of the Environment used the emissions scenario RCP 8.5 to estimate changes between the average of the historical period (1980 – 2010) and the average of the projection period (2035 – 2065). According to the projections, all the subsub-watersheds of the Maule region will increase the temperature by 1.05 to 1.83 degrees Celsius (°C) (Figure 7), and precipitation will decrease by 16.68% to 18.25% (Figure 8) (ARClim, 2020).

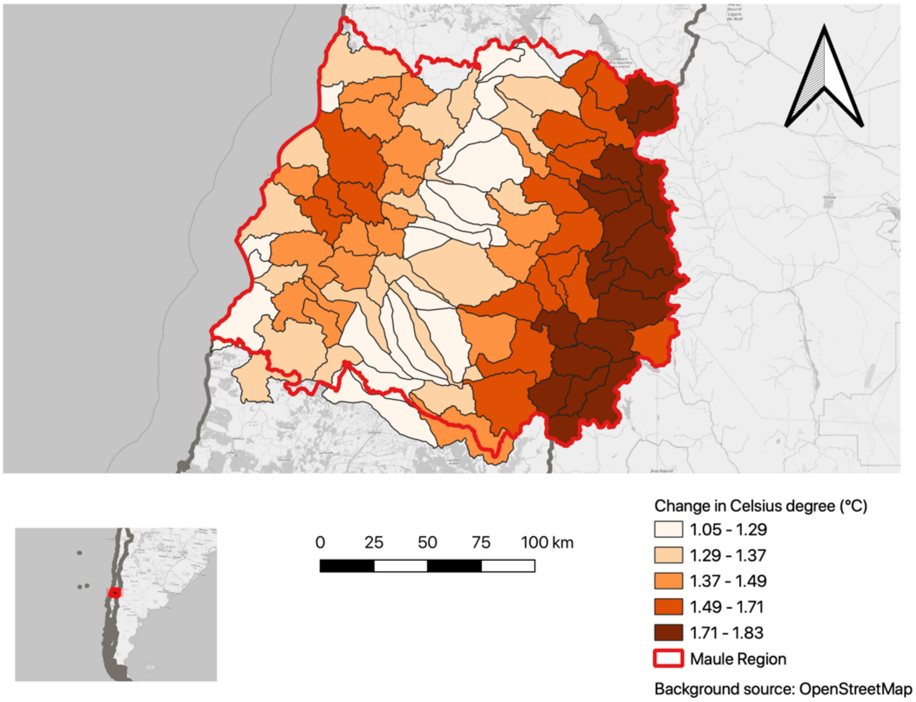
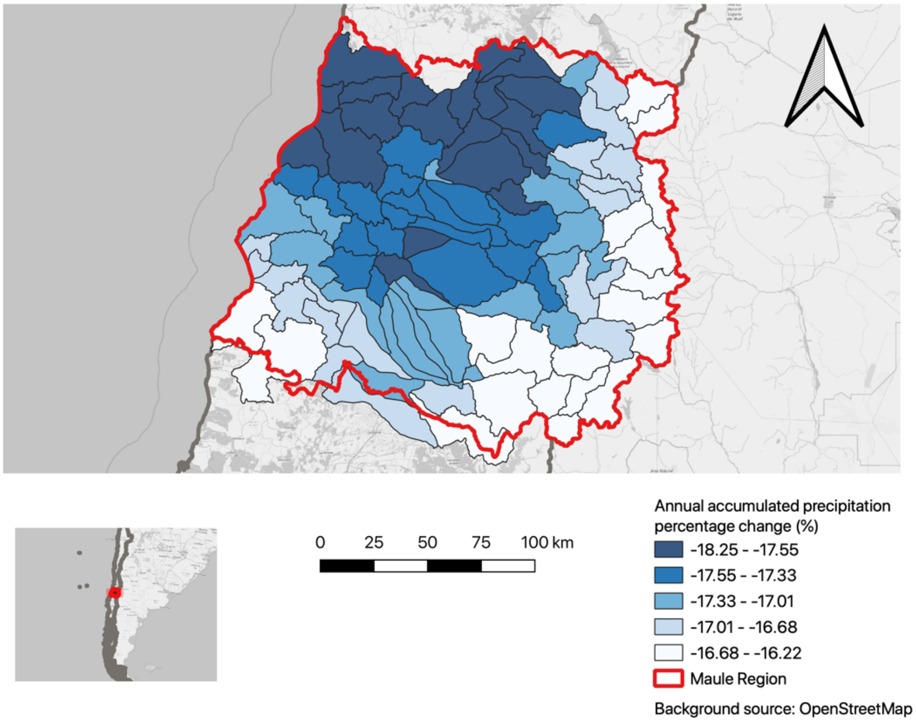


Figure 7. Projected change in temperature for each subsub-watershed. The increase in the maximum daily temperature between the average of the historical period (1980 – 2010) and the average of the projection period (2035 – 2065) using the emissions scenario RCP8.5 is shown. The expected increase for the entire Maule region is between 1.05 and 1.83 degrees.



Background source: OpenStreetMap

Figure 8. Projected change in precipitation for each subsub-watershed. The percentage decrease in accumulated annual precipitation between the average of the historical period (1980 – 2010) and the average of the projection period (2035 – 2065) using the emissions scenario RCP8.5 is shown. The expected decrease for the entire Maule region is between 16.68 and 18.25%.

The mega drought affecting Maule Region's agriculture is related to anthropogenic forcing, such as greenhouse gas emissions (Garreaud et al., 2020). On the other hand, conventional agriculture is considered to be a trigger of anthropogenic forcing, causing pressure on most of our planetary boundaries (Steffen et al., 2015). Therefore, Chile's agriculture, apart from being a victim of the drought effects, is also part of the problem.

1.2 Conventional Agriculture

Our food system is a significant contributor to the anthropogenic forcing. It is responsible for 21% of greenhouse gas emissions (FAO, 2016), uses 38% of the earth's terrestrial surface (Foley et al., 2011), and it has a significant impact on biodiversity (Butler et al., 2007; Laurance et al., 2014; Scales & Marsden, 2008). Also, it is responsible for 32% of the terrestrial acidification (Poore & Nemecek, 2018), causes 78% of the eutrophication (Poore & Nemecek, 2018), and uses 73% of freshwater (Hoekstra & Chapagain, 2006). Climate change has been generating unstable conditions for agriculture, with a greater probability of droughts and floods (Fischer et al., 2005). The risk to food security by climate change will become more acute in the future, with a world population estimation of 9.7 billion for the year 2050 (United Nations, 2015). The impacts caused by, and the insecure future of, the conventional agricultural system show the need for a different approach to agriculture.

1.3 Agroforestry system

Agroforestry could be a solution to the foreseen challenges connected to climate change and potential water shortages. Agroforestry is considered to be a productive, resilient, and sustainable food system (Agroforestry Network, 2018) that can be defined as a system that combines trees with crops or livestock (Nair, 1991), or agricultural land with more than 10% tree cover (Zomer et al., 2016). Agroforestry is linked to many other concepts, such as agroecology, syntropy, holistic agriculture, organic agriculture, permaculture, and regenerative agriculture, among others (Andrade et al., 2020). Among all these names, we can find a common factor in these systems, the focus on soil health considering aspects such as soil carbon, soil physical quality, and soil biodiversity (Schreefel et al., 2020). The main activities in these systems to improve soil health are minimizing tillage (Seitz et al., 2019), mixed farming (LaCanne & Lundgren, 2018), minimizing external inputs, crop rotation, use of manure and compost, and use of perennials (Schreefel et al., 2020).

Improving soil health has multiple environmental benefits. Agroforestry systems on average reduce surface runoff, soil, organic carbon, nutrient, and pollutant losses by 58%, 65%, 9%, 49%, and 50%, respectively (Zhu et al., 2020). Increasing soil carbon sequestration helps mitigate climate change by keeping carbon in the ground (Branca et al., 2013). Agroforestry is also better adapted to extreme and variable weather, has improved pest control, and enhanced biodiversity (Agroforestry Network, 2018).

Even though agroforestry incorporates a higher amount and diversity of species than conventional agriculture, water can be saved. Because of the improved soil condition, the system can reduce runoff velocity, enhance water infiltration and improve soil water storage (Zhu et al., 2020). Through the deep roots of trees, deeper waters can be accessed and redistributed to the upper layers. This process is known as hydraulic lift, improving water management in places affected by drought (Bayala & Prieto, 2020). The increase of shade in the agroforestry system by canopy species further reduces water loss. The shade increases soil moisture and decreases soil evaporation and crop transpiration (Lin, 2010). Also, the system generates other water-related benefits, such as improved water quality, reduced leaching to groundwater, removal of pollutants, and flood regulation (Pavlidis & Tsihrintzis, 2018).

Next to the environmental benefits of the agroforestry system, economic factors are crucial. Agroforestry will only be an effective solution if it can compete commercially with conventional agriculture (Lefroy & Stirzaker, 1999). Regarding yield performance, sustainable land management generally leads to increased yields, especially in areas of low and variable rainfall (Branca et al., 2013). Studies show that in cocoa agroforestry systems, the cocoa yields were 25% lower than in monocultures. Still, the total system yields were about ten times higher, and the profitability was similar to monocultures (Niether et al., 2020). In another regenerative agriculture study, the yields decreased by 29%, but the profits were 78% higher than in traditional production systems, because of cost savings and higher prices (LaCanne & Lundgren, 2018). Given these results, agroforestry can be considered to be a system that produces food while balancing social, economic, and environmental goals (Andrade et al., 2020).

1.4 Research Questions

To face the threat of water scarcity, it is critical to explore the use of agroforestry and its potential to reduce the agricultural water footprint as it has the potential to achieve similar economic gains as conventional monocultures, while making more sustainable use of environmental resources. In this study, we answer the main research question:

What is the potential for water savings in the Maule watersheds, moving from conventional agriculture to agroforestry without affecting economic returns?

To answer this research question, we make use of a case study in the Maule Region, the agroforestry project called "Huertas A Deo" (HAD) which began in 2020, developing a two hectares demonstration farm. This farm can serve as a model farm in the region for the transition from conventional agriculture to sustainable agriculture. We will address the following three subquestions to answer the main research question:

1. How are the HAD project's yield productivity and water footprint compared with those from conventional monoculture farms in the region?
2. What is the economic performance of the HAD project in comparison with conventional monoculture farms in the region?
3. What is the water saving potential of agroforestry when changing the entire agricultural system in the region?

The remainder of the thesis is structured as follows. First, chapter two will describe the methodology used in this research. Chapter three outlines the results of the performance in yield productivity and water footprint, as well as the economic analysis of the agroforestry system, and the spatial analysis. Chapter four discusses the implications of these results. In chapter five, the conclusions of this study with reference to the research questions are presented.

2 Methodology

For this study, we collected three main types of data: information from literature, spatial data, and interviews. The literature review was done through Google Scholar and Science Direct search engines. For the search, the keywords agroforestry and water, agriculture and water, and regenerative agriculture were used. Other papers cited in the selected studies were also reviewed. We used information from the Government of Chile, from institutions such as the Office of Agricultural Studies and Policies (Oficina de Estudios y Políticas Agrarias, ODEPA), the General Board of Water (Dirección general de Aguas, DGA), the Natural Resources Information Center (Centro de Información de Recursos Naturales, CIREN), and the Geospatial Data Infrastructure (Infraestructura de Datos Geoespaciales, IDE). Finally, data from interviews with experts in Chile and the founder of the HAD agroforestry project were realized. These three types of data were used to study the productivity of the agroforestry system, calculate the water footprint of this system, and perform the economic and spatial analyses. The following paragraphs give a detailed description of data and methods used for the different analyses performed in this study.

2.1 The case study

For this research we make use of a case study named the "Huertas A Deo" (HAD). HAD is an agroforestry project, located in the community of Pelluhue, Maule Region, Chile. HAD is located at -35º87'N, -72º65'W in the Dry Coast Area and the South Coast Watershed (Figure 9). It has an average altitude of 100 meters above sea level, with a total area of four hectares, where two of them are productive (Figure 10). We are using this case study as a base line of comparison with monocultural systems to evaluate the environmental and economic performance of the agroforestry system. Therefore, this chapter will describe how data on the case study was collected as well as the present state of the HAD.

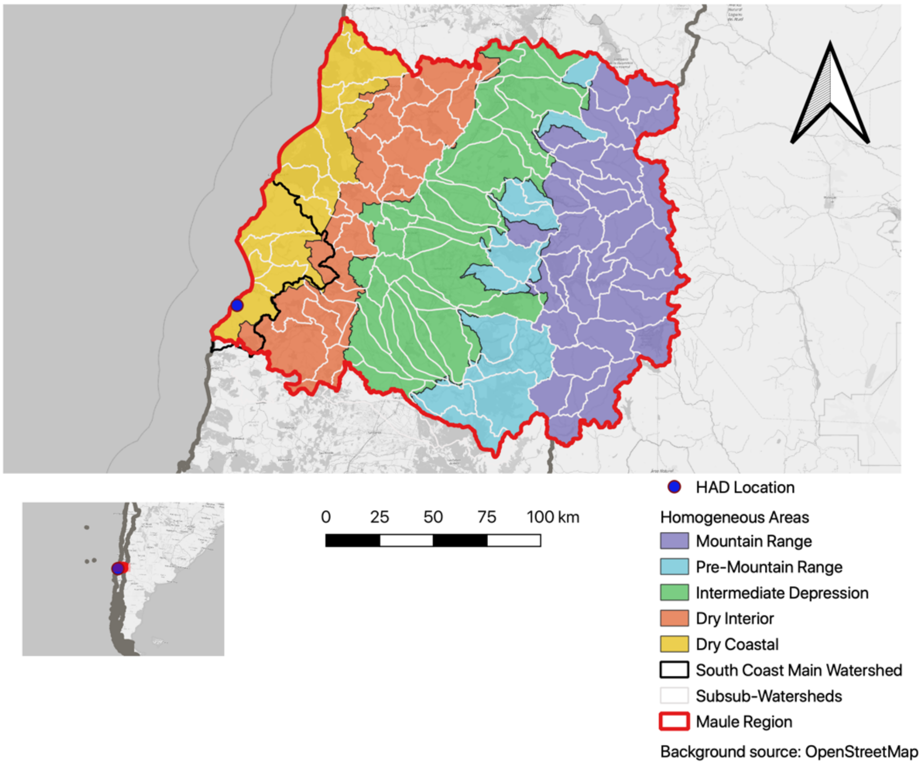


Figure 9. Location of the HAD project. It is inside the Dry Coastal area and the South Coast Watershed.

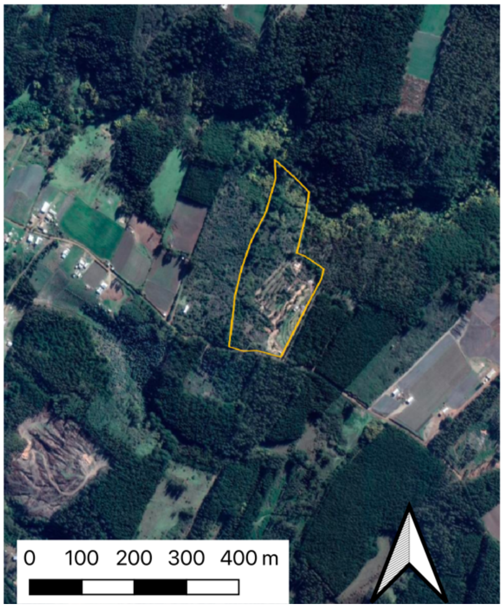


Figure 10. Context of the area and shape of the HAD project (Google Earth). The HAD has two productive hectares.

Interviews with the founder of the project, Raimundo Labbé, were held to collect primary data about the HAD project. We collected information on the present species, their distribution, harvest dates, water consumption, investment costs, and operating costs. The agroforestry system design includes 14 production lines per hectare. Each line is 0.7 meters wide and 100 meters long, separated by seven meters between them. The space in between lines is used for self-consumption of grazing animals, following the traditional agroforestry scheme (Elevitch et al., 2018) (Figure 11). Each production line has 15 different species, with the along-line separation distance depending on the species (Table 1). The full-grown agroforestry system will consist of different height layers as the different species will have different maximum heights (Figure 12). The project was started in 2020 and all species were planted in September 2020. At the time of data collection of this study (June 2022) the project was close to completing its second year.

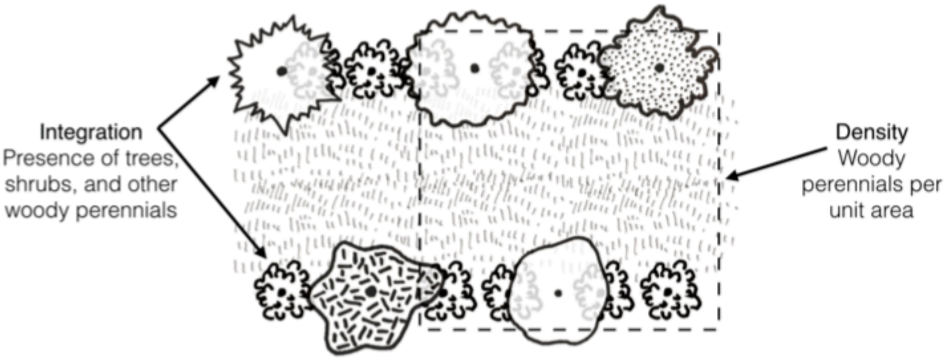


Figure 11. Overview of the agroforestry system. Each line is 0.7 meters wide and 100 meters long, with 7 meters between the lines for grazing animals.

Table 1. Along-line separation (m) between individuals of the same species.

Common name species	Scientific name species	Separation between individuals of the same species (mts)
Eucalyptus	Eucalyptus globulus	1
Mint	Mentha spicata	4
Rosemary	Salvia rosmarinus	4
Lavender	Lavandula	4
Geranium	Pelargonium	4
Raspberry	Rubus idaeus	4
Blueberry	Vaccinium	4
European hazel	Corylus avellana	3
Lemons	Citrus limon	9
Oranges	Fukumoto	9
Avocados	Persea americana	9
Olive	Olea europaea	3
Grape	Vitis vinifera	3
Almond	Prunus dulcis	3
Chestnut	Castanea sativa	6

Figure 12. Side view of multilayer design of the HAD project. The herb layer consists of mint, rosemary, lavender, and geranium. The shrub layer includes raspberry and blueberry shrubs. The first tree layer contains shorter trees including lemon, orange, avocado, olive, and almond trees and grape vines. The last layer consists of three types of taller trees with increasing height: european hazel, eucalypt, and chestnut trees.

2.2 Performance of the Agroforestry System

2.2.1 Productivity

Data distribution and performance per hectare of each species in a monoculture were used to calculate productivity of this project by using an agroforestry productivity conversion value. Most of the data were retrieved from the Office of Agricultural Studies and Policies (ODEPA, 2021). Data from the Maule Region were prioritized, but if the data of the region was not available, the next region to the north was searched, which has the same Mediterranean climate. Ultimately, data from the O'Higgins, Valparaiso, and Metropolitan regions were used. As a last option, international data on crops were used, which are specified in the results section 3.1.

With the collected data, we calculated the average production in kilogram per individual for each species. A 50% productivity discount was used to convert the monoculture productivity to agroforestry productivity. This difference is primarily caused by the use of less water (Shepard, 2013). To calculate the estimated production for the next 10 years, a conservative criterion was used by assuming that the crop does not have any production until it reaches its full production. We used the information from the interviews with the founder of the HAD project to define the years when each specie reaches the full production. The productivity was maintained over time until the end of the period of analysis corresponding to 12 years. The period of 12 years was used because is the same period used in the productivity studies for the Maule Region (CIREN, 2021).

2.2.2 Water footprint

We used the blue water footprint to calculate the water footprint of the HAD agroforestry system and compare it to the monocultures in the Maule Region. The blue water footprint is related to the direct use from the aquifers, leaving out the green water footprint related to rain, and the gray water footprint related to the assimilation of pollutants. For the HAD project, we assumed that the water consumption would remain the same during the years, even if some studies show that the water consumption could be reduced when the system reaches maturation (Bayala & Prieto, 2020; Lin, 2010). For the monocultures, we used the data of blue water footprint of Chile by crop in m3/ton (Donoso et al., 2012). We multiplied by the data obtained in section 2.2.1 on productivity to obtain the blue water footprint in m3/ha. We used the blue water footprint from the Maule Region, and if the data were not available, we used the data from the O'Higgins Region.

The Chilean water footprint study (Donoso et al., 2012), used the methodology of the water footprint manual (Hoekstra et al., 2009). The blue water footprint (WF_{blue}, m^3/ton) is calculated as the component in crop water use (CWU_{blue}, m^3/ha) divided by the crop yield (Y, ton/ha) (eq. 1).

$$\mathrm{WF}_{\mathrm{blue}} = \frac{\mathrm{CWU}_{\mathrm{blu}}}{Y} \tag{1}$$

To calculate the $\mathrm{CWU}_{\mathrm{blue}}$, the sum of the blue water evapotranspiration ($\mathrm{ET}_{\mathrm{blue}}$, mm) from the first day of sowing until the day of harvest (hd) is taken (eq. 2). A factor of 10 is used to transform the water depths in mm, into water volumes in m^3/ha.

$$\mathrm{CWU}_{\mathrm{blue}} = 10x \sum_{d=1}^{hd} \mathrm{ET}_{\mathrm{blue}} \tag{2}$$

For the $\mathrm{ET}_{\mathrm{blue}}$, the CROPWAT (FAO, 2009) was used. The blue water evapotranspiration of reference (ET_0, mm) is multiplied by the crop coefficient (K_c) and by the water stress coefficient (K_s) (eq. 3).

$$\mathrm{ET}_{\mathrm{blue}} = \mathrm{ET}_0 \text{ x } K_c \text{ x } K_s \tag{3}$$

2.3 Economic Analysis

With the purpose to compare the economic performance of the agroforestry system with the monocultures, we started measuring the annual profits per hectare in full production. For that we need to calculate the earnings and subtract the costs. The data of the monocultures were obtained from the profits reports per crop, of the Office of Agricultural Studies and Policies (ODEPA, 2021). the most recently updated year was prioritized, and if data from the Maule Region were not available, data from the O'Higgings region were used.

To calculate the annual profits per hectare of the HAD project, we started calculating the expected earnings of the project in full production. Although organic farming can charge a higher price compared to conventional farming (LaCanne & Lundgren, 2018), we use a conservative criterion assuming that the sale price would be equal to the price used for the monoculture crops.

To calculate the costs, the agroforestry system has fewer types of costs the conventional agriculture, since it does not use machinery, fertilizers, or pesticides (LaCanne & Lundgren, 2018). The main cost of the agroforestry system is the labor cost. To calculate the expected labor cost for the HAD project, we separated it between the labor cost per plant and the labor cost of harvest per kilogram of production. The labor cost per plant is related to pruning, replenishing infrastructure, maintenance, and irrigation revision. For that, we used the labor cost per plant from the profit's reports of monocultures (ODEPA, 2021). Because we are using an agroforestry conversion of half of productivity compared to a monoculture, we need the double individuals per specie to obtain the same production. Therefore, the HAD project has more plants to maintain to obtain the same production as the monoculture. The harvest cost per kilogram is related to activities such as harvesting, quality control, loading, and packaging. To calculate the harvest cost, we used again the data from the profit's reports of monocultures (ODEPA, 2021). With the expected earnings and cost of the HAD project, it is possible to obtain the expected profits, subtracted the costs to the earnings.

To obtain the expected cash flow of the HAD project we need the profit per year. We used a duration period of 12 years, according to the productivity studies for the Maule Region (CIREN, 2021). The investment costs of the project are incorporated in the year 0 and were calculated based on data collected from the interviews with the founder of the project, incorporating the costs of the plants, the irrigation system, light machinery, and labor (Table 11, appendix). The production of the project changes over the years as was explained in section 2.2.1. With the kilograms of production per specie per year, it has been possible to calculate the earnings and the harvest cost per year. The labor cost per plant is constant throughout the period, because even though there is no production in the first two years, it is necessary to do the activities such as pruning, replenishing infrastructure, maintenance, and irrigation revision. The cash flow for the monocultures was calculated in the same way as the HAD project, assuming the same investment, but adjusted for the amount and cost per specie.

We calculated the following four economic indicators to estimate the economic performance of the agroforestry system: Net present value (NPV), Internal Rate of Return (IRR), Payback Period, and the Return on Investment (ROI).

The NPV is used to bring the net cash flow of each year (R_y) to the present value using a discount rate of 10% (i). This rate was chosen based on the productivity studies for the Maule Region (CIREN, 2021) (eq. 4).

$$NPV = \frac{R_y}{(1+y)^i} \tag{4}$$

The Internal Rate of Return (IRR) was also used, which calculates the discount rate, at which the NPV is zero. This indicator is useful to compare projects, where the bigger IRR represents that the project has a better performance. For this, the net cash flow of each year must be added to the last year (Y), discounting the IRR (eq 5).

$$NPV = \sum_{y=0}^{N} \frac{Ry}{(1 + IRR)^{y}} \tag{5}$$

Another indicator used is the Payback Period, which corresponds to the year in which the initial investment is recovered. This is reached when the cumulative cash flow is bigger than 0.

Finally, the Return on Investment (ROI) per year was used, using the year of full production. The indicator corresponds to the profit of the year divided by the investment (eq 6)

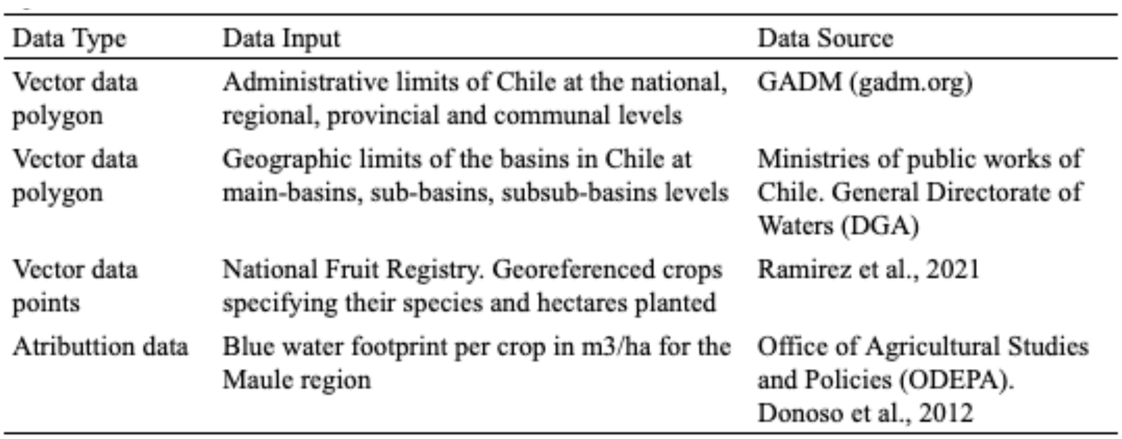
$$ROI = \frac{Profit\ in\ full\ production}{Investment} \tag{6}$$

To convert the local currency to euros, the average of the conversion rate of the last two years was used (July 2020-June 2022), corresponding to 901,1 Chilean pesos per 1 euro (Investing, 2022).

2.4 Spatial Analysis

To calculate the potential water footprint savings per subsub-watershed, we used spatial analysis. For this spatial analysis, we used four data layers (Table 2). The data refers to the shapes of the regions and the types of watersheds. Also considered are the georeferenced points of the monoculture's fruits in the Maule Region, and the blue water footprints per crop (m^3/ha).

Table 2. Data layers used for the spatial analysis, specifying the type, input, and source.



Data Type	Data Input	Data Source
Vector data polygon	Administrative limits of Chile at the national, regional, provincial and communal levels	GADM (gadm.org)
Vector data polygon	Geographic limits of the basins in Chile at main-basins, sub-basins, subsub-basins levels	Ministries of public works of Chile. General Directorate of Waters (DGA)
Vector data points	National Fruit Registry. Georeferenced crops specifying their species and hectares planted	Ramirez et al., 2021
Atributtion data	Blue water footprint per crop in m3/ha for the Maule region	Office of Agricultural Studies and Policies (ODEPA). Donoso et al., 2012

In 2021, The National Fruit Database included 42,171 plantations within the Maule region, with 87,692 hectares planted(Ramirez et al., 2021). When considering the 14 crops with water footprint information (Donoso et al., 2012), a sum of 68,073 hectares is reached, equivalent to 77.6% of the total plantation area in the region. For the 22.4% area of the total plantation without data on blue water footprint, with crops such as blackberry, mango, and papaya, a conservative criterion was used. The blue water footprint from the agroforestry system was used, that is the lowest one per hectare (as could be seen later in the results). In this way, these crops will show an undervalued water footprint in the absolute results of the conventional agriculture scenario and will not add water footprint savings when moving to the agroforestry system scenario.

The process for spatial analysis has different steps (Figure 13). The process started using the National Fruit Database 2021 (Ramirez et al., 2021) with the software Microsoft Excel. The data was filtered for the Maule Region. Each row represents a plantation with its spatial georeferenced, plantation area, and type of crop. The water footprint in the conventional scenario was calculated by multiplying the blue water footprint per crop (m^3/ha) with the total area of each plantation (ha). The water footprint in the agroforestry scenario was calculated using blue water footprint per crop in the HAD project (m^3/ha) with the total area of each plantation (ha). Then it was possible to calculate the difference in water footprint in each scenario. The units were converted from m^3/year to m^3/second.

Once the water footprint was added to the database, the data were uploaded in the software QGIS-LTR, 3.16.6 version as vector points. Here, the WGS 84 / UTM zone 19S projection

(EPSG: 32719) centered for Chile has been used. Also, the subsub-watersheds for the Maule Region were added as vectors polygons. Using the vector tool "Join attribute by location (summary)", it was possible to calculate the potential water footprint savings per subsub-watersheds.

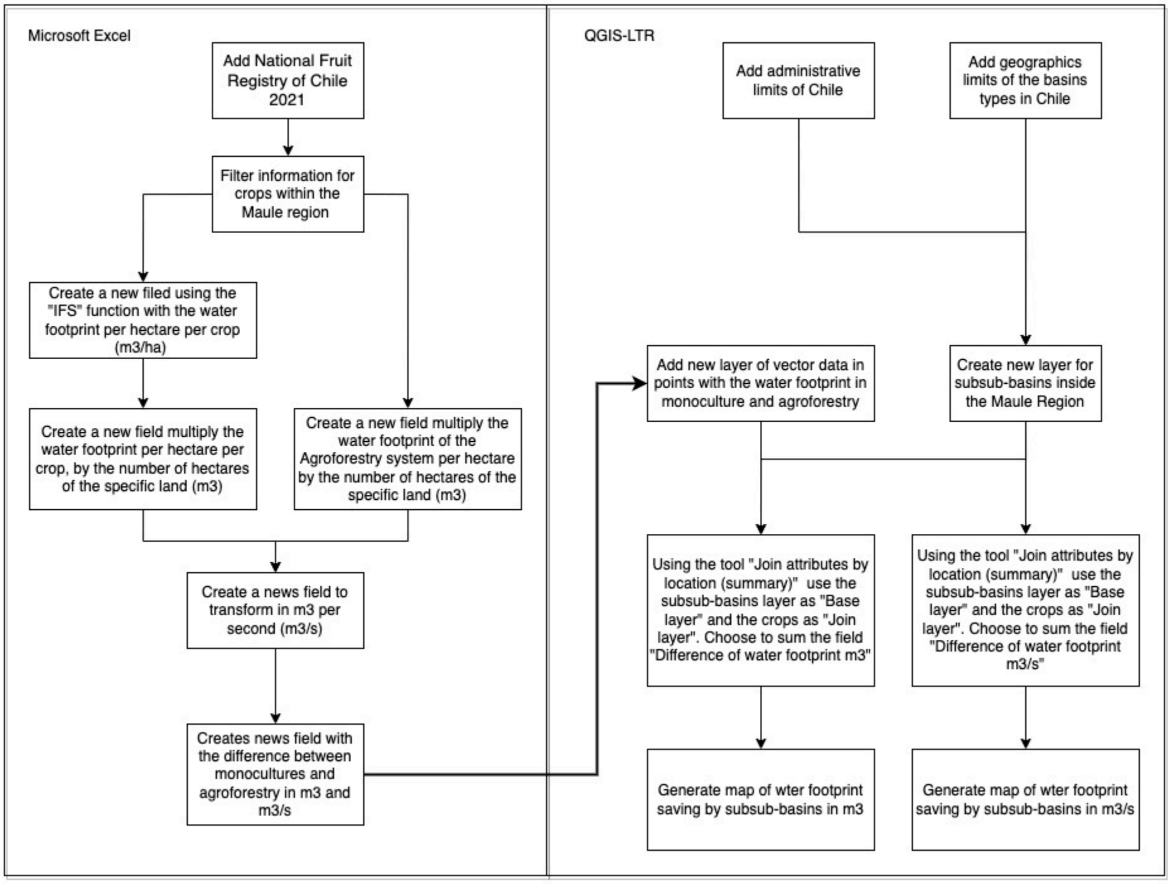


Figure 13. Flow chart specifying the steps followed in the spatial analysis.

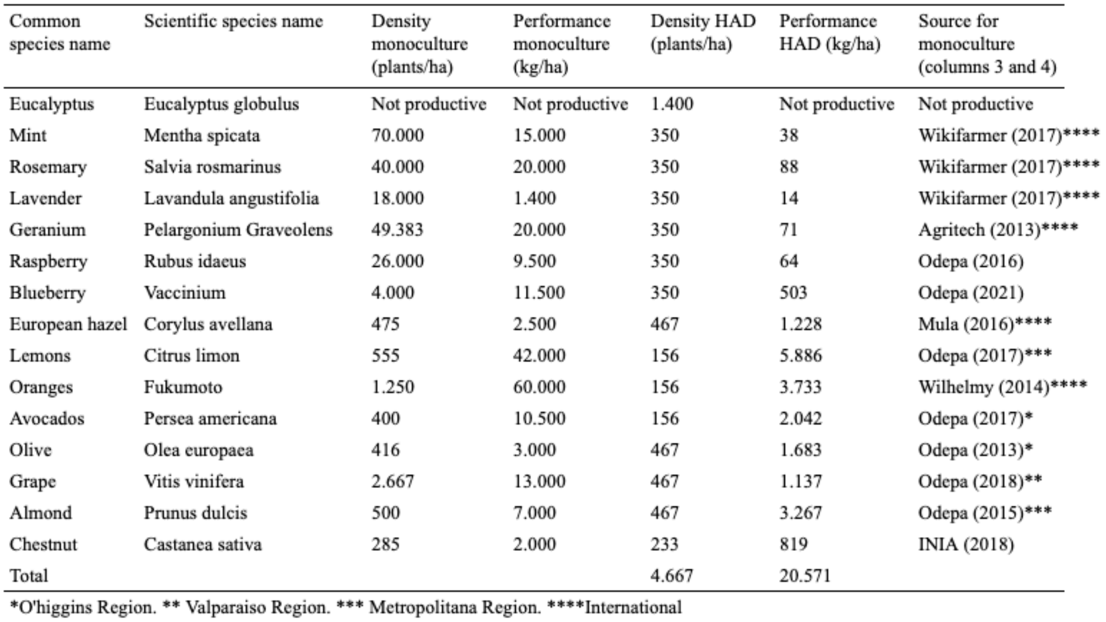
3 Results

The results obtained from applying the described methodology to the case study and monocultures seek to answer the main research question related to the potential for water savings in the Maule watersheds, using agroforestry profitably. Each section shows results related to a sub-research question: the performance of the agroforestry system in productivity and water footprint, the economic analysis compared to the monocultures, and the spatial analysis in the Maule Region.

3.1 Performance of the Agroforestry Systems

The HAD project has an expected performance in yield productivity of 20,571 kilograms of production per hectare in full maturity (Table 3). The monocultures of lemons and oranges are the only ones with a higher total number of kilograms produced per hectare than the HAD. Regarding the number of plants per hectare, HAD project reached 4,667 individuals. Only the monoculture of raspberries would have more individuals than the HAD project if we left out the crops in the herb layer (mint, rosemary, lavender, and geranium).

Table 3. Expected productivity of the HAD project in full maturity, using a conversion factor of 50% from the monoculture's productivity.



Common species name	Scientific species name	Density monoculture (plants/ha)	Performance monoculture (kg/ha)	Density HAD (plants/ha)	Performance HAD (kg/ha)	Source for monoculture (columns 3 and 4)
Eucalyptus	Eucalyptus globulus	Not productive	Not productive	1.400	Not productive	Not productive
Mint	Mentha spicata	70.000	15.000	350	38	Wikifarmer (2017)****
Rosemary	Salvia rosmarinus	40.000	20.000	350	88	Wikifarmer (2017)****
Lavender	Lavandula angustifolia	18.000	1.400	350	14	Wikifarmer (2017)****
Geranium	Pelargonium Graveolens	49.383	20.000	350	71	Agritech (2013)****
Raspberry	Rubus idaeus	26.000	9.500	350	64	Odepa (2016)
Blueberry	Vaccinium	4.000	11.500	350	503	Odepa (2021)
European hazel	Corylus avellana	475	2.500	467	1.228	Mula (2016)****
Lemons	Citrus limon	555	42.000	156	5.886	Odepa (2017)***
Oranges	Fukumoto	1.250	60.000	156	3.733	Wilhelmy (2014)****
Avocados	Persea americana	400	10.500	156	2.042	Odepa (2017)*
Olive	Olea europaea	416	3.000	467	1.683	Odepa (2013)*
Grape	Vitis vinifera	2.667	13.000	467	1.137	Odepa (2018)**
Almond	Prunus dulcis	500	7.000	467	3.267	Odepa (2015)***
Chestnut	Castanea sativa	285	2.000	233	819	INIA (2018)
Total				4.667	20.571	

*O'higgins Region. ** Valparaiso Region. *** Metropolitana Region. ****International

When comparing the productivity of monocultures and the HAD project, it is important to not only consider species present in the agroforestry system, but also others that are commonly planted in the Maule Region. These fruits include, for example, cherry, red apple, walnut, kiwi, pears, and peach. In the comparison between 14 monocultures and the HAD, the project ranks sixth out of 15 in productivity, expressed in kg/ha/year (Figure 14).

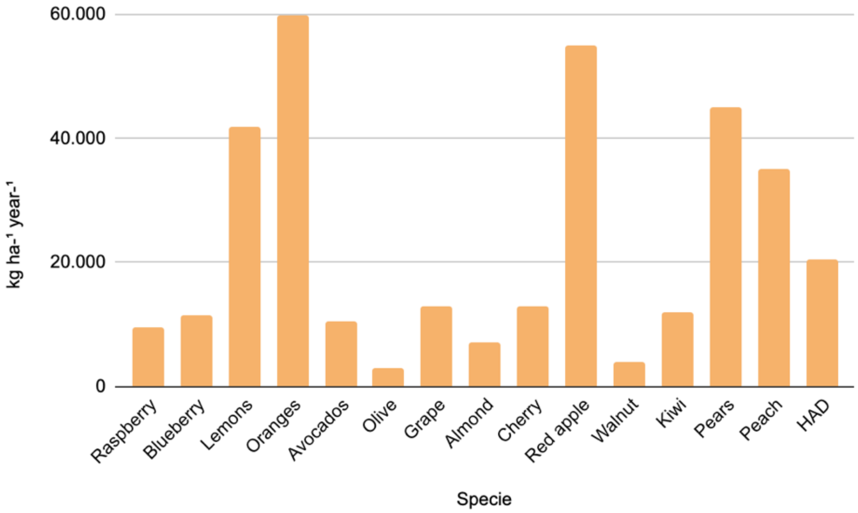
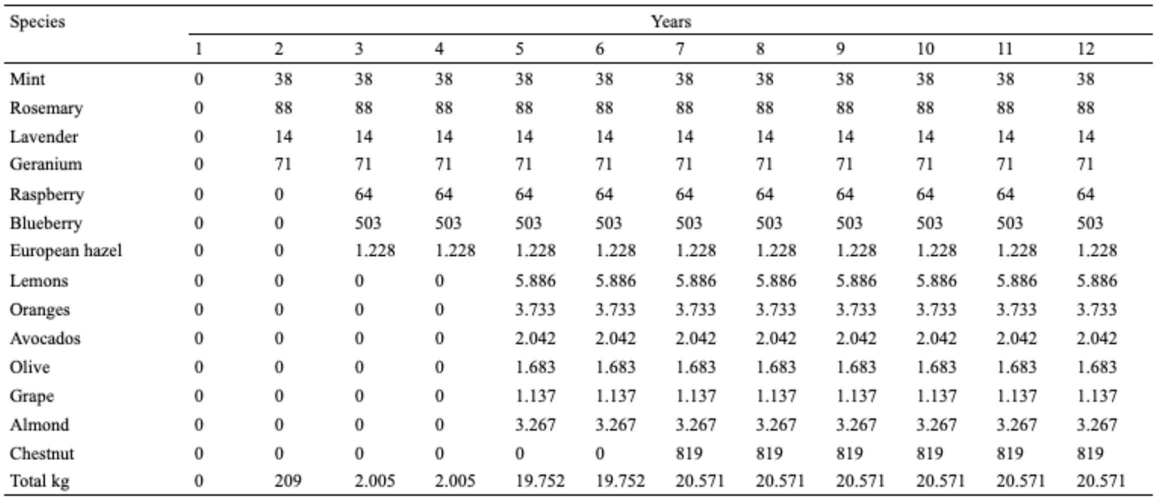


Figure 14. Comparison in productivity in full maturity between the expected productivity of the HAD project and the common fruits in the Maule Region.

The productivity of the agroforestry system is changing over the years. We assumed that the project will not produce anything until full maturity of production is reached, therefore numbers jump from zero production to full production at once (Table 4). The first producing crops are in the herb layer (mint, rosemary, lavender, and geranium) in year two. In year three the raspberry, blueberry, and european hazel reach full production. During year five, the production increased exponentially, with the production of lemons, oranges, avocados, olives, grapes, and almonds, reaching an expected productivity of 19,752 kilograms per hectare. The full productivity of the system is reached after seven years with the production of chestnuts.

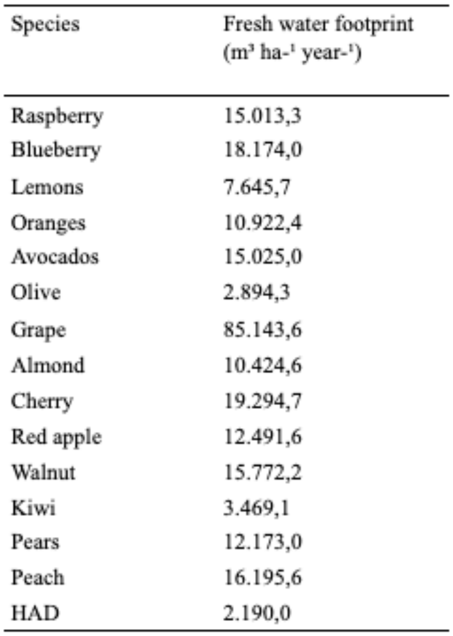
Table 4. Predicted production (kg/ha) per year in the HAD project. It was assumed that the project will not produce anything until full maturity of production is reached, therefore numbers jump from zero production to full production at once. The full productivity of the system is reached after seven years.



Species	Years											
	1	2	3	4	5	6	7	8	9	10	11	12
Mint	0	38	38	38	38	38	38	38	38	38	38	38
Rosemary	0	88	88	88	88	88	88	88	88	88	88	88
Lavender	0	14	14	14	14	14	14	14	14	14	14	14
Geranium	0	71	71	71	71	71	71	71	71	71	71	71
Raspberry	0	0	64	64	64	64	64	64	64	64	64	64
Blueberry	0	0	503	503	503	503	503	503	503	503	503	503
European hazel	0	0	1.228	1.228	1.228	1.228	1.228	1.228	1.228	1.228	1.228	1.228
Lemons	0	0	0	0	5.886	5.886	5.886	5.886	5.886	5.886	5.886	5.886
Oranges	0	0	0	0	3.733	3.733	3.733	3.733	3.733	3.733	3.733	3.733
Avocados	0	0	0	0	2.042	2.042	2.042	2.042	2.042	2.042	2.042	2.042
Olive	0	0	0	0	1.683	1.683	1.683	1.683	1.683	1.683	1.683	1.683
Grape	0	0	0	0	1.137	1.137	1.137	1.137	1.137	1.137	1.137	1.137
Almond	0	0	0	0	3.267	3.267	3.267	3.267	3.267	3.267	3.267	3.267
Chestnut	0	0	0	0	0	0	819	819	819	819	819	819
Total kg	0	209	2.005	2.005	19.752	19.752	20.571	20.571	20.571	20.571	20.571	20.571

The water footprint performance was calculated using the data of blue water footprint per ton of crop and the productivity of ton per hectare, which obtained the blue water footprint per hectare (Table 5). The crop with the biggest blue water footprint is the grape, with 85,144 m^3/ha in one year. On the other hand, the system with the lowest water footprint was the HAD project, with 2,190 m^3/ha in one year.

Table 5. Blue water footprint per monoculture species and for the HAD project. The water footprint was calculated using the data of blue water footprint per ton of crop and the productivity in ton per hectare.



Species	Fresh water footprint (m^3 ha^{-1} $year^{-1}$)
Raspberry	15.013,3
Blueberry	18.174,0
Lemons	7.645,7
Oranges	10.922,4
Avocados	15.025,0
Olive	2.894,3
Grape	85.143,6
Almond	10.424,6
Cherry	19.294,7
Red apple	12.491,6
Walnut	15.772,2
Kiwi	3.469,1
Pears	12.173,0
Peach	16.195,6
HAD	2.190,0

We analyzed the relationship between the kilograms produced and the cubic meter of water, using the productivity and water footprint results. The system with the highest ratio was the HAD project, with an expected ratio of almost ten kilograms of production per cubic meter of water used. Among the crops with high ratios stand out lemons, oranges, and red apples, with more than four kilograms of production per cubic meter of water. The grape is the crop with the lowest ratio, with 0.15 kilogram of production per one cubic meter of water (Figure 15).

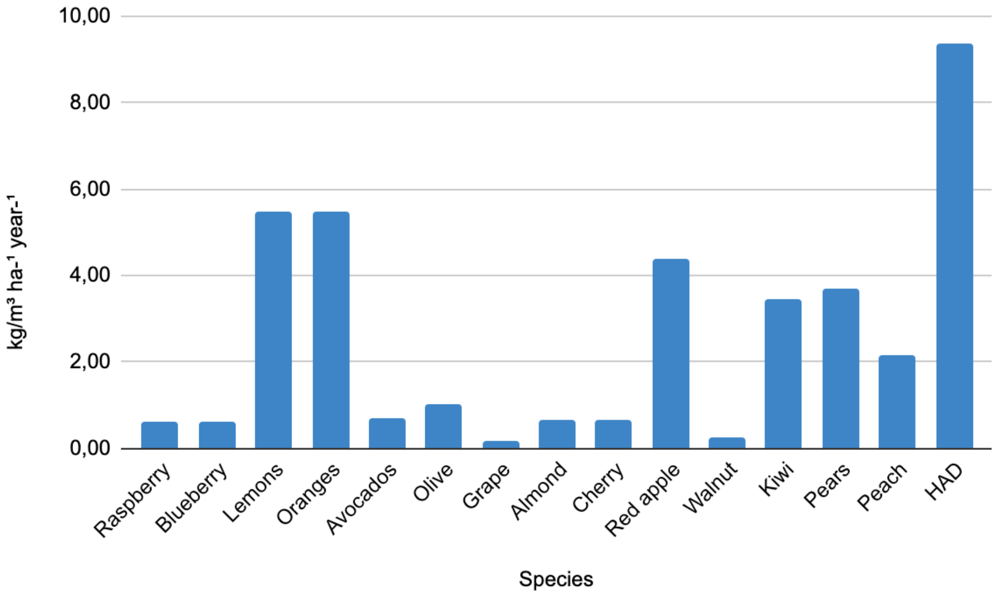
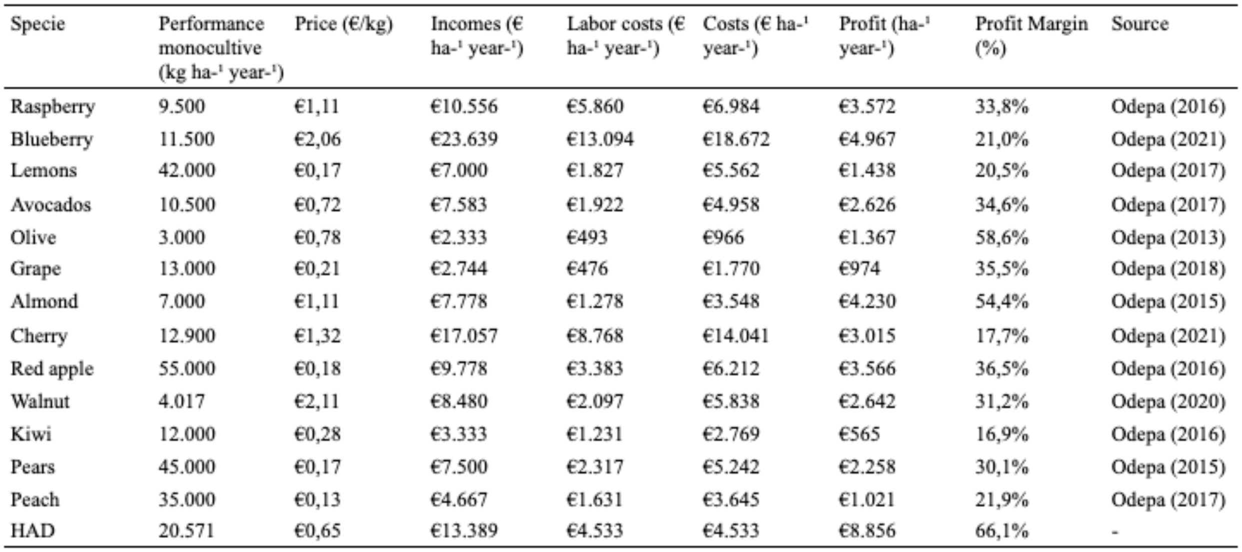


Figure 15. Relationship between the production and the blue water footprint per crop. The HAD project is the system with the highest ratio, close to 10 kg/m3.

3.2 Economic Analysis

The economic analysis was done to study the HAD project's profitability in comparison to the region's monocultures. When comparing the systems in full production, the blueberry crop monoculture has the highest income of €23,639, but also the highest costs of €18,672, generating a profit margin percentage of 21% (Table 6). The system with the most significant profit is the agroforestry system, with an expected profit of €8,856 per year per hectare. It also has the biggest profit margin with a percentage of 66.1%. The operational costs of the agroforestry system are all related to the labor cost, unlike the monocultures that also have costs for machinery, fertilizers, or pesticides (Figure 16).

Table 6. Annual profits per species in a year in full production. The HAD project has the largest (expected) profit margin (66,1%), followed by olive and almond monocultures.



Specie	Performance monocultive (kg ha-^{1} year-^{1})	Price (€/kg)	Incomes (€ ha-^{1} year-^{1})	Labor costs (€ ha-^{1} year-^{1})	Costs (€ ha-^{1} year-^{1})	Profit (ha-^{1} year-^{1})	Profit Margin (%)	Source
Raspberry	9.500	€1,11	€10.556	€5.860	€6.984	€3.572	33,8%	Odepa (2016)
Blueberry	11.500	€2,06	€23.639	€13.094	€18.672	€4.967	21,0%	Odepa (2021)
Lemons	42.000	€0,17	€7.000	€1.827	€5.562	€1.438	20,5%	Odepa (2017)
Avocados	10.500	€0,72	€7.583	€1.922	€4.958	€2.626	34,6%	Odepa (2017)
Olive	3.000	€0,78	€2.333	€493	€966	€1.367	58,6%	Odepa (2013)
Grape	13.000	€0,21	€2.744	€476	€1.770	€974	35,5%	Odepa (2018)
Almond	7.000	€1,11	€7.778	€1.278	€3.548	€4.230	54,4%	Odepa (2015)
Cherry	12.900	€1,32	€17.057	€8.768	€14.041	€3.015	17,7%	Odepa (2021)
Red apple	55.000	€0,18	€9.778	€3.383	€6.212	€3.566	36,5%	Odepa (2016)
Walnut	4.017	€2,11	€8.480	€2.097	€5.838	€2.642	31,2%	Odepa (2020)
Kiwi	12.000	€0,28	€3.333	€1.231	€2.769	€565	16,9%	Odepa (2016)
Pears	45.000	€0,17	€7.500	€2.317	€5.242	€2.258	30,1%	Odepa (2015)
Peach	35.000	€0,13	€4.667	€1.631	€3.645	€1.021	21,9%	Odepa (2017)
HAD	20.571	€0,65	€13.389	€4.533	€4.533	€8.856	66,1%	-

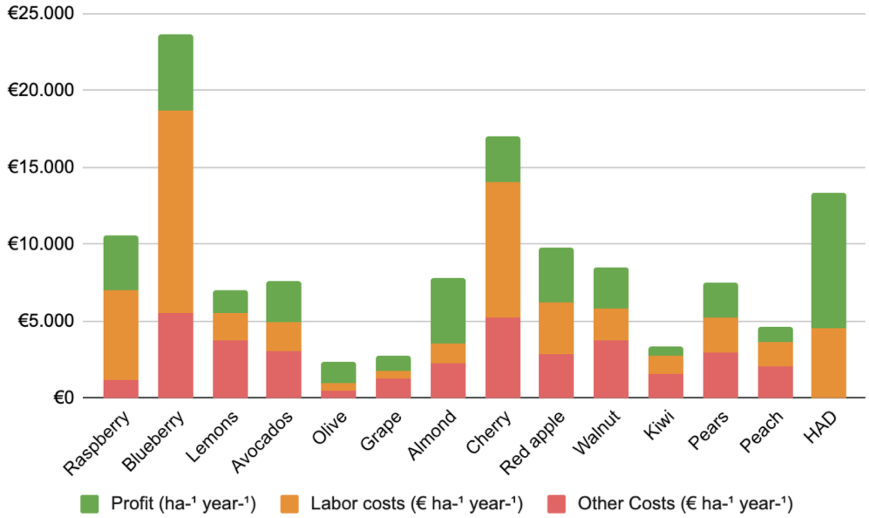
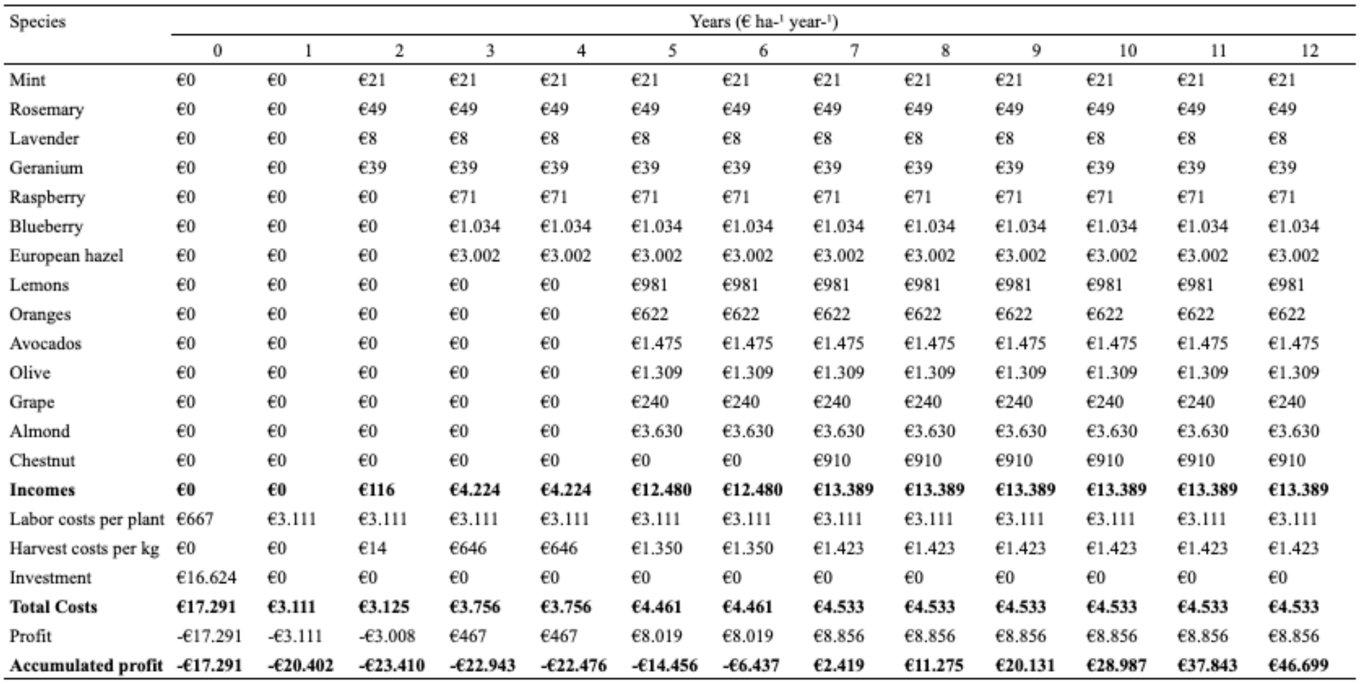


Figure 16. Annual profits per species in full production with distinction in labor costs and other costs. The other costs include the costs of machinery, fertilizers, and pesticides. The HAD project has the third highest annual income compared to the monocultures, the highest profit, and it doesn't have "other costs."

The expected cash flow of the HAD project is built with the incomes from the predicted production over the years. The costs start with the investment in the year 0, considering the costs of the plants, irrigation system, light machinery, and labor. The investment cost is only for the beginning of the project and will not be repeated for the following years. The labor cost per plant is constant during the analyzed time, considering activities of pruning, replenishing infrastructure, maintenance, and irrigation revision. The harvest costs depend on the kilogram of production per year. With the incomes and expenses per year, the expected profits for each year were calculated (Table 7). The profits of the agroforestry project turns positive in year three, and the payback occurred in year seven when the accumulated profit is expected to be higher than zero.

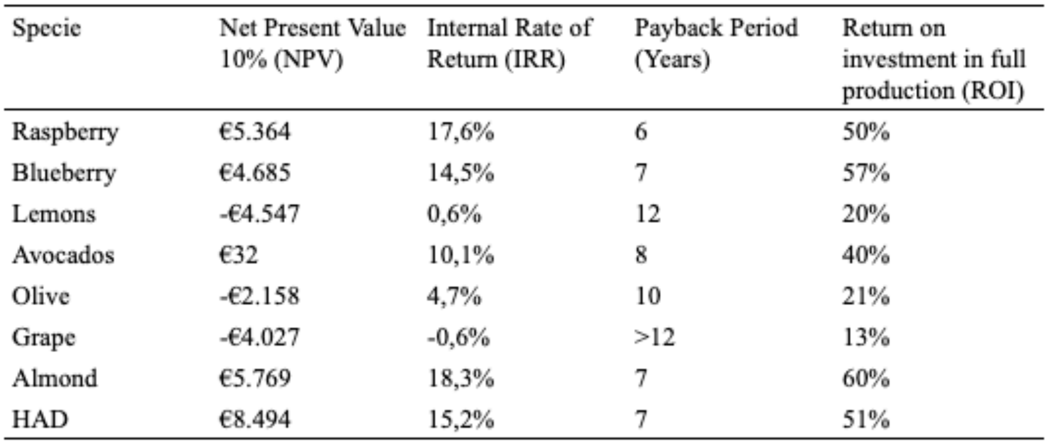
Table 7. Expected cash flow of the HAD project. The profits of the agroforestry project are expected to turn positive in year three, and the payback is expected to occur in year seven, when the accumulated profit is higher than zero.



Species	Years (€ ha-¹ year-¹)												
	0	1	2	3	4	5	6	7	8	9	10	11	12
Mint	€0	€0	€21	€21	€21	€21	€21	€21	€21	€21	€21	€21	€21
Rosemary	€0	€0	€49	€49	€49	€49	€49	€49	€49	€49	€49	€49	€49
Lavender	€0	€0	€8	€8	€8	€8	€8	€8	€8	€8	€8	€8	€8
Geranium	€0	€0	€39	€39	€39	€39	€39	€39	€39	€39	€39	€39	€39
Raspberry	€0	€0	€0	€71	€71	€71	€71	€71	€71	€71	€71	€71	€71
Blueberry	€0	€0	€0	€1.034	€1.034	€1.034	€1.034	€1.034	€1.034	€1.034	€1.034	€1.034	€1.034
European hazel	€0	€0	€0	€3.002	€3.002	€3.002	€3.002	€3.002	€3.002	€3.002	€3.002	€3.002	€3.002
Lemons	€0	€0	€0	€0	€0	€981	€981	€981	€981	€981	€981	€981	€981
Oranges	€0	€0	€0	€0	€0	€622	€622	€622	€622	€622	€622	€622	€622
Avocados	€0	€0	€0	€0	€0	€1.475	€1.475	€1.475	€1.475	€1.475	€1.475	€1.475	€1.475
Olive	€0	€0	€0	€0	€0	€1.309	€1.309	€1.309	€1.309	€1.309	€1.309	€1.309	€1.309
Grape	€0	€0	€0	€0	€0	€240	€240	€240	€240	€240	€240	€240	€240
Almond	€0	€0	€0	€0	€0	€3.630	€3.630	€3.630	€3.630	€3.630	€3.630	€3.630	€3.630
Chestnut	€0	€0	€0	€0	€0	€0	€0	€910	€910	€910	€910	€910	€910
Incomes	**€0**	**€0**	**€116**	**€4.224**	**€4.224**	**€12.480**	**€12.480**	**€13.389**	**€13.389**	**€13.389**	**€13.389**	**€13.389**	**€13.389**
Labor costs per plant	€667	€3.111	€3.111	€3.111	€3.111	€3.111	€3.111	€3.111	€3.111	€3.111	€3.111	€3.111	€3.111
Harvest costs per kg	€0	€0	€14	€646	€646	€1.350	€1.350	€1.423	€1.423	€1.423	€1.423	€1.423	€1.423
Investment	€16.624	€0	€0	€0	€0	€0	€0	€0	€0	€0	€0	€0	€0
Total Costs	**€17.291**	**€3.111**	**€3.125**	**€3.756**	**€3.756**	**€4.461**	**€4.461**	**€4.533**	**€4.533**	**€4.533**	**€4.533**	**€4.533**	**€4.533**
Profit	-€17.291	-€3.111	-€3.008	€467	€467	€8.019	€8.019	€8.856	€8.856	€8.856	€8.856	€8.856	€8.856
Accumulated profit	**-€17.291**	**-€20.402**	**-€23.410**	**-€22.943**	**-€22.476**	**-€14.456**	**-€6.437**	**€2.419**	**€11.275**	**€20.131**	**€28.987**	**€37.843**	**€46.699**

The economic indicators calculated were: Net present value (NPV), Internal Rate of Return (IRR), Payback Period, and Return on Investment (ROI) (Table 8). The NPV shows some crops with negative amounts corresponding to lemons, olives, and grapes. The highest NPV was found for the HAD project. The highest IRR was found for almonds, followed by the raspberry, and in third place the HAD project. The raspberry is the crop that has the shortest Payback Period, and thus recovers investment the fastest, during the sixth year. The ROI in full production shows that the best performance is for almonds with a 60% rate, followed by the blueberry (57%) and the HAD project (51%) in third place.

Table 8. Economic Indicators per species using the Net present value (NPV), Internal Rate of Return (IRR), Payback Period, and Return on Investment (ROI). The HAD has the highest NPV. It is in third place in IRR, second place in payback (tied with other crops), and third place in ROI.

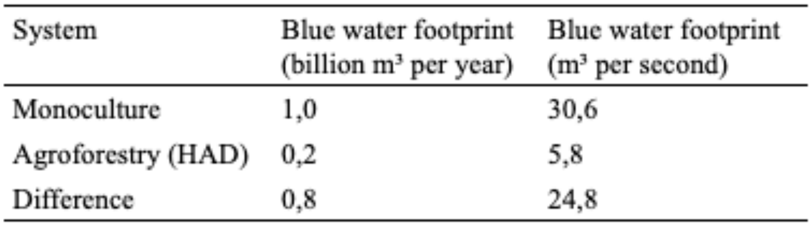


Specie	Net Present Value 10% (NPV)	Internal Rate of Return (IRR)	Payback Period (Years)	Return on investment in full production (ROI)
Raspberry	€5.364	17,6%	6	50%
Blueberry	€4.685	14,5%	7	57%
Lemons	-€4.547	0,6%	12	20%
Avocados	€32	10,1%	8	40%
Olive	-€2.158	4,7%	10	21%
Grape	-€4.027	-0,6%	>12	13%
Almond	€5.769	18,3%	7	60%
HAD	€8.494	15,2%	7	51%

3.3 Spatial Analysis

The Spatial Analysis results show that the expected blue water footprint of the fruits monoculture in the Maule region is around 1 billion m3 per year, equivalent to 30,6 m^3/s (Table 9). The Maule River is the main watershed with the highest blue water footprint, with almost 17 m^3/s, followed by the Mataquito River, with nearly 14 m^3/s (Table 10). Most of the subsub-watersheds without crops correspond to the environmental homogeneous area of the "Mountain Range." Most of the water use occurs in the subsub-watersheds located in the central zone of the region, corresponding to the environmental homogeneous area of the "Intermediate Depression", where most of the crops are cultivated. Some subsub-watersheds can reach more than 3 m^3/s of blue water footprint (Figure 17).

Table 9. Blue water footprint of monoculture in Maule Region and if the monoculture change to agroforestry system. The saving in water by the transition from monoculture to agroforestry is approximately five times.



System	Blue water footprint (billion m³ per year)	Blue water footprint (m³ per second)
Monoculture	1,0	30,6
Agroforestry (HAD)	0,2	5,8
Difference	0,8	24,8

Table 10. Blue water footprint by main watershed in Maule Region under the monoculture and agroforestry scenario. The Maule River and the Mataquito River show reduction of more than 10 m^3/s.

Main Watersheds	Maule River (m^3/s)	Mataquito River (m^3/s)	North Coast (m^3/s)	Central Coast (m^3/s)	South Coast (m^3/s)	Total (m^3/s)
Monoculture	16,871	13,745	0,006	0,020	0,020	30,662
Agroforestry (HAD)	3,511	2,339	0,002	0,003	0,003	5,859
Difference	13,360	11,406	0,004	0,017	0,017	24,803

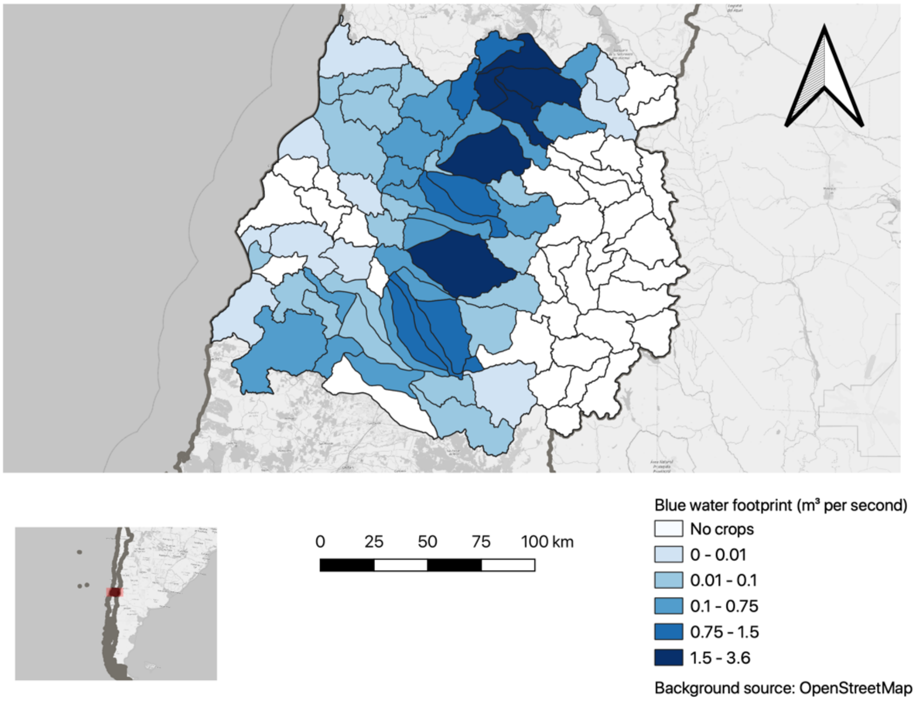


Figure 17. Blue water footprint per subsub-basins with monoculture system (m^3/s). Some subsub-watersheds can reach more than 3 m^3/s, and are located in the "Intermediate Depression" area.

In the scenario where all the monocultures changed to agroforestry systems, the Maule region would use around 0,2 billion m^3 of water per year, equivalent to 5,8 m^3/s (Table 9). The main watersheds of Maule River and Mataquito River would reduce the blue water footprint, using less than 4 m^3/s (Table 10). In the new scenario with agroforestry, none of the subsub-watersheds will exceed the 0,75 m^3/s of blue water footprint (Figure 18).

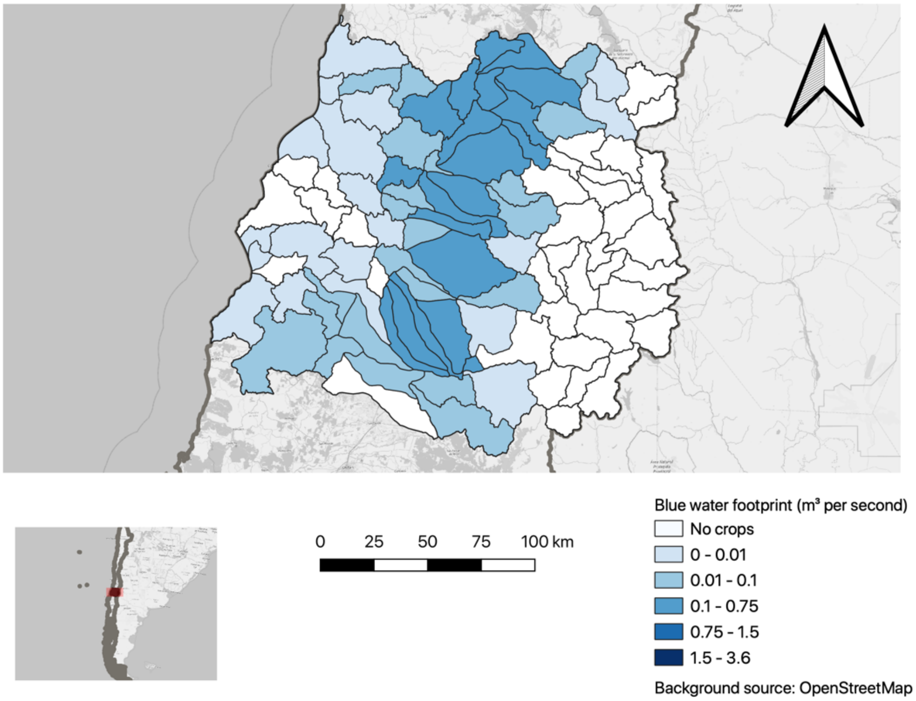
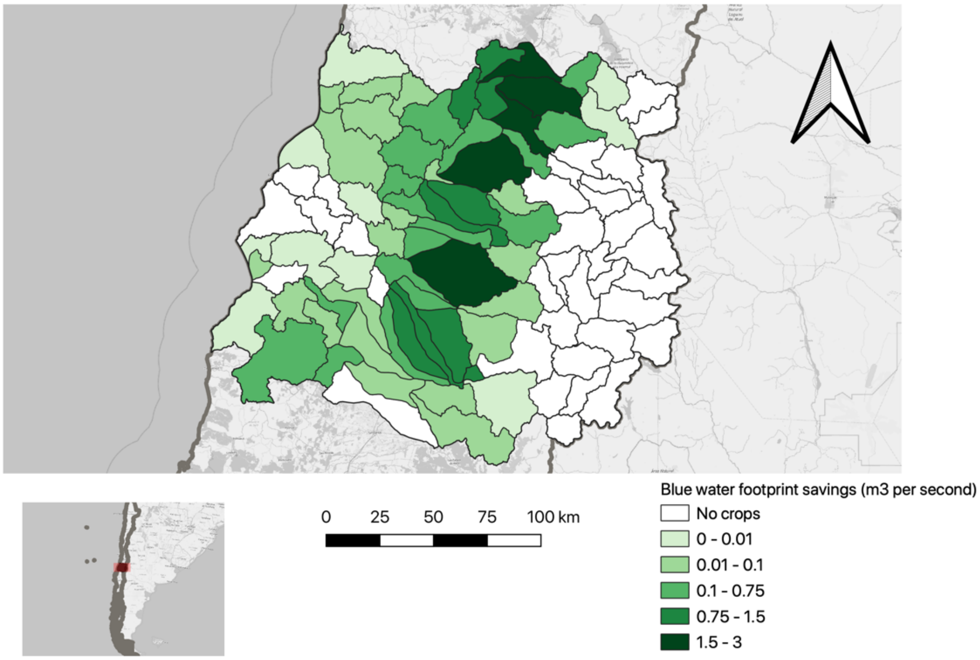


Figure 18. Blue water footprint per subsub-basins with agroforestry system (m^3/s). None of the subsub-watersheds will exceed the 0,75 m^3/s of blue water footprint under the agroforestry scenario.

The reduction of freshwater use from the monoculture to the agroforestry system in the Maule region is approximately five times, reaching a saving of 26.1 m^3/s and 8 billion m3 in one year (Table 9). Most of the reductions will occur in the subsub-watersheds located in the central zone of the region, where most of the monocultures are located. The water saving in the subsub-watershed could reach until 3 m^3/s (Figure 19).



Background source: OpenStreetMap

Figure 19. Blue water footprint savings per subsub-basins in m^3 *per second, in the scenario that all monocultures in the Maule Region change to agroforestry. The water saving could reach until 3* m^3/s *in some watersheds.*

4 Discussion

The study results look promising, as the predictions for the agroforestry system show significant results in water use reduction combined with high economic performance. The main findings are discussed in the next section, identifying new opportunities and challenges. It also discusses some limitations of the study and opportunities for further research.

4.1 Main findings

4.1.1 Performance

The results show that even using an agroforestry conversion with 50% yield reduction per plant, agroforestry could be highly productive due to the integration of multiple species. The increase of species does not increase the amount of water used. The agroforestry system has the lowest water consumption per hectare. The relation between these two factors leads to the agroforestry system reaching the highest ratio in production efficiency by water use. The following factors should be considered for the analysis of the results:

- *Yield Productivity*

The HAD project is in the second year of production, so the system performance over the 12 years has been based on future projections. One crucial assumption is the agroforestry conversion of a 50% reduction in yield per plant. Some studies have shown other conversation rate close to 30% (LaCanne & Lundgren, 2018; Niether et al., 2020). The lower conversion from other studies means that the system may perform even better, but it is an assumption that should be verified through the follow-up of the project in the following years.

- *Water footprint*

The HAD project has the lowest blue water footprint compared to the region's monocultures, but some factors could increase or decrease this difference. The blue water footprint of the monocultures was calculated based on a study in 2012 (Donoso et al., 2012), and the water footprint in the monocultures in the region may have changed in the last ten years. The farms may have applied improvements in water use management, reducing the water use difference between monocultures and agroforestry. On the other hand, we assumed that the HAD project would maintain the same water consumption in the future, but some studies suggest that the water used by the agroforestry system would be reduced when the system reaches maturation (Bayala & Prieto, 2020; Lin, 2010). If that happens, the projected difference in water consumption between monocultures and the HAD project will increase.

4.1.2 Economic Analysis

The economic results show that the HAD project has the highest profit among the crops analyzed once the systems reach full maturity. Conversely, the HAD project has the highest initial investment, making it not the best in all the economic indicators but always in the top positions. The economic indicators could increase even more for the HAD project when considering the following factors:

- *New designs*

The HAD project is a demonstrative farm, where its design focuses primarily on integrating different species, which may not necessarily have led to the most profitable design. With the results obtained from this study, we discussed alternative designs that could maximize profits with the project's founder. One suggestion was to reduce some crops of the herb layer and increase crops of the shrub layer, such as raspberry and blueberry, with considerably higher profits. However, when considering changing the design, it is crucial to consider that each layer and specie play a role in the system. The core concept of agroforestry is to enhance the diversity of species on the land, leading to greater environmental benefits (Andrade et al., 2020).

- *Organic prices*

Another factor that would increase the economic performance of the HAD project is that the production is considered organic by not using artificial pesticides and fertilizer, with the possibility of access to higher product prices (LaCanne & Lundgren, 2018). We did not consider this potential price increase in this study, and, similarly, also excluded other costs related to the organic products, such as the cost of certification (Niether et al., 2020).

- *Value added products*

The HAD project has created an innovative business plan that does not directly sell fresh fruit but incorporates new processes that can add value to the products. From the herb layer crops (mint, rosemary, lavender, and geranium), they create essential oils that the founder already tested in the market with good results. The HAD project is exploring creating natural drinks from fruits (raspberry, blueberry, lemons, oranges, grapes) and using the nuts (almond, hazel, chestnut) to create oils and “milk”. We did not consider the business model with value added in the economic analyses because the goal was to compare the same parameters to the monocultures, but it does open new opportunities for future economic studies. In the same way, to compare the same parameters with monocultures, we did not consider the economic benefits of the livestock. The animals use the in-between lines and help with the organic fertilization of the crops. The HAD project has sheep and rabbits and plans to have cows, pigs, and chickens in the future. They use the livestock for self-consumption but this also has the potential to be a profitable business (LaCanne & Lundgren, 2018).

- *Investment*

The HAD project has the highest profit in full production and NPV among the monocultures, but it did not perform best on the other economic indicators. For example, almonds have the highest IIR and ROI, raspberries has a faster payback. The difference exists because, in the analysis, the monoculture requires a lower starting investment than the agroforestry system. The most considerable cost in the initial investment for the HAD project was the acquisition of the species to plant, and due to the agroforestry conversion of 50% reduction in productivity, the system needs more plants than the monocultures. Also, the project uses non-productive plants, such as eucalyptus, for a canopy role. If agroforestry projects such as HAD could receive support in the investment, it could have the best economic indicators and stimulate the transition from monoculture to agroforestry. In Chile, one example of support from the government is the System of Incentives for the Recovery of Degraded Soils (Sistema de Incentivos para la Recuperación de Suelos Degradados, SIRSD), that have given, on average, a subsidy of € 120 per hectare, to finance activities such as plant cover and crop rotation, that agroforestry projects could apply (Artacho et al., 2009). Another way is to receive support from private international institutions specialized in sustainable farming, such as Farmland LP, Renature, PUR Project, Terra Genesis, 12Tree, Initiative 20x20, and Commonland.

4.1.3 Spatial Analysis

The spatial analysis results show the potential for water savings in the Maule watersheds in the scenario where agroforestry replaces monocultures. The expected results are significant, reducing five times the blue water footprint for fruit production in the Maule Region. Some points to consider are:

- *Watersheds Approach*

The territories' administrative divisions use fictional boundaries, such as provinces and communities. The territories' subsub-watersheds divisions use geographical boundaries instead, making it possible to have spatial results according to the water distribution in the area. We did not find parameters of recommended levels of water use for agriculture per subsub-watershed without putting too much pressure on the ecosystem. However, the study results show that the monocultures could use as much as 3 m3/second of water in some subsub-watersheds. After the change to agroforestry, it is expected that none of the subsub-watershed in the region would surpass the 0,75 m3/second. The shift in agroforestry could remove some water scarcity pressure in the watersheds' ecosystem.

- *Environmental Homogeneous Areas*

The spatial results show that the biggest water footprint savings occur in the subsub-watersheds in the central zone of the region, which corresponds to the "Intermediate Depression" area, by the environmental homogenous areas classification. Most monocultures are located in this area, and most of the water could be saved. Most subsub-watersheds without crops are in the region's east, which corresponds to the "Mountain Range" area. Also, this area shows the highest increase in temperature by the ARClim projections between 2035 and 2065 (ARClim, 2020) (Figure 7). Even if there are no crops in the watershed of the "Mountain Range" area, the water in Chile flows from east to west (from the mountains to the ocean). The increase in temperature can affect the subsub-watersheds below the hills, corresponding to the "Intermediate Depression" area. Therefore, transit to an agricultural system more resilient to climate change, such as agroforestry, could benefit this area.

- *Blue water footprint data*

We found that 22.4% of the hectares with monoculture fruits in the Maule Region did not have data for blue water footprint. As explained in the methodology section, a conservative assumption was defined using the lowest blue water footprint in the farms with fruits without data. Because the lowest water footprint belongs to the HAD project, the fruits without data do not add to water footprint savings when moving to the agroforestry system scenario. However, it is probable that these fruits without data, such as blackberry, mango, and papaya, have a higher blue water footprint than the HAD project. Therefore, the expected difference in blue water footprint between monocultures and agroforestry in the Maule region could increase even more.

4.2 Limitations

Despite the promising results of the HAD project in the study, some limitations should be considered if this kind of project will be replicated in the rest of the region:

- *Scale up*

If farmers want to be part of the transition from conventional agriculture to agroforestry, we detected some limitations in the scale-up process. First, the monoculture farms specialize in one crop, and it is easier to manage their requirements, such as water needed, nutrients, harvest planning, and logistics in the sales. Agroforestry has more diversity in the system, and a broader "know-how" and planning are necessary to manage multiple species (Andrade et al., 2020). Second, an attribute to scaling up agriculture projects is to no depend exclusively on labor work and support in technology and machinery (Andrade et al., 2020). Agroforestry minimizes tillage to protect the soil, not using heavy machines, and most of the labor work is done manually. However, to decrease the technology gap, some lightweight machinery has been developed for agroforestry (Andrade et al., 2020). Finally, as was commented before, the HAD project has a higher investment than monocultures, and despite the bigger profit in full production, the investment could be a barrier for farmers to want to start the transition to sustainable agriculture.

- *Size and location of the project*

The HAD project is a demonstrative center of two hectares. Meanwhile, on average, the fruits monoculture farms in the Maule River watershed have 25.9 hectares (Apey, 2020). Therefore, it will be necessary to study in the future the performance of agroforestry projects in the region with similar areas. Also, the HAD project is located in the environmentally homogenous areas of "Dry Coastal," and most of the monocultures are located in the "Intermediate Depression" area. The areas can have differences in micro-climate, relief of the territory, and height above sea level. Extrapolating the HAD project's expected results in the region can differ from the reality because of the difference in size and location. However, this limitation could also be an advantage. Increasing the project size could reach economies of scale and reduce costs. Also, most of the farms are in the "Intermediate Depression" because the area has better conditions for agriculture (Apey, 2020), so agroforestry projects in this area could have even better yield performance results.

- *Data collection*

Data is crucial for improving the projects and making better decisions, but some limitations in data collection related to the institutions have been detected. For example, the spatial analysis used the location of fruit plantations by georeferenced points. The result would be more accurate if we could use the farm's spatial shapes (by use of polygons) to link the plantation with the subsub-watershed. The polygon data is in the national fruit cadaster from the CIREN institution but is not openly available for research. Another limitation in data collection is that the water-related institutions are fragmented and experience coordination problems (Valdés-Pineda et al., 2014). This fragmentation makes it challenging to obtain updated water use data and clarity in the environmental protection of each subsub-watershed. A new institution is needed that can unify the others and have a more expansive view of the water issue in Chile (Valdés-Pineda et al., 2014).

4.3 Future Research

The results of the study open new opportunities for future researchers. We identified at least three main topics:

- *Follow up*

It is essential to remain that the HAD project is in the second year of production, so the system performance over the 12 years has been based on future projections. Following up on the project's performance indicators for the next years will be important. Continue measuring the results would allow us to adjust the yield production and the harvest per year until it reaches full maturity. Also, future monitoring is important to validate if the yield productivity in full maturity is stable over time or starts to decrease at some point. Additionally, it could be possible to validate if the system's water consumption would decrease after reaching maturation, as some studies suggest (Bayala & Prieto, 2020; Lin, 2010).

- *Business Model*

The HAD project's original business plan sells value-added products, not fresh fruits. Products include essential oils, drinks, plant-based milk, and regenerative meat. These products can be stored for more time and use digital platforms and e-commerce for distribution, improving the logistics compared to fresh products. Also, it could be possible to join different agroforestry farms with the same model under the same regenerative brand, reducing costs and access to better prices. These factors can improve economic performance and accelerate the transition from conventional agriculture to agroforestry, but it will be necessary to incorporate these new processes in the economic analysis of a further study.

- *Spatial planning*

The spatial result by subsub-watersheds could be used in future studies to plan the expansion or redistribution of agriculture in the region, with a better adaption to climate change and water scarcity. For example, the ARCLim projections of future precipitations show a higher decrease in the subsub-watershed of the northwest of the region (Figure 8). If we can also complement information on the risk of water scarcity per subsub-watershed, the spatial analysis results could help decide which subsub-watershed is a priority to encourage the transition to agroforestry systems. Also, because of the promising HAD project's results in the "Dry Coastal" area, it would be possible to create future agroforestry projects in this area and remove pressure from the subsub-watersheds in the "Intermediate Depression" area, which is over-exploited with agriculture and water use. Apart from the water savings, other environmental benefits from agroforestry can be considered in the spatial planning, such as enhancing biodiversity, increasing soil carbon sequestration, reducing agrochemicals pollution, and reducing erosion. Agroforestry significantly decreases soil erosion (Hunt et al., 2019; Muoni et al., 2020; Torralba et al., 2016) which could be highly beneficial for the Maule region. It is estimated that 49% of the land in the Maule Region is affected by erosion, and the erosion is mainly for anthropogenic forcings, such as conventional agriculture (Flores et al., 2010). Therefore, future reserach should identify the subsub-watersheds with more risk of water scarcity and soil erosion and prioritize future actions.

5 Conclusions

The study seeks to answer the research question: What is the potential for water savings in the Maule watersheds, moving from conventional agriculture to agroforestry without harming economic returns?

In this study, we examined the expected production, economic benefits, and water saving potential of an agroforestry case study, HAD. We found that this project has high production, economic benefit, and water saving potential. Our results show that the agroforestry system is a powerful tool to face water scarcity in the region, adapting better to climate change without decreasing productivity and economic performance.

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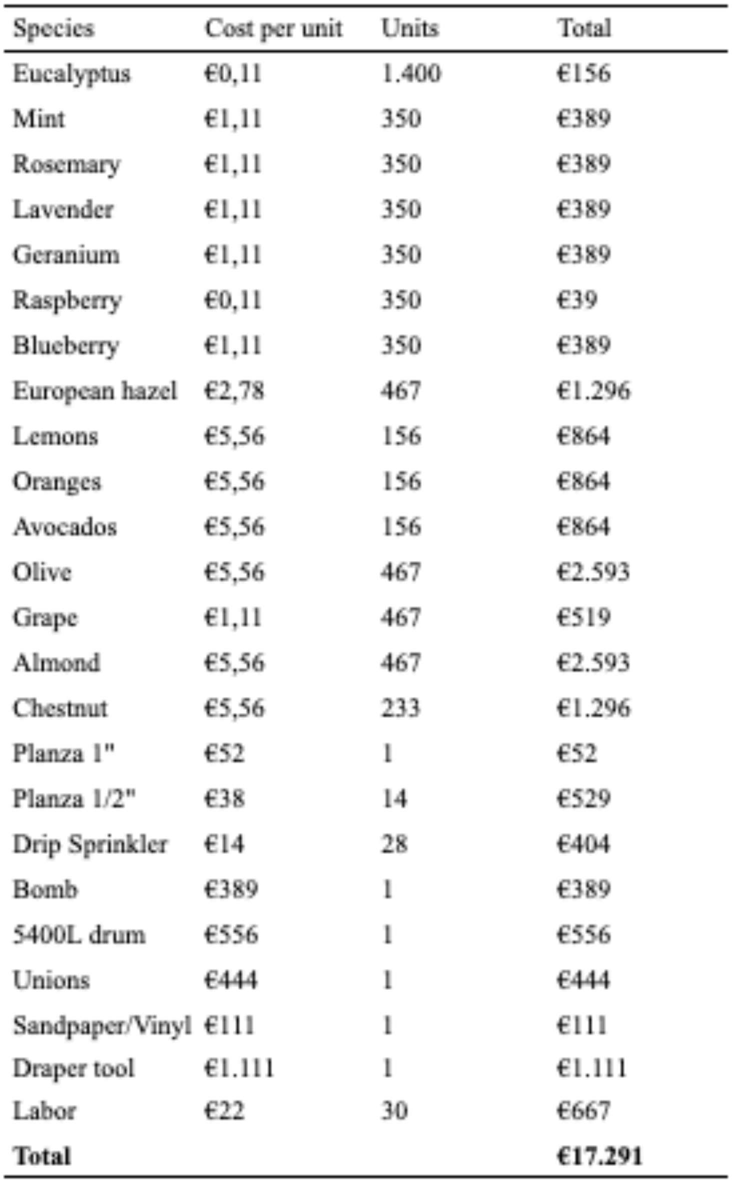
7 Appendix

Table 11. The initial investment for the HAD project specified the costs of the plants, the irrigation system, light machinery, and labor.



Species	Cost per unit	Units	Total
Eucalyptus	€0,11	1.400	€156
Mint	€1,11	350	€389
Rosemary	€1,11	350	€389
Lavender	€1,11	350	€389
Geranium	€1,11	350	€389
Raspberry	€0,11	350	€39
Blueberry	€1,11	350	€389
European hazel	€2,78	467	€1.296
Lemons	€5,56	156	€864
Oranges	€5,56	156	€864
Avocados	€5,56	156	€864
Olive	€5,56	467	€2.593
Grape	€1,11	467	€519
Almond	€5,56	467	€2.593
Chestnut	€5,56	233	€1.296
Planza 1"	€52	1	€52
Planza 1/2"	€38	14	€529
Drip Sprinkler	€14	28	€404
Bomb	€389	1	€389
5400L drum	€556	1	€556
Unions	€444	1	€444
Sandpaper/Vinyl	€111	1	€111
Draper tool	€1.111	1	€1.111
Labor	€22	30	€667
Total			**€17.291**