Soft fruits and Doñana: Can Regenerative Agriculture Balance Production and Sustainability?

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This research was subsidised by the Embassy of the Kingdom of the Netherlands in Madrid (5200047572) and AquaConnect project (6160021511).

Wageningen Environmental Research
Wageningen, September 2025

Reviewed by:
Arjan Budding
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Approved for publication:
Karin Andeweg

Report 3455
ISSN 1566-7197

Angel de Miguel Garcia, Alex Fernández Poulussen, Sebastién Guery, Oscar Gody, 2025. *Soft fruits and Doñana: Can Regenerative Agriculture Balance Production and Sustainability?* Wageningen, Wageningen Environmental Research, Report 3455. 28 pp.; 9 fig.; 4 tab.; 27 ref.

Keywords: regenerative agriculture, water, soil, biodiversity, impacts, soft fruits

The pdf file is free of charge and can be downloaded at https://doi.org/10.18174/700556 or via the website www.wur.nl/environmental-research (scroll down to Publications – Wageningen Environmental Research reports). Wageningen Environmental Research does not deliver printed versions of the Wageningen Environmental Research reports.

Wageningen Environmental Research Report 3455 | ISSN 1566-7197

Photo cover: vegetation strips to favour biocontrol in a blueberry plantation in Huelva.
Author: Angel de Miguel Garcia

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Verification

Report: 3455
Project number: 5200048531

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date: September 2025

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Summary

Doñana National Park, located in south-western Spain, is one of the most important wetlands in Europe. It is renowned for its extraordinary biodiversity and for being a key habitat for migratory birds, endangered species such as the Iberian lynx, and for hosting unique ecosystems including marshes, dunes and forests. However, this natural area and its surrounding forest are under severe pressure from water scarcity, intensified agricultural and tourism activities, population pressure, pollution and climate change.

The production of 'soft fruit', a term typically used to refer to berries (strawberries, blueberries, raspberries and blackberries) is a major agricultural activity in the vicinity of Doñana National Park. This region has become one of the leading berry production hubs in Europe. But in recent years, intensive agriculture has been the subject of growing international concern due to its potential environmental impact, putting the area at the centre of the sustainability debate.

In this context, **regenerative agriculture** arises as a promising approach capable of restoring ecosystems and enhancing produce through soil conservation, efficient water use and biodiversity protection. However, this review shows that, although there is **potential for applying this model in the berry industry**, its adoption **is not fully or automatically** aligned with current production conditions, thus calling for careful deliberation and adaptation. Opportunities and limitations can be summarised as:

Opportunities
- Greater viability for multiannual crops (blueberries and raspberries), where regenerative practices related to soil and biodiversity can be introduced. However, a large water consumption is expected.
- Potential for soilless systems* through circularity strategies (effluent recirculation, nature-based solutions).
  * Soilless systems can cultivate plants without traditional soil and rely on nutrient-rich water.
- Growing interest in European markets for produce with verifiable regenerative qualities, which opens up options for market differentiation.

Limitations:
- Much of the industry relies on intensive systems either with or without soil, which are difficult to align with regenerative principles.
- High transition costs and lack of clear incentives for growers.
- Lack of specific standards and certifications to provide credibility.
- Low end-consumer awareness of regenerative agriculture.

Recommendations
- Progress gradually, starting with crops that are more compatible with the regenerative approach.
- Promote applied research and pilot projects to adapt practices to the berry context.
- Design economic incentives and payment schemes for ecosystem services to make the transition viable.
- Define a reliable, distinguished certification framework.
- Strengthen collaboration between growers, institutions, marketers and government bodies to integrate this model into the Doñana Action Framework.

Regenerative agriculture **should not be understood as a perfect or immediate solution** for the soft fruit industry in Doñana. Rather, it is an approach with future potential that can help to restore ecosystems, improve the reputation of the industry and open up new market opportunities, as long as it implemented through specific, gradual measures. Its success will depend on how current limitations are dealt with and the collective ability to combine innovation, incentives and shared governance.

Acknowledgments

This work would not have been possible without the support and agreement reached between the WRAP collective action initiative in Spain, led by Good Stuff International (GSI), and the Embassy of the Kingdom of the Netherlands in Spain, which, through its agricultural counsellor, Machiel Kommers, and his team, provided funding for this project.

We would like to especially thank several individuals and organisations who provided valuable information, support, and contacts throughout the implementation of the project. In particular, we would like to mention Pedro Báñez, secretary of the Irrigation Community of Huelva County, for his time and dedication in connecting us with producers and for raising awareness about the water, social, and sectoral reality of the area. We would also like to thank Felipe Fuentelsaz of WWF Spain, who shared his knowledge of the local situation from a conservation perspective and the connection between agricultural activity and the ecosystems of Doñana. To the representatives of marketing companies such as Berries' Pride, DPS, SVZ, and Angus Fruit, specifically José Castilla, Alejandro Marín, Silvi Navarrete, and Maria Jesús Martínez, for sharing their knowledge of the value chain and for facilitating contacts with local suppliers. To the Institute for Agricultural and Fisheries Research and Training of the Andalusian Regional Government (IFAPA), especially Pedro Gavilán, Luis Miranda, and Miguel Talavera, for sharing their extensive knowledge and showcasing their experimentation and testing center.

Finally, and with special thanks, we would like to thank all the producers who opened their farms to showcase their practices and explain firsthand the measures they take in berry cultivation. We also thank the technical office of the Doñana Action Framework for their participation in the activities. Due to space and discretion, we cannot mention all the participating companies and producers, but we would like to acknowledge their interest, their willingness to collaborate, and all those who participated in the participatory workshop in El Rocío, as well as in the surveys conducted.

1 Introduction

1.1 Background

Doñana National Park, located in south-western Spain, is one of the most important wetlands in Europe. It is renowned for its extraordinary biodiversity and for being a key habitat for migratory birds, endangered species such as the Iberian lynx, and for hosting unique ecosystems including marshes, dunes and forests. However, the park and its surroundings are facing a number of environmental and socio-economic challenges that are threatening itsexistence. Water scarcity, intensified agricultural and tourism activity, population pressure, pollution and climate change are putting a strain on ecosystems and biodiversity.

Addressing these problems requires a coordinated effort between productive industries and activities, local authorities and conservation organisations in order to implement sustainable water management, regulate farming practices and mitigate climate risks. Without urgent intervention, Doñana's unique ecosystems could suffer irreversible damage, jeopardising its position as one of Europe's most important nature reserves.

Figure 1 *La Rocina Stream in spring 2025.*

The production of soft fruit, a term typically used to refer to berries (strawberries, blueberries, raspberries and blackberries) is a major agricultural activity in the vicinity of Doñana National Park. This region has become one of the leading berry production hubs in Europe, supplying several European markets, especially in winter, thanks to its mild climate, fertile soils and access to water resources. In recent years, intensive soft fruit farming has been the subject of growing international concern due to its potential environmental impact, particularly due to groundwater abstraction. This practice has given rise to environmental law disputes related to land and water use, as excessive groundwater abstraction is endangering Doñana's ecosystem.

The "Water Roadmap Collective Action Project (Southern Spain)" initiative promoted by WRAP and several European food companies, led by Good Stuff International (GSI), has established several lines of work to help improve the health and resilience of this water situation, one of them being the promotion of best agricultural practices. To this end, the initiative has created a multi-stakeholder platform that serves as a tool to define the actions to be carried out. As part of the line of work related to good agricultural practices, the initiative, together with the British Embassy in the Netherlands and Wageningen University and Research (WUR) wants to explore whether the concept of **regenerative agriculture** can be applied to intensive soft fruit cultivation, and to assess the extent to which the regenerative model can be widely adopted.

For more information about the platform and a complete description of the water, socio-economic and environmental context surrounding this production area, as well as the main pressures on the conservation of Doñana National Park and its surrounding forest, please visit the Collective Action Portal for Water in Doñana-Huelva[1].

1.2 A Plan for Sustainability: The Doñana Action Frameworks

In order to curb environmental degradation and restore ecological balance in Doñana National Park, the Spanish Ministry for Ecological Transition and the Demographic Challenge (MITECO), together with Andalusia's Regional Government, has launched the Doñana Action Framework, a comprehensive plan that seeks to bring environmental protection into line with economic and social development in the region. The agri-food industry is a priority under this plan, with measures that promote sustainability without compromising competitiveness. These include:

- Rewilding farmland
- Promoting rainfed crops
- Transitioning to organic production models
- Optimising water and fertiliser use through digitalisation

However, the adoption of these initiatives depends largely on the willingness of growers, especially in an industry where yield per hectare is much higher than for any conventional crop.

1.3 Objectives

Focusing on water, soil and biodiversity management on farms, but without losing sight of the farms' own relationship with their environment, this research aims to assess how regenerative agriculture principles could be applied to a type of intensive farming that uses plastic tunnels.

To this end, the type of good regenerative practices that could help reduce water consumption, improve soil health and increase biodiversity have been identified and critically analysed. Using technical, economic and social criteria, this work seeks to prioritise the type of practices that have greater potential for adoption, and to identify the main barriers and possible tools to overcome them. Finally, through a participatory strategy, the aim is to design a range of "regenerative agriculture models" in line with the reality of the industry, as well as with the measures proposed in the Doñana Action Framework. These models must be able to respond to different production scenarios and be compatible with the surrounding environment.

This whole process has been carried out through:

1. A review of the existing scientific and technical literature
2. Interviews with local stakeholders and individual farm visits
3. Surveys of growers and other players in the value chain
4. A participatory workshop

This report aims to summarise the main results obtained during the process and outline potential lines of action that could be pursued in future.

[1] https://storymaps.arcgis.com/stories/c7b0a68cedf1469c849d9b7937c0a89b

2 What is Regenerative Agriculture?

Regenerative agriculture (RA) is an emerging alternative to traditional agriculture that seeks to restore farming ecosystems through practices that improve soil health, biodiversity and the efficient use of resources required in farming, particularly water. Through a holistic, systemic approach, this model seeks to restore the agrosystem's ability to cope with the possible effects of climate change, while promoting long-term economic profitability. Regenerative models also seek harmony with the surrounding environment, taking into account the environmental and social characteristics of the areas where they are implemented. Although there is still no agreed definition of RA, its main objectives are to use soil as a base, to restore and support a range of ecosystem services, and to improve the environmental and socio-economic aspects of sustainable food production (Schreefel et al., 2020).

Under the premise of **"doing it better"**, RA is a results-based approach, relying on the adoption of good agricultural practices with positive impacts (restoration) that can be measured and demonstrated in the long term. RA is governed by 6 fundamental principles:
- P1. Minimise soil disturbance
- P2. Keep the soil covered
- P3. Enhance plant and microbial diversity
- P4. Keep living roots for as long as possible
- P5. Integrate livestock (or by-products) into crop production
- P6. Minimise the application of chemical fertilisers and pesticides, together with the use of natural resources.

The concept of regenerative agriculture is gaining momentum across various fields, from the scientific community to agribusiness, as a possible tool to bring food production into line with a long-term sustainability strategy. Proof of this is the growing number of scientific publications on the subject released in the last 5 years (Figure 2) and the increasing number of institutions that use this term within their strategies. According to some studies, the regenerative agriculture market could account for around 14% of total food production by 2035[2].

Nevertheless, it is important to note that rapidly growing interest in regenerative agriculture may cause certain sectors to trivialise the concept, which could be used as a "greenwashing"[3] strategy rather than as a real opportunity for change.

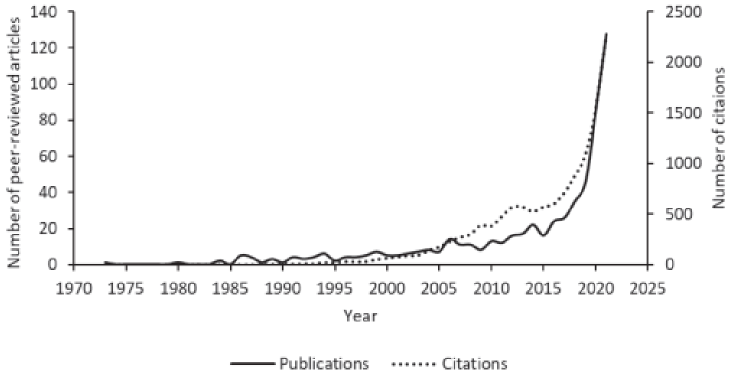

Figure 2 *Trend of the number of scientific publications and citations referring to regenerative agriculture (Schreefel et al., 2020).*

2 www.polarismarketresearch.com.
3 Misleading practice whereby companies or brands present themselves as more environmentally friendly than they really are, with the aim of boosting their image and attracting sustainability-conscious consumers.

2.1 Regenerative Agriculture and Berry Production: Antagonism or Synergy?

In the context of Doñana, applying the RA concept to the soft fruit industry would imply acknowledging the **interdependence between agriculture, the environment and local communities**. This means working not only to boost farming production, but also to **protect the surrounding ecosystems** by reducing the potential impact of farms and strengthening the environment's resilience to climate change and water variability.

There is a wide range of good regenerative agricultural practices applicable to soft fruit production that can significantly improve the use of natural resources and minimise their impacts. Despite this, whether due to cost, technological difficulties or simple ignorance, these practices are not widely applied by all growers.

The concept of regenerative agriculture models could therefore help the industry to better integrate sustainable practices, highlighting the need for a coordinated effort between growers, marketers, consumers and public institutions. The compatibility of these regenerative models with a range of measures proposed by the Doñana Action Framework can also be a catalyst for their adoption.

How the concept of regenerative agriculture could be applied to highly modified farming systems, which often use plastic tunnels, is yet to be determined. What is clear is that the practicality of its implementation depends not only on technical factors, but also on economic and social ones.

A preliminary analysis of the compatibility between the principles governing RA and the different types of production in the berry industry in Huelva gives rise to the following suggestions (see Table 1 for more details):

- ***Production of strawberries (or other annual crops) in soil***. This system requires the crop to be replanted annually and therefore involves a high level of soil intervention (including annual soil disinfection), which makes it difficult to apply many of the regenerative principles.
- ***Production of blueberries and raspberries (or other multiannual crops) in soil***. This system possibly has the greatest potential for the application of RA principles, as it requires minimal soil intervention. For example, the use of cover crops on pathways can clearly improve soil health, provide shelter for predators and act as bait plants for pest control.
- ***Production in soilless systems (bags or hydroponics)***. Although heavily modified, these systems could go some way towards improving soil health, reducing soil disturbance and allowing certain beneficial crops to be established. They also allow for greater control of the water and nutrient cycle, supporting their reuse and minimising the release of pollutants into the environment.

For all production systems identified, the principles of incorporating organic by-products (greater circularity) also apply, as well as the efficient use of inputs (water, fertilisers and other agrochemicals). Naturalisation of non-crop areas, such as farm perimeters, road humps, drainage systems, water reservoirs, etc., can also have a major positive impact on the sustainability of the system, connecting farms with their environment.

Table 1 *Compatibility of RA principles with different types of berry production in Huelva (the colour scale represents compatibility: red, not very compatible; yellow, compatible, although with limitations; green, compatible).*

<table>
<tr><th>RA Principles</th><th>Application to strawberries grown in soil</th><th>Application to blueberries and raspberries grown in soil</th><th>Application to crop grown in substrate or hydroponically</th></tr>
<tr><td>P1 - Minimise soil disturbance</td><td>Low compatibility due to high soil disturbance during the preparation phase.
Possibility of maintaining ridges for several seasons or even creating ridges alternately (using the streets for the construction of new ridges).</td><td>Applicable to the area between crop rows.</td><td>Applicable to the soil on the farm, mainly if the substrate is placed on a tray.</td></tr>
<tr><td>P2 - Use of cover crops</td><td>Only compatible in non-crop areas, either on pathways or other non-crop areas.
Possible also in period between crops but implying a large water consumption.</td><td colspan="2">Applicable to farm pathways and non-crop areas.
Native species can be used as shelter for beneficial organisms, bait plants or even as a green manure/nitrogen-fixing plant.</td></tr>
<tr><td rowspan="3">P3 - Enhance biodiversity: soil, farm and landscape</td><td>At soil level, the usual practice of soil disinfection at the start of the season limits its application.</td><td colspan="2">At soil level, due to the gradual improvement of soil properties.</td></tr>
<tr><td colspan="3">At farm level, it could be done by improving non-crop areas.</td></tr>
<tr><td colspan="3">At landscape level, close relationship with neighbouring ecosystems depending on the location of the farm.</td></tr>
<tr><td>P4 - Keep living roots for as long as possible</td><td>Difficult to apply due to the current system, whereby the crop and its root system are removed after harvest (early summer).</td><td>Multiannual crop that could also benefit from growing alongside cover crops.</td><td>Through the use of cover crops in specific areas of the facility itself.</td></tr>
<tr><td>P5 - Integrate livestock (or by-products)</td><td colspan="3">Direct: difficult to directly integrate livestock, even when the crop is removed
By-products: possible, mainly in terms of integrating agri-food by-products (compost, organic matter, etc.).</td></tr>
<tr><td>P6 - Precise application of inputs</td><td colspan="3">Highly applicable, with several good practices available that focus on minimising the use of inputs (water, nutrients, agrochemicals) or the output of pollutants from the system.</td></tr>
</table>

3 Potential Regenerative Practices Applicable to the Berry Industry

The application of good agricultural practices to the berry industry is nothing new, and thanks to the coordinated effort of growers and research centres, many of these practices have already been evaluated and adapted to local conditions, with more and more growers willing to apply them. These good practices include efficient water use, integrated pest management, soil conservation and reduced agrochemical use. Their adoption is essential to ensure sustainable, profitable and environmentally friendly production. They also promote product quality and access to demanding markets. A detailed analysis of these practices, how they link to some of the principles of regenerative agriculture and their potential environmental impact is presented below.

3.1 Good Water Management Practices

3.1.1 Current Situation

The efficient use of water is one of the great 'workhorses' in the berry industry. Although growers have already made significant progress in this respect, there is still much room for improvement to considerably reduce the need for water and nutrients, without significantly impacting their yields. Such practices would be directly compatible with the "minimise the use of natural resources" objective as foreseen by the principles of regenerative agriculture.

According to a study carried out by Garcia-Morillo et al., (2015) on 22 farms in the Huelva area, water applied by strawberry growers varies significantly, ranging from 4,100 to 15,200 m^3/ha per season, with no direct linear relationship between water use and yields obtained. However, it is important to note that the water consumption figures presented in this study were collected already more than 10 years ago. A significant improvement is expected over the last years, with reduction over 30%, due to the large adoption of water saving technologies by producers, as observed during the consultation process.

Water use is not only important during the strawberry cultivation stage, but taking care of this during the soil preparation and planting stages can save a significant amount of water. Another study carried out by IFAPA obtained similar results, with an average water use of about 7600 m^3/ha (Gavilán et al., 2021). Raspberry and blueberry cultivation also consume a considerable amount of water, with averages of around 4292 m^3/ha and 8752 m^3/ha respectively (Gavilan et al., 2024).

If we look at the amount of water needed to yield one unit of produce, a concept known as the water footprint, strawberry cultivation in the Huelva area moves in the range of 90-110 m^3/tonne (Gavilán et al., 2021). For raspberry and blueberry cultivation, the average water footprint is 245 and 280 m^3/tonne respectively (Gavilan et al., 2024).

3.1.2 Strategies to Reduce Water Consumption

The adoption of efficient irrigation techniques, not only through the use of localised irrigation systems, but also by scheduling irrigation according to the actual demand of the crop, can save a significant amount of water (and nutrients). As can be seen in Table 2, the use of optimised irrigation scheduling based on combined information from soil moisture sensors, predictions of weather conditions both inside and outside the tunnel, and the use of local crop coefficients (Kc) can help save 20–44% of water compared to traditional management. This is directly reflected in the water footprint, which can be as low as 55–60 m^3 water per ton of strawberries produced, almost 40% less than that observed in conventional systems (Gavilán et al., 2021). For blueberry and raspberry cultivation, the water footprint can be as low as 200 m^3 per ton and 180 m^3 per ton, a reduction of 17% and 35% respectively.

Although the initial investment in these systems is high, it is important to note that the costs of managing irrigation systems and the volume of water used during the season represent 4–5% of total operating costs, being much lower in more efficient systems (García Morillo et al., 2015). But managing information from various sources can be difficult for growers when scheduling irrigation. Nowadays, there are several tools, both free and paid, that allow for more or less automated management. In this regard, IFAPA has developed the free app Riego Berry[4], an intuitive, user-friendly tool that helps to save around 40% of water for strawberries and 15-30% for raspberries and blueberries (Gavilan et al., 2024).

The use of deficit irrigation strategies (defined as a strategy when less water is applied than required to save water and improve profitability rather than maximising yield per hectare) could also be an attractive option to help growers reduce water consumption, particularly in situations of water scarcity (see Table 2). For example, as reported by Ariza et al., (2021), irrigation efficiency and fruit quality of highly productive strawberry varieties can be improved by deficit irrigation strategies (reducing plant water requirements by 20–40%), maintaining profitability despite potential yield losses (20–30% of total yield).

Table 2 *Table summarising the results obtained by various authors when evaluating different water-saving technologies for strawberry cultivation in the Huelva area.*

Reference	Technology used	Water use (m^3/ha)	Yield (t/ha)	Water productivity (kg/m^3)	Water saving benefit (%)
(Lozano et al., 2016)	Estimation of ***crop coefficients*** for irrigation scheduling	5,500–8000	48	8.7–14.5	Irrigation efficiency up to 80%
(García-Tejero et al., 2018)	Use of ***local crop coefficient*** and ETc inside and outside of tunnel	3,500–4,000	~40–45	~11–13	—
(Gavilán et al., 2021)	***Scheduled irrigation*** according to crop coefficient and irrigation uniformity control	Farmer: 7,622 Scheduled: 4,252	~40–48	Farmer: 8.9 Scheduled: 14.5–18	44% (scheduled vs. farmer)
(García Morillo et al., 2017)	***Efficient irrigation scheduling*** by modelling (HYDRUS 2-D)	~4,200–4,400	~45	~11–13	~20–25% (model vs. farmer)
(Gavilan et al., 2024)	Use of the Berry app for ***irrigation scheduling**** *S = strawberry B = blueberry R = raspberry	Conventional S: 8,043 B: 8,752 R: 4,292 Scheduled: S: 4,740: B: 6,177 R: 3,053:	Conventional S: 69.7 B: 31.1 R: 14.1 Scheduled: S: 68.9 B: 30.6 R: 14.1:	Conventional S: 41 B: 59 R: 59 Scheduled: S: 67 B: 81 R: 84:	Scheduled vs Conventional: S: 42% B: 30% R: 28%
(Ariza et al., 2021)	***Deficit irrigation*** (80% of water required) using short pulses (20 minutes)	Deficit: 2,700 Conventional: 3,700	Deficit: 60 Conventional: 72	Increases of around 20%	20%
(Marcellini et al., 2022)	***Deficit irrigation*** (80%)	-	10% less than conventional irrigation	14% higher than conventional irrigation	~20% (deficit vs. conventional)

The type of production system also affects water consumption. Although most berry growers in the Doñana area use a very similar system, with cultivation in soil and in tunnels, there are certain differences that may have a significant impact on factors related to water use, in terms of both the amount of irrigation applied and the demand per unit of produce (Table 3). In this regard, the use of soilless systems (hydroponics or containers), although costly to implement, can help to reduce water consumption by up to 40% compared to conventional systems, while maintaining very high yields. On the other hand, organically managed systems, even with a lower water demand, have more limited yields, meaning their water footprint is higher than that of conventional systems.

4 https://www.juntadeandalucia.es/servicios/sede/tramites/procedimientos/detalle/24730.html

Recirculation of water from irrigation drains, especially for soilless crops (hydroponics or potting), can also help to reduce the total water (and nutrients) required on the farm. However, this method has limitations, as the accumulation of salt in the water reduces its recirculation level to 25–40%.

In addition to irrigation, a very important factor to take into account is the deterioration of groundwater quality due to the possible leaching of nitrates as a result of disinfection, but above all fertilisation. This phenomenon, which is particularly significant in sandy soils, can have a highly negative effect on surrounding groundwater, as evidenced by the "Condado" and "La Rocina" water bodies being declared as vulnerable to nitrate pollution (Green et al., 2024). In case of pollution, organically managed systems, followed by those with integrated management, perform best (Table 3). However, a proper and effective management of the organic fertilisation is also essential to avoid the leaching of nutrients through the mineralisation of the organic amendment applied.

It should be noted that, although collecting and storing effluent from soilless systems for subsequent recirculation can reduce water consumption, this may have a negative effect on pollution due to the accumulation of nitrates in irrigation water. For this reason, the final discharge of this effluent can have very high nutrient levels, reaching up to 60% of applied nutrients (Garcia-Caparros et al., 2017), and it is highly recommended that they be treated using nature-based technologies prior to discharge.

Table 3 *Comparison of different strawberry production systems in Huelva (Romero-Gámez and Suárez-Rey, 2020).*

	Macro tunnel in soil, with integrated management	Macro tunnel in soil, with conventional management	Macro tunnel in soil, with organic management	Soilless macro tunnel, with integrated management	Soilless macro tunnel, with conventional management	Micro tunnel in soil, with integrated management	Micro tunnel in soil, with conventional management	Conventional open system
Productivity (tonne/ha)	55	55	32	59	60	55	55	13
Irrigation applied (m^3/ha)	7,529	7,768	4,000	4,500	4,725	7,529	7,768	1,900
Water productivity (kg/m^3)	7.31	7.08	8.00	13.11	12.70	7.31	7.08	6.84
Water footprint (m^3/tonne)	136.9	141.2	125.0	76.3	78.8	136.9	141.2	146.2
Nitrate leaching (kg/ha)	73.5	80.9	0	39.2	185.6	72.5	80.9	292.5

3.2 Good Soil Management Practices

3.2.1 Current Situation

One of the basic objectives of regenerative agriculture is to achieve healthier soil by adopting less aggressive practices (such as use of chemicals), mainly focused on minimising soil disturbance, the use of ground cover or even crop diversification. Soil management in berry cultivation can be divided into two main groups: annual crops and multiannual crops. Each of them has some highly important characteristics when considered from the perspective of soil health and potential good practices that could be implemented. The main tasks carried out may be summarised as follows:

- *Annual crops*, such as strawberries, where soil preparation begins with soil disinfection during the summer months to eliminate pathogens. This is followed by deep tillage to improve soil structure, then levelling, which is important to avoid waterlogging and facilitate irrigation. Afterwards, organic matter is added and basal fertiliser is applied to improve fertility. Raised ridges are then formed and covered with plastic (mulch), leaving the soil ready for planting. Once the plant begins to grow, the soil along the pathways is kept free of vegetation through the use of herbicides or other means of mechanical removal. All these tasks, while necessary to ensure high productivity in an intensive monoculture system, cause a significant change in soil structure and ecology.

- *Multiannual crops*, such as blueberries or raspberries, where the need for tillage and soil preparation focuses on the year of crop establishment, and is reduced or even not required in subsequent years, being relegated to vegetation control on ridges and pathways. This control, which can be done by chemical or mechanical means, will have a certain impact depending on the level of soil disturbance.

3.2.2 Strategies to Improve Soil Health

Soil Disinfection Tasks
Soil disinfection is seen as a fundamental strategy to ensure the productivity of annual crops such as strawberries, and is the main strategy used to eliminate soil pathogens, nematodes and weeds to ensure a good crop start. The most commonly used method of disinfection is chemical disinfection with products such as 1,3-Dichloropropene and Chloropicrin, which have an efficacy of around 90% (Table 4). However, in recent years, other more sustainable techniques have also been used. These include solarisation, which consists of covering wet soil with transparent plastic during the hottest months, or biosolarisation, which consists of adding organic by-products to the soil. These techniques can also be highly effective. The latter can also help to improve both soil structure and fertility, as well as to reduce the use of agrochemicals. Although a promising technique, its adoption is still limited among some farmers due to the need for technical expertise and the variability of results in different contexts (de los Santos et al., 2021).

Table 4 *Effects of various soil disinfection treatments. Table created based on results obtained in various trials (de los Santos et al., 2021; Domínguez et al., 2014; Talavera et al., 2019).*

Treatment	Type	Controlled Pathogens	Average efficacy
1,3-Dichloropropene + Chloropicrin	Chemical	Nematodes (*M. hapla*, *P. penetrans*), fungi	>90%
Chloropicrin alone	Chemical	*Fusarium spp.*, *M. phaseolina*.	>90%
Dazomet	Chemical	Nematodes, *Fusarium spp.*	50–90%
Metam sodium	Chemical	Nematodes, fungi	40–80%
Dimethyl disulfide (DMDS)	Chemical	*Fusarium spp.*, *M. phaseolina*.	>90%
Methyl iodide + Chloropicrin	Chemical	Nematodes (*M. hapla*), fungi	>70% nematodes, >90% fungi
Sodium azide	Chemical	Nematodes	<40%
Furfural	Chemical	Nematodes	<40%
Allyl isothiocyanate	Chemical (alternative)	*Fusarium spp.*, *M. phaseolina*.	>90%
Biosolarisation with chicken manure	Non-chemical	Nematodes and fungi (*Fusarium spp.*, *M. phaseolina*)	68–80% nematodes, 79–80% fungi
Biosolarisation + Trichoderma	Non-chemical	Fungi	High plant survival
Biosolarisation with beet vinasse	Non-chemical	Fungi	Moderate efficacy
Biosolarisation with *Brassica* pellets	Non-chemical	Fungi	Moderate efficacy
Biosolarisation with dried (olive) pomace	Non-chemical	Fungi	Low to moderate efficacy
Untreated control (fermented manure only)	Control	—	Low efficacy / high mortality

Although the positive effects of disinfection on strawberry crop yield have been proven extensively, it is important to note that this technique does not distinguish between beneficial and harmful micro-organisms, leading to a reduction of useful microbiota, such as growth-promoting bacteria and mycorrhizal fungi. It also leads to a clear imbalance in the soil ecosystem, reducing microbial life in the soil and making it more vulnerable to new infections or recolonisation by opportunistic pathogens. In this regard, the use of regenerative techniques, although limited, can help to reduce unwanted effects. To this end, the following is recommended:

- Alternate methods (chemical and physical) with regenerative practices such as organic matter inputs, biofumigation or crop rotation.
- Promote the restoration of beneficial microbiota through specific organic amendments and microbial preparations.
- Conduct soil analysis before treatment, in order to apply disinfection only if necessary.

Use of Soil Amendments
The use of organic amendments, such as compost, biochar, plant residues or manures, is proving to be a key strategy to improve soil health and optimise berry production (strawberry, blueberry, blackberry, raspberry). They provide carbon and nutrients, increasing the soil's capacity to retain water and essential nutrients, supporting constant availability to plant roots. Organic matter improves the formation of stable aggregates, increases porosity and reduces compaction, facilitating root penetration and healthy root system development in berry plants. They also promote a favourable environment for the growth and diversity of beneficial micro-organisms in the soil. This microbiota is essential for nutrient recycling, mineralisation of organic matter and maintaining the soil's natural fertility.

Biochar, a carbonaceous material obtained by pyrolysis of plant biomass, has become an organic amendment of increasing relevance in sustainable farming systems. Its porous structure and high specific surface area give it unique properties that support soil health and crop development. In sandy soils, where water and nutrient retention is limited, biochar acts as a sponge, improving water holding capacity and reducing leaching of nutrients such as nitrogen and potassium. Several studies have shown that the application of biochar combined with compost or composted manure improves key parameters such as root development, plant mass and fruit yield during the first years of crop establishment (Alghamdi et al., 2023; Chiomento et al., 2021; Sales et al., 2022). Furthermore, in regions where farm waste management is a priority, the use of biochar made from pruning residues (e.g. from fruit trees or vines) represents a sustainable, local alternative, with the potential to reduce costs and close nutrient cycles.

Use of Soil Covers and Organic Mulches
Although little adopted by farmers, the use of soil covers, whether living or non-living (also known as mulching), especially for blueberries, can have great potential, as in addition to helping control "*weeds*"[5], it can help improve soil health and increase carbon storage. According to work carried out by several researchers, this type of management is effective for controlling weeds, although the results vary according to the type of material or plant used. For example, pine needles suppress weeds better, while certain composts may favour the growth of some unwanted species, but at the same time improve the nutrition and strength of the plants (Burkhard et al., 2009; Rudolph et al., 2020; Smith et al., 2025). According to these studies, the potential competition between living mulch and blueberry crops is minimal, if properly managed. The use of innovative technologies, such as robotic systems for mechanical cover crop management, seeks to facilitate the adoption of these practices. This would therefore reduce reliance on plastic and improve both environmental sustainability and effective soil management for soft fruit crops. Finally, it is important to note that the regular use of organic mulches, such as shredded bark or prunings, significantly increases the carbon stored in the soil, thus favouring climate change mitigation and soil fertility in the medium term.

The use of biodegradable mulch can also be an alternative to the use of plastics. Although this type of material generally breaks down faster, its performance is comparable to polyethylene in terms of temperature, soil moisture, weed control and productivity (Wang et al., 2022). These include biodegradable plastics (BDMs) and biodegradable paper mulch. The latter usually maintains a slightly lower soil temperature than black plastic, but helps to enhance biological activity in the soil, leaving no polluting residues after decomposition (Pinto et al., 2022).

Extending the life of ridges or using multi-year varieties
Although not very common in the area, using the same ridge for several strawberry seasons (producers have been reported to have managed to use it for up to 3-4 crops) could facilitate the implementation of regenerative techniques, also reducing implementation costs and plastic waste production, as the same irrigation tape can be used for multiple seasons. The use of varieties that allow for multi-year cultivation, as is done in other more northern areas, could be another option to explore, also allowing for combining multi-year systems with other crop rotations that could be beneficial at the soil level.

[5] The term "weeds", although widely used, has a negative connotation, however it refers to a type of vegetation that can have positive effects from an ecological point of view.

3.3 Good Biodiversity Management Practices

Fostering biodiversity is one of the key objectives of regenerative agriculture, as it can help improve soil health while significantly reducing the use of external inputs. At the same time, greater biodiversity both on the farm itself and in the surrounding area has a direct impact on the health of surrounding ecosystems.

Pollinators play a crucial role in berry production and quality, increasing fruit weight and seed fertility, which improves fruit shape and commercial value. Lack of biological pollination reduces yields by 25%, which significantly impacts the farming economy (Gudowska et al., 2024). The global loss of pollinators due to intensive farming practices, excessive use of pesticides and the destruction of natural habitats threatens the sustainability of these crops (Fountain, 2022). For this reason, purchasing commercial hives to encourage pollination by honey bees is a common practice among berry growers in the Doñana area, involving significant costs for farms.

In this context, implementing good agricultural practices aimed at conserving and promoting the biodiversity of natural pollinators may be more effective in sustaining and increasing productivity in the long term. These practices can also be an effective strategy for biological pest control, by encouraging not only the presence of pollinating organisms, but also parasites and predators. Good practices in favour of these local communities include (Feltham et al., 2015; Fountain, 2022; Howard et al., 2021; Trillo et al., 2020):

1. **Sowing flower strips and ecological corridors:** planting wildflower strips near the crops (either inside tunnels or in neighbouring areas) increases the abundance and diversity of pollinators, boosting visits to the crops by up to 25%. These strips also provide shelter and alternative food resources for pollinators and natural enemies of pests (such as hoverflies, lacewings or parasitoids), encouraging them to stay and reproduce near the main crop. The use of perennials weeds, such as fennel or laminacae varieties has been also reported positive by several farmers.
2. **Integrated Pest Management (IPM) and reduction of pesticides:** Minimising or even eliminating pesticide use, especially at critical flowering periods, protects pollinator populations and beneficial insects that control pests. Integrating biological and cultural methods helps to reduce chemical dependency.
3. **Diversification of the farming landscape:** maintaining natural or semi-natural habitats close to crops, such as forests or grasslands, supports the presence of pollinators and natural enemies, improving ecological connectivity and agro-ecosystem stability.
4. **Transition from the use of commercial pollinators to wild pollinators**. Although the introduction of commercial bees can complement wild pollinators, the high densities required increase the risks of competition, disease transmission, and hybridization with native species.
5. **Strength soil fauna functionalities:** Create a fertile and biodiverse soil, facilitating the establishment of complex food chains with abundant numbers of individuals and predator species in their larval and adult stages, which reduce the proliferation of nematode and fungal pests.
6. **Ongoing monitoring and evaluation:** Implementing methods to monitor pollinator activity and diversity means the effectiveness of applied practices can be evaluated and strategies can be adjusted to maximise profits.

4 Perception of Local Stakeholders

A range of surveys have been carried out to assess the level of knowledge that the various local stakeholders have about the concept of regenerative agriculture, the possible adoption of good practices and potential existing barriers. These surveys focused on both large growers and other players in the value chain including marketers, supermarkets, technical advisors and scientific institutions. With a total of 27 respondents, the main results obtained are summarised below.

4.1 Regenerative Agriculture

Although the adoption of regenerative practices is currently non-existent among berry growers in the Huelva area, the popularity of such an approach is evident. In this regard, 50% of growers surveyed claimed to be familiar with the concept of RA and to apply practices that could be considered regenerative, another 20% considered it attractive and the remaining 30% considered that this concept was of no application or utility to their way of growing. It is important to note that most of the growers surveyed already work under some kind of environmental certification scheme, such as GlobalGAP, Spring or Leaf, mainly associated with international market demand. Of these, only two of the growers surveyed worked under organic farming standards[6].

About 2/3 of the value chain players surveyed, including wholesale distributors, supermarkets and service providers, were fully aware of this production approach, while the remaining 1/3 had heard of it. Most considered that this approach had a clear effect on improving soil health and reducing agricultural inputs (water, fertilisers, energy, etc.), and therefore a lower environmental impact (Figure 3). Moreover, many identified this farming approach with greater system resilience to climate change.

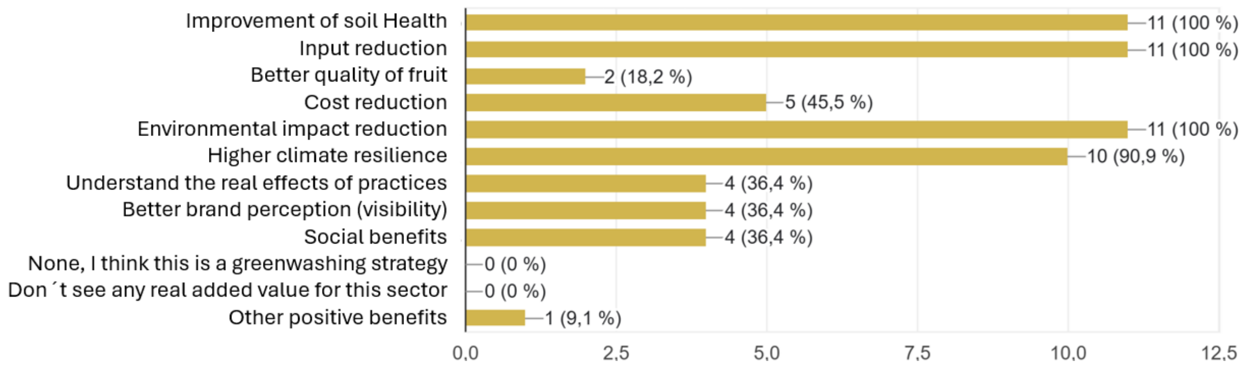

Figure 3 *Identification of main benefits of regenerative agriculture by value chain players surveyed (n=12).*

[6] Although there are many parallels, organic farming is different from the concept of regenerative agriculture in many respects.

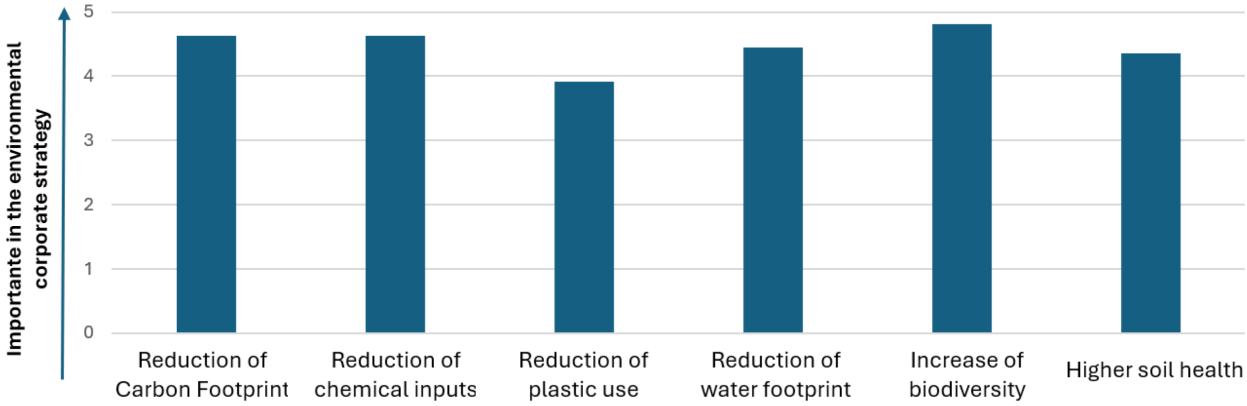

Figure 4 *Level of importance of the different environmental objectives within the sustainability strategies of companies surveyed (n=12).*

Farming based on a regenerative approach is perfectly aligned with most of the priority environmental objectives within the sustainability strategies of the surveyed companies. In this regard, a reduced carbon footprint, reduced use of chemical inputs and increased biodiversity were identified as some of the most important elements of such strategies (Figure 4).

Both growers and the rest of the players in the value chain also considered that most RA principles could be aligned in one way or another with the berry industry and its different production models. In this context, a participatory exercise with more than 30 participants revealed that certain principles are highly applicable to the industry, for example boosting biodiversity or the precise application of inputs. However, other principles are less compatible, such as those related to soil conservation, mainly due to the annual nature of some production systems such as strawberries.

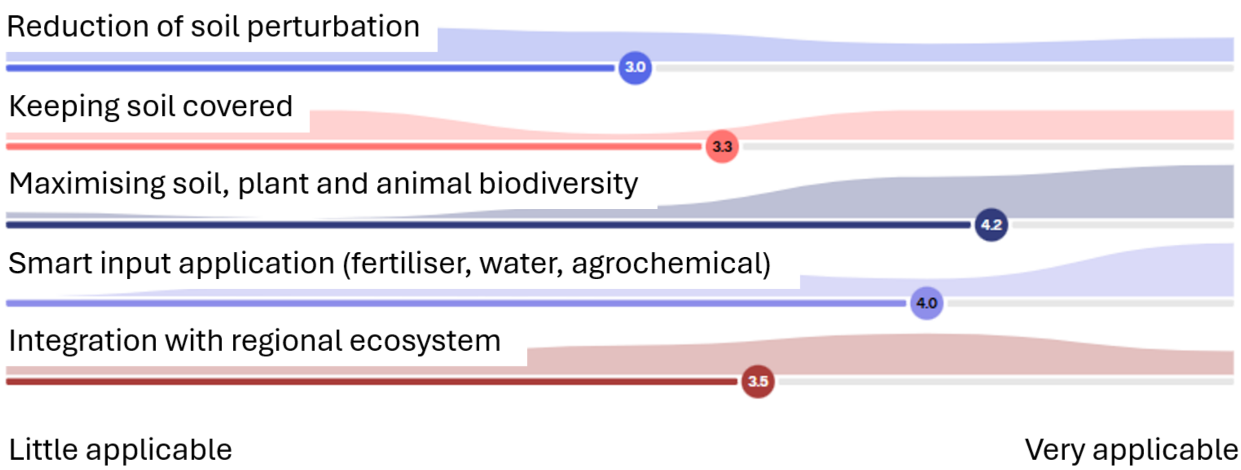

Figure 5 *Alignment of regenerative agriculture principles with the berry industry (average of responses, n=30).*

4.2 Adoption of Good Practices

Of the growers surveyed, 70% considered that adopting Good Agriculture Practices (GAPs) could make their business more profitable, while the remaining 30% were not entirely sure. Even so, as the following sections make clear, most growers have already adopted a number of GAPs in their day-to-day operations to improve water, soil and/or biodiversity management.

4.2.1 GAPs Related to Water

More than 90% of growers surveyed reported that they already used smart systems for irrigation scheduling, combining weather data with moisture sensors installed at different points on the farm. In almost all cases, growers also used water meters to monitor the amount of water used (70%), and also carried out regular maintenance of the system including irrigation uniformity measures (80%). In all cases, growers confirmed that one of their goals was to make the system more efficient and reduce the total volume of irrigation water required. It should also be noted that at least three of the growers consulted already recirculated effluent from fertigation in hydroponic systems, allowing them to improve the efficiency of the whole system. Finally, most growers consulted reported that they had needed to reduce their irrigated area, or even the length of the season, as a result of drought-related cuts to irrigation allocations in previous seasons.

4.2.2 GAPs Related to Soil

The results of the surveys carried out confirm that disinfection is one of the most common practices in the Huelva area, with 80% of growers surveyed stating that they used chemical disinfection, while only 10% used biosolarisation. In terms of weed control, most growers reported using plastic mulch on the ridges, in addition to regular weed control by ploughing between pathways or using chemical methods. However, it is important to note that 25% of the blueberry growers surveyed maintained ground cover along pathways, which they controlled regularly using mechanical techniques.

In terms of fertilisation, most respondents reported using a combination of chemical and organic fertilisers. They also adjusted the dosage based on measurements taken regularly from the soil and the plant. Organic fertilisers were mainly used at the start of the season, through the application of organic matter, although some growers also applied soluble organic fertilisers through fertigation. It is also important to note that some growers reported the use of biostimulant products to improve crop response and resilience.

4.2.3 GAPs Related to Biodiversity

Most growers surveyed had an integrated pest management system in place, using both chemical and biological methods for pest control. Meanwhile, only 30% of growers reported using solely biological methods, including the release of predatory organisms. Another common biological method was to use bait plants to attract and host predators (vegetation strips). On the other hand, almost all growers surveyed reported the use of commercial hives and bumblebees to improve pollination rates, with only 50% also promoting the growth of multiflora plant species outside or between tunnels to attract pollinating insects.

Regarding the growers' perception of their farm's relationship with the environment, the results show that there is a general interest in environmental conservation, with 50% of growers stating that improving their environment could have a positive impact on their own activity.

4.3 Potential Barriers

There is a variety of barriers to the adoption of regenerative models and practices, ranging from purely technical requirements in implementing potential regenerative practices to the marketability of produce grown under such an approach and its potential demand.

The growers surveyed identified the potential main barriers as the lack of a higher price for marketing these products, high application costs and lack of support (Figure 6). Even so, almost 70% of the respondents considered that the application of GAPs would boost the profitability of their production. Lack of technical knowledge was also identified as a major barrier, even though access to technical advice is considered good to excellent in this region, with applied research institutions such as IFAPA or CSIC, together with input suppliers themselves being the main sources of advice.

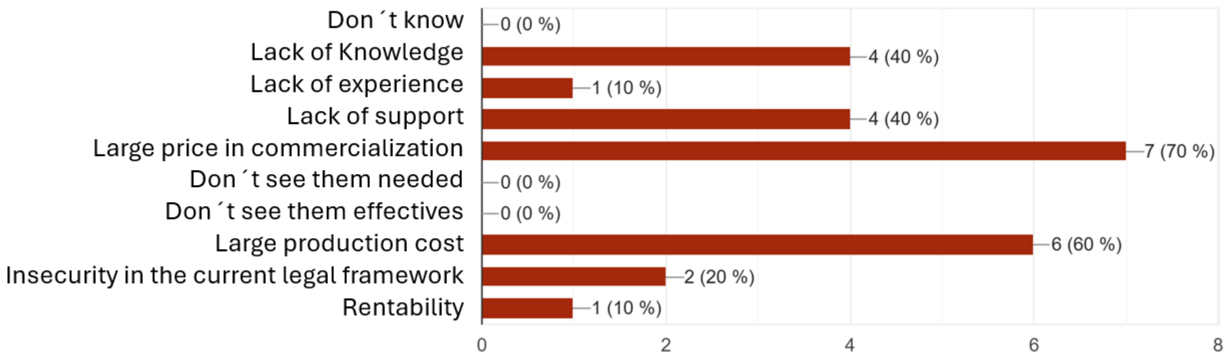

Figure 6 *Identification of the main barriers to adoption by growers surveyed in percentage of responses (n=12).*

Players involved in the value chain showed a clear interest in adopting regenerative practices, with almost 90% of respondents willing to promote them among their suppliers. This is true even if the marketing potential for regenerative produce is not entirely clear, as only 20% of respondents thought that consumers would be willing to pay a hypothetical higher cost for such products.

Competitive pricing, a clearer regulatory framework including certifications, as well as greater consumer demand, were some of the main factors that would influence their decision to market such products. Similarly, the main barriers identified were related to the lack of certifications or standards regulating this production method, uncertainty as to how to assess its impacts, and the lack of knowledge on the subject (Figure 7).

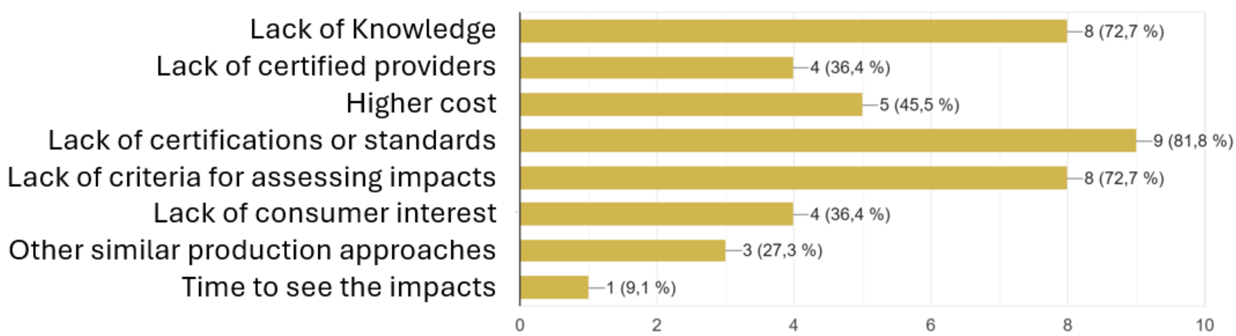

Figure 7 *Identification of the main barriers to marketing regenerative products by value chain players surveyed (n=11).*

5 Towards a Regenerative Model

5.1 Building Regenerative Models

As seen above, a wide range of good agricultural practices align with the principles of regenerative agriculture. These practices pose a number of difficulties in their implementation, with varying degrees of impact. To facilitate their adoption, a prioritisation exercise has been carried out to enable producers and other stakeholders to align their transition strategies towards more sustainable production models. As can be seen in Figure 8, practices such as the creation of biodiversity islands, the use of ground cover (living or non-living), the use of soil amendments (such as biochar) and the use of on-demand irrigation systems could be very effective measures with low adoption costs. Other high-impact practices, though requiring more effort to adopt, could be recirculating effluent from irrigation, using beneficial micro-organisms, soil biodisinfection, minimising tillage and encouraging the mechanical removal of "weeds", and interspersing flowering species within the tunnels.

Even so, the varying opinions on the expected impacts and the costs of applying each practice, as well as the difficulty of standardising practices that adapt to the idiosyncrasies of the industry, make it very difficult to have a clear perspective.

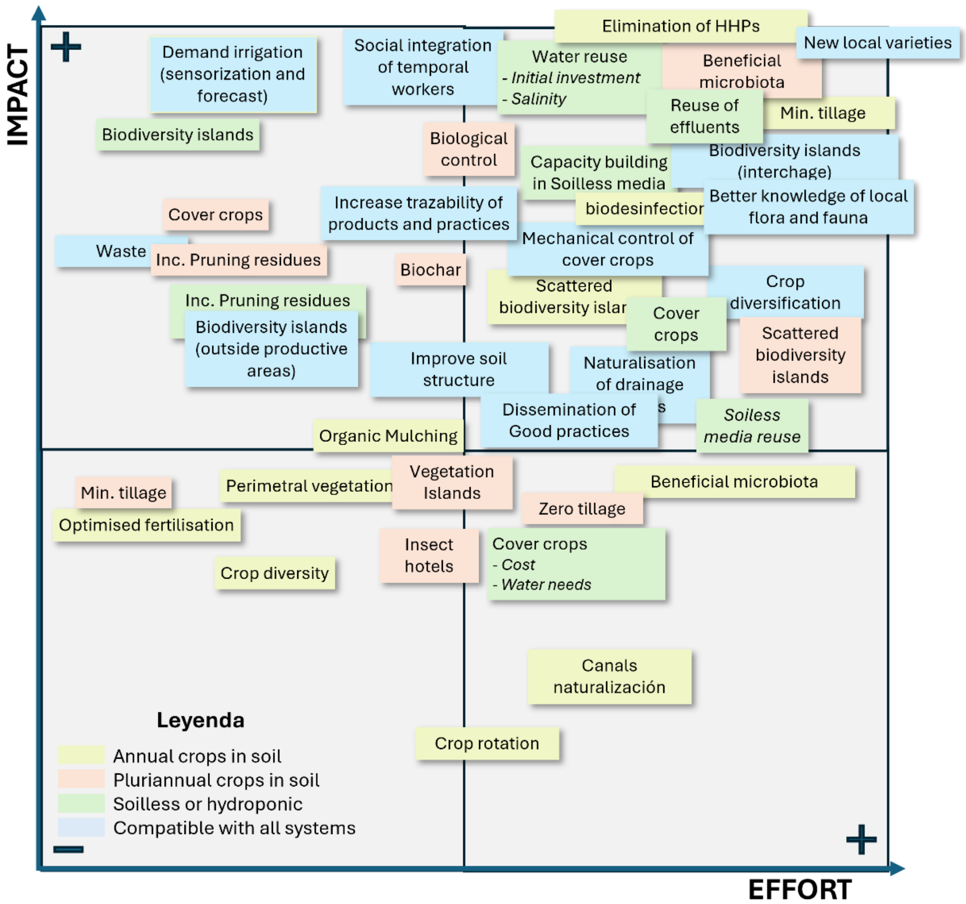

Figure 8 *Effort/Impact Matrix for a range of good regenerative practices. Results obtained from a participatory process with more than 30 collaborators.*

5.2 Can the Concept of Regenerative Agriculture Be Adopted by the Berry Industry?

The concept of **regenerative agriculture (RA)** poses interesting opportunities for the soft fruit industry in Spain, although it also faces some limitations. As has been discussed throughout this paper, there is a wide range of **good agricultural practices** that could be adopted by berry growers in order to **boost the resilience of production systems and minimise their environmental impact**. Many of these practices are aligned with RA principles.

However, the current situation of berry production in Spain is characterised by **highly modified** systems in which common practices, such as **regular soil disinfection for annual crops**, raise doubts about compatibility with regenerative principles. This is a **significant limitation** to fully adopting this approach, especially in the case of annual crops (strawberries). The production of **multiannual crops** has the greatest potential for compatibility, as the implementation of **soil conservation strategies** can offer clear benefits without the need for radical transformations in current management or large investments. This is clear from the consultation with local stakeholders where this type of system was chosen as the one where regenerative practices make the most sense (Figure 9). The case is somewhat similar for soilless systems, where, although it is difficult to define them as "regenerative", it is clear that some RA principles can contribute to **"improving"** the production system.

In short, although it is not clear whether the industry can currently be considered "regenerative", adopting this view may be a valuable tool for focusing strategic decisions towards a more **sustainable, competitive model that is prepared for the challenges of the future**, inviting both growers and marketers to **think in the long term**: it is not just about minimising impacts, but also about **improving the structure and functioning of the farming system** to ensure its future viability. Thus, **looking after the soil and biodiversity** as the fundamental basis of agriculture, together with the **rational use of natural resources**, particularly water, are fundamental to this transition.

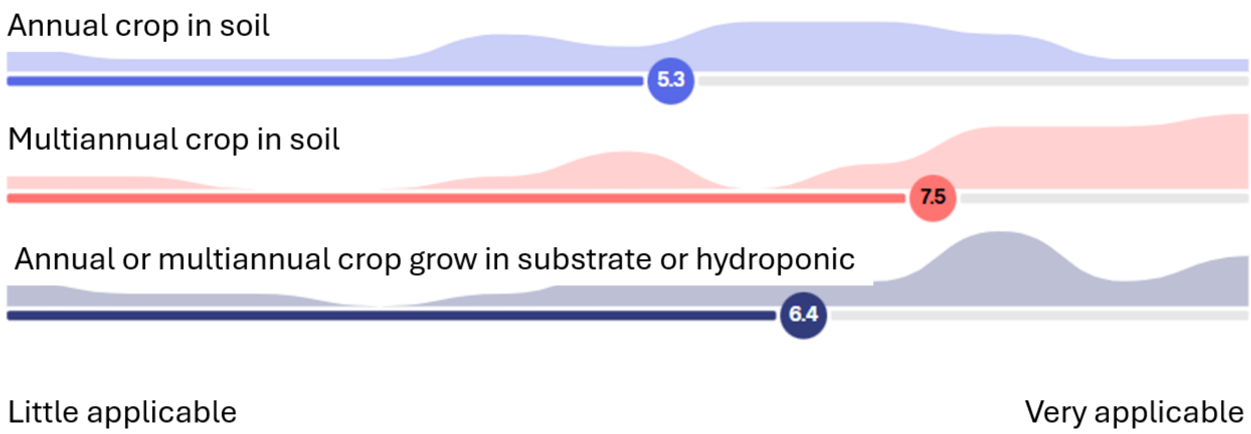

Figure 9 *Application of regenerative agriculture to the various existing production models in the berry industry (n=30).*

5.3 Next Steps

It is clear that the future of Doñana and its agricultural sector depends on a coordinated effort between **growers, marketers, consumers and public institutions**. A commitment to more sustainable production will not only ensure the protection of this valuable ecosystem, but will also strengthen the long-term viability of the sector.

The **regenerative agriculture** approach could therefore be a tool that helps to **transform the soft fruit industry** into a more sustainable, resilient and environmentally friendly farming model, without trading off profit for farmers. However, an effective transition would require tailored actions, coordination between the stakeholders in the value chain and a clear framework to overcome the technical, economic and social barriers identified. Listed below are a number of steps that could guide this process of change:

- **Promote the transition for multiannual crops:** Prioritise the adoption of regenerative practices for existing lands of blueberry and raspberry, where there is greater compatibility with soil conservation and less need for drastic changes in management. However, due to large water consumption, it is not desired to increase the total land planted.
- **Explore the potential of soilless systems:** promote circularity strategies such as effluent recirculation and the use of nature-based solutions to reduce diffuse pollution.
- **Gradually adopt key regenerative practices** such as the efficient use of water and nutrients through smart irrigation, introducing organic amendments and biochar to improve soil health, or planting flower strips and ecological corridors with native species to strengthen biodiversity, pollination and soil fauna as a pest control system.
- **Incentivise applied research and technology transfer,** strengthening the role of national institutions such as IFAPA, CSIC and universities in the endorsement of regenerative practices adapted to the berry industry. To this end, it is important to favour pilot and demo projects on real farms to reduce uncertainty among growers.
- **Explore a certification framework and clear standards**, aligned with international criteria along with verifiable indicators to distinguish true regenerative agriculture from possible cases of greenwashing. This framework should also provide for a way of monitoring and evaluating the results of the measures implemented.
- **Promote economic incentives and supportive public policies,** designing specific aid to fund the transition to regenerative practices. To this end, it would be worth considering whether the Doñana Action Framework can explicitly promote and incorporate regenerative models.
- **Strengthen collaboration between industry stakeholders** (producers, marketers, institutions and consumers), through multi-stakeholder platforms, such as the "Water Roadmap Collective Action Project (Southern Spain)" initiative, to coordinate the implementation of specific measures and to share experiences.
- **Promote consumer awareness and demand for regenerative produce**, making the European market aware of the added benefits of berries grown under this approach.

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Report 3455
ISSN 1566-7197

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Report 3455
ISSN 1566-7197

The mission of Wageningen University & Research is “To explore the potential of nature to improve the quality of life”. Under the banner Wageningen University & Research, Wageningen University and the specialised research institutes of the Wageningen Research Foundation have joined forces in contributing to finding solutions to important questions in the domain of healthy food and living environment. With its roughly 30 branches, 7,700 employees (7,000 fte), 2,500 PhD and EngD candidates, 13,100 students and over 150,000 participants to WUR’s Life Long Learning, Wageningen University & Research is one of the leading organisations in its domain. The unique Wageningen approach lies in its integrated approach to issues and the collaboration between different disciplines.