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Evaluation of the Effects of Asparagus Decline Syndrome on Yield and Quality Parameters over Three Years in Western Europe

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Abstract: Asparagus decline syndrome (ADS) poses a critical challenge to the productivity and quality of asparagus (*Asparagus officinalis* L.), threatening the sustainability of its cultivation. This study evaluated the impact of ADS over four years in Western Europe by comparing soils with and without a history of the syndrome. The results revealed a consistent reduction in yield, with losses of 36% in 2019 and 2020 and 23% in 2021 compared to the results for the control soils. ADS also increased the proportion of non-commercial spears, peaking at 52% in 2020. Key quality parameters were significantly affected by ADS, especially in the final year of the trial, with reductions observed in spear weight, diameter, firmness, and volume. On the other hand, °Brix values increased by 10% to 16%, while juiciness decreased by 10% to 28%, depending on the year, enhancing sweetness but compromising texture, and thereby, marketable quality. The findings highlight the detrimental effects of replanting asparagus in ADS-affected soils and the need for integrated management strategies to mitigate its impacts. This research contributes valuable insights into ADS dynamics, offering a foundation for developing agronomic solutions that enhance productivity and ensure the long-term viability of asparagus cultivation in affected regions.

Keywords: asparagus decline syndrome; *Asparagus officinalis*; marketable spears; production parameters; replanting; spear quality; yield

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Academic Editor: Daniel Drost

Received: 16 December 2024
Revised: 16 January 2025
Accepted: 28 January 2025
Published: 2 February 2025

Citation: López-Moreno, F.J.; Navarro-León, E.; Atero-Calvo, S.; de la Lastra, E.; Ruiz, J.M.; Soriano, T. Evaluation of the Effects of Asparagus Decline Syndrome on Yield and Quality Parameters over Three Years in Western Europe. *Horticulturae* **2025**, *11*, 159. https://doi.org/10.3390/horticulturae11020159

1. Introduction

Asparagus (*Asparagus officinalis* L.) is a globally important crop, celebrated for its nutritional value, unique taste, and high market demand. Cultivated in more than 60 countries, asparagus is a key agricultural product in many regions, providing significant economic returns and supporting rural employment. However, the sustainability of asparagus production faces increasing challenges, particularly from asparagus decline syndrome (ADS). This syndrome, first documented in Spain during the 1980s [1], has since become a major threat to global asparagus cultivation [2]. Characterized by a combination of reduced yield, diminished spear quality, and premature plant mortality, ADS has profound economic and agronomic implications.

Asparagus production represents a valuable sector of global agriculture, with over 1.6 million hectares dedicated to its cultivation and an annual yield exceeding 8 million metric tons [3]. In Spain, which ranks among the top five global producers, asparagus plays a vital role in regional economies, particularly in Andalucía, where 69% of the country's production area is concentrated [4]. The crop's profitability stems from its relatively high market value, with premium prices awarded for larger, uniform spears of optimal quality [5].

Asparagus plants are dioecious perennials with a productive lifespan of 10 to 12 years. Male plants typically outyield females, producing more spears of smaller diameter, while female plants yield fewer but thicker spears [6]. The fourth or fifth year of cultivation marks the peak production period, after which yield gradually declines. For asparagus producers, maximizing productivity and maintaining spear quality are critical for ensuring profitability. High-quality spears, characterized by optimal weight, uniform diameter, and sweetness (measured as °Brix), command the highest market prices, especially during the early season when supply is limited [7].

Despite its economic importance, asparagus cultivation is under threat from ADS, a syndrome that drastically reduces both yield and spear quality. In severely affected fields, plants suffer from stunted growth, decreased vigor, and eventual mortality, often within a few years of initial planting. This shortens the productive lifespan of the fields, forcing growers to abandon affected areas and relocate their operations, further straining available agricultural land [8].

ADS is a complex syndrome attributed to both biotic and abiotic factors. Among the biotic contributors, root and crown rot caused by *Fusarium* spp. is a primary concern. Pathogens such as *F. oxysporum* f. sp. asparagi, *F. proliferatum*, and *F. solani* have been implicated in ADS, with their persistence in the soil posing significant challenges for control [9]. These fungi infect the plant's vascular system, reducing its ability to transport water and nutrients, which leads to visible symptoms such as wilted foliage, reduced spear size, and eventual death [10].

Abiotic factors also play a significant role in exacerbating ADS. Among these, allelopathy, or the production of autotoxic compounds by asparagus plants, has garnered attention. Compounds such as phenolics have been shown to accumulate in the soil over successive asparagus planting cycles, inhibiting root growth and reducing plant vigor [11]. Additionally, soil nutrient depletion, residual herbicides, and structural degradation are common issues in intensive asparagus monoculture, further weakening plants and predisposing them to biotic stresses [12].

Interactions between biotic and abiotic factors complicate the management of ADS. For instance, allelopathic compounds may predispose plants to fungal infections, while environmental stressors, such as drought and soil compaction, can exacerbate the severity of symptoms [13]. This multifactorial nature underscores the need for integrated approaches to ADS mitigation.

The economic impact of ADS is profound, as it reduces both the quantity and quality of harvested spears. Yield losses are attributed to diminished plant vigor, reduced crown size, and increased mortality rates, particularly in fields with a history of asparagus cultivation [9]. Affected plants produce fewer spears, which are often of lower marketable quality due to deformities, reduced size, and compromised sweetness [14]. Spear quality is a critical determinant of market value. In asparagus production, high-quality spears are defined by their weight, diameter, uniformity, and sweetness. ADS often results in a higher proportion of non-commercial spears, which fail to meet these criteria. Common defects include open heads, discoloration, and mechanical or pest-related damage. Such defects not only reduce the marketable yield but also increase post-harvest losses, further compounding economic losses for growers.

The presence of *Fusarium* spp. in ADS-affected fields has been shown to significantly alter the biochemical composition of the spears. Studies suggest that fungal infections can reduce the sugar content of the spears, affecting their flavor and marketability. Furthermore, allelopathic compounds in the soil may impact the nutrient uptake and physiological health of plants, indirectly affecting spear quality [15]. However, few studies are available evaluating the effects on asparagus quality in successive harvesting periods.

This study is based on the hypothesis that ADS negatively impacts both production and quality parameters in asparagus cultivation during various harvesting periods. Specifically, the syndrome is expected to reduce yield, increase the proportion of non-commercial spears, and alter key quality traits such as weight, diameter, and °Brix. The primary objective of this research is to analyze the effects of cultivating asparagus in soils previously used for asparagus cultivation and affected by ADS. By evaluating various production and quality parameters, the study aims to provide a comprehensive understanding of how soil conditions and ADS influence asparagus performance. This mid-term study, conducted between 2018 and 2021, will contribute to developing targeted management strategies to mitigate the effects of ADS and improve the sustainability of asparagus cultivation in affected regions.

2. Materials and Methods

2.1. Experimental Design

The study was carried out at IFAPA Camino de Purchil (Granada, Spain; 37°10′18.0″ N 3°38′16.6″ W) in isolated containers measuring 6×4 m^2, with a depth of 130 cm. The containers were lined with continuous plastic along the sides and perforated plastic at the bottom, with a 30 cm layer of gravel to aid drainage. The soil for the Control treatment was sourced from a plot at IFAPA that had not been used for asparagus cultivation for over a decade. In contrast, the soil for the SDE treatment came from a plot severely impacted by ADS, exhibiting high levels of plant mortality and significantly reduced yields. This soil was sourced from a field that had been cultivated with asparagus for 8 years, and it already showed clear signs of ADS. Both soils showed similar texture properties. The experimental design was completely random, with three replications per treatment. Each replication consisted of one container, resulting in a total of six containers.

On 21 May 2018, asparagus crowns of the Grande variety were transplanted at a depth of 20 cm, following a planting scheme of 1×0.3 m. Each container accommodated six rows of plants, totaling 72 plants per container. Growing conditions were optimized using drip irrigation and fertigation tailored to meet the crop's specific requirements. Fertigation, carried out on demand with a high-tech system from the manufacturer Guadalfeo, used groundwater from the Vega de Granada aquifer and simultaneously addressed the crop's water and nutritional needs. The irrigation amounts and frequencies were determined based on data obtained from soil moisture sensors (ECH20 EC5, Decagon Devices). To assess the evolution of plant survival over time, periodic counts of the number of living plants were conducted from 3 July 2018 to 7 October 2020.

2.2. Climatic Conditions

Climate data were collected from the IFAPA Camino de Purchil weather station located in Granada, Spain (Figure 1). The data used for this analysis include average monthly temperature (°C), relative humidity (%), and precipitation (mm), recorded between April 2018 and May 2021. The data were retrieved from the publicly available platform hosted by the Spanish Ministry of Agriculture, Fisheries, and Food at https://servicio.mapa.gob.es/websiar/SeleccionParametrosMap.aspx?dst=1 (accessed on 29 January 2025).

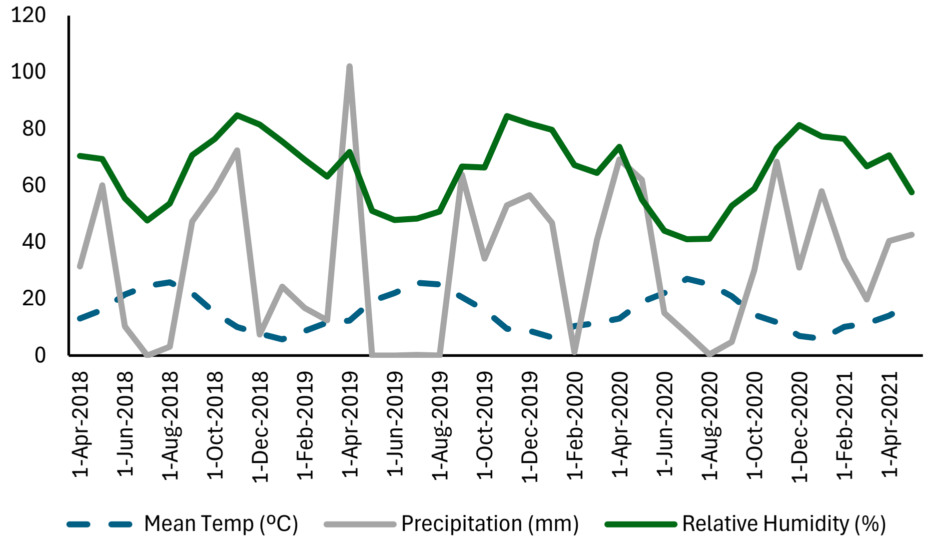

Figure 1. Average climate data (mean temperature in °C, relative humidity in %, and precipitation in mm) recorded at the IFAPA Camino de Purchil, Granada, weather station.

2.3. Harvest

The harvest was carried out during the period between February and March in the first year (2019) to avoid exhausting the plants in their first year, and between mid-to late February and early May in 2020 and 2021. The duration of the harvest was determined by the climatic conditions of each year and various circumstances that arose, such as the confinement caused by the COVID-19 pandemic in 2020. All asparagus spears from every plant in each plot were harvested three times a week—on Mondays, Wednesdays, and Fridays—throughout the entire harvest period each year. The spears were cut to a length of 24 cm (commercial length) and divided into two groups: commercial and non-commercial. Non-commercial spears included those that were misshapen, displayed open heads, or were damaged, by insects or mechanically, among other defects.

2.4. Quality of Spears

To assess harvest quality parameters, the spears were collected at three different times during the harvest period (beginning, middle, and end). The average of all asparagus spears harvested at these three time points was calculated for the quality analysis.

- Unit Weight: Direct measurements were performed using a Cobos AJ-1200CE Complet balance (Cobos Precisión, S.L., Barcelona, España), weighing all harvested spears individually.
- Diameter: The diameter of each spear was measured using a Mitutoyo digital caliper at three points, i.e., the basal, intermediate, and apical sections. The average of these measurements was calculated.
- Hardness: Measurements were taken using a T.R. Turoni Decco Iberica penetrometer (100 g–1000 g). These readings were also taken at the basal, intermediate, and apical sections, and the average was calculated.
- Volume: The spear volume was estimated by approximating its shape to a truncated cone. The following equation was applied:

$$V = \frac{1}{3} \cdot \pi \cdot h \cdot \left(R^2 + r^2 + R \cdot r \right)$$

where "h" is the total spear length, "R" is the larger (basal) radius, and "r" is the smaller (apical) radius.

- °Brix: To measure the total concentration of dissolved sucrose in the extracted asparagus spear juice (°Brix), a Hanna Instruments HI 96801 Digital/Optical Refractometer (Hanna Instruments, Woonsocket, RI, USA) was used. A few drops of the extracted juice were applied to the refractometer, and the measurements were taken directly from the screen.
- Juiciness: Juiciness was calculated as the ratio between the volume of juice obtained after the pressing process and the total mass of the sample used for extraction, expressed as a percentage. To determine this, small pieces of spears, selected from among all harvested spears in each elementary plot, were mixed homogeneously. These were weighed and placed in a Craftsman hydraulic press to extract the aerial sap and obtain the juice.

2.5. Statistical Analysis

To assess the differences between treatments, a one-way analysis of variance (ANOVA), with 95% confidence, was performed. The mean and standard error of each treatment was calculated from the nine individual data of each parameter analyzed. Means were compared using Fisher's least significant differences (LSD0.05). A two-tailed ANOVA was applied to ascertain whether the ADS and the year significantly affected the results. In addition, to examine the relationships among the physiological, agronomic, and quality parameters of the asparagus spears, a Spearman's rank-order correlation analysis was conducted. The significance levels were indicated as * $p < 0.05$, ** $p < 0.01$, *** $p < 0.001$, or NS (not significant). All statistical analyses were carried out using Statgraphics Centurion 16.1.03 software.

3. Results and Discussion

3.1. Mortality

The results of the trial demonstrate a decline in the number of living asparagus plants over the three years of the study. However, this decline was more pronounced in the plots with soil that had a prior history of ADS. The first count, conducted on 3 July 2018, recorded a 100% sprouting of asparagus crowns, with a total of 72 plants. By the second count, on 12 July 2018, differences between treatments were already evident, with a lower number of surviving plants in the plots containing soil with a prior ADS history. Over time, the number of surviving plants continued to decrease across all plots. By the final count, conducted on 7 October 2020, 60 plants remained in the control plot, while only 49 were observed in the ADS-affected plot. This corresponds to plant mortality rates of 23% and 37%, respectively, highlighting the detrimental impact of ADS-affected soil on plant survival (Figure 2).

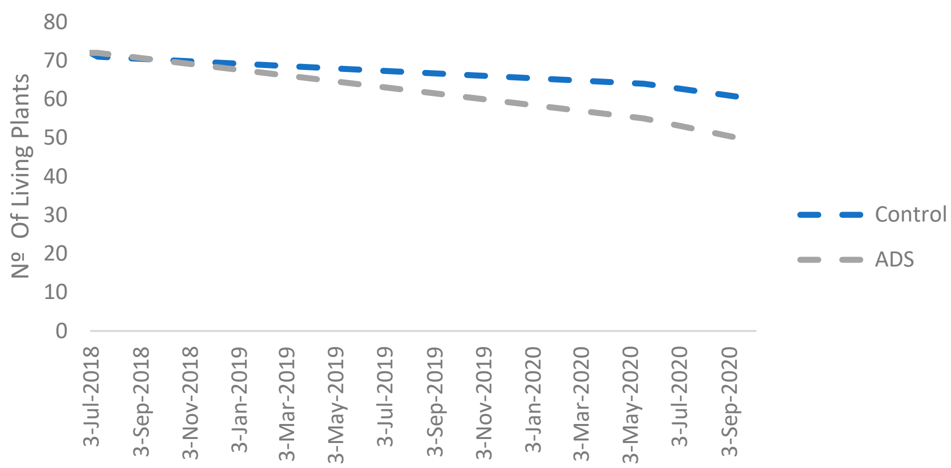

Figure 2. Evolution of asparagus plant survival for the Control and ADS treatments over the three years of experimentation (2019, 2020, and 2021).

3.2. Yield

The results obtained for the commercial yield of asparagus in the different treatments (Control and ADS) showed significant differences between them during the study years (2019, 2020, and 2021) (Table 1). These findings are consistent with previous research that has demonstrated the influence of asparagus decline syndrome on crop productivity [10,16,17].

Table 1. Cumulative values (kg/ha) of commercial and non-commercial yield at the end of the harvest period for the years 2019, 2020, and 2021.

		Commercial Yield (Kg/ha)	**Non-Commercial Yield (%)**
2019	Control	2816.18	2.51
	ADS	1795.19	2.83
	p-value	**	*
2020	Control	4199.64	40.33
	ADS	2685.54	52.56
	p-value	***	**
2021	Control	4297.20	7.90
	ADS	3309.69	5.83
	p-value	*	***
	Multivariant analysis		
	ADS (A)	***	***
	Year (Y)	***	***
	A×Y	NS	***

The differences between means were compared using Fisher's least significant difference (LSD) test. Significance levels are expressed as * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; and NS (not significant), with $p > 0.05$.

In 2019, the Control asparagus achieved a significantly higher yield, averaging 2816.18 kg/ha, followed by ADS, with an average of 1795.19 kg/ha (36% lower) (Table 1). In 2020, a similar trend was observed, with the Control again showing the highest yield, averaging 4199.64 kg/ha, followed by ADS, with an average of 2685.54 kg/ha (36% lower). Finally, in 2021, the results once again showed that the Control achieved a superior yield, averaging 4297.20 kg/ha; ADS reached a value of 3309.69 kg/ha, 23% lower than that of the Control. These results indicate that ADS can cause losses of 20% to 40% of the asparagus yield, which is a great economic loss. On the other hand, for the three years of the study, the Control treatment, consisting of soil with no history of asparagus cultivation, had the highest commercial yield (Table 1). These results are consistent with the findings of Djalali Farahani-Kofoet et al. [18], who reported that soils free from asparagus decline syndrome promote higher yields and better crop quality.

The multivariate analysis revealed significant effects of both ADA and the year on the commercial and non-commercial yield. The interaction between ADS and the year was not significant for commercial yield, suggesting a consistent effect of ADS on yield reduction across years. However, a significant interaction was observed for non-commercial yield, indicating that the effect of ADS on the proportion of non-marketable spears varied, depending on the year, and environmental or agronomic factors may modulate the impact of ADS on spear quality.

If we observe the temporal evolution of the harvest, we can see that in the first two years, the yield of the Control plots is higher than that of ADS group in the entire harvest period. The trend toward the equalization of commercial production between the Control and ADS treatments in the third cycle is also worth noting. In 2019 and 2020, the production in the ADS group was 36% lower than in the Control, while in 2021, it was only 23% lower (Figure 3). The possibility of soil contamination during agricultural operations is a plausible hypothesis that could explain this similarity in final yields. Agricultural practices, such as soil preparation, may contribute to the spread of pathogens or harmful microorganisms in the soil. If these pathogens were present at the end of the three cycles in the Control (soil without asparagus decline syndrome), they could have been accidentally introduced during agricultural activities, potentially impacting the commercial production of asparagus.

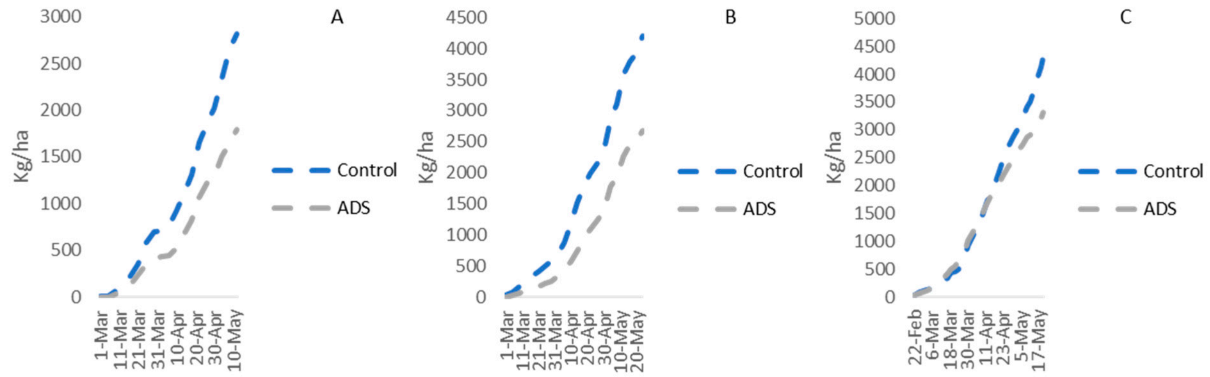

Figure 3. Evolution of commercial yield (Kg/ha) for the Control and ADS treatments over the harvest period during the 3-year trial: 2019 (**A**), 2020 (**B**), and 2021 (**C**).

With respect to the relationship between non-commercial yield and commercial yield, in 2019, the non-commercial yield represented approximately 2.5% and 2.8% for the Control and ADS treatments, respectively. In 2020, there was a significant increase in the proportion of non-commercial spears, representing approximately 40% and 52% for the Control and ADS treatments, respectively. In 2021, the non-commercial yield represented approximately 7.9% and 5.8% for the Control and ADS treatments, respectively.

Analyzing these percentages, it can be observed that the values in 2019 and 2021 are generally low, indicating that non-commercial spears account for a relatively small proportion compared to the total number of commercial spears.

In 2020, however, there was a very significant increase in non-commercial yield percentages for all treatments, coinciding with the COVID isolation period. This resulted in an increased incidence of pests and diseases and in general, poorer crop management. Additionally, more spaced-out harvests led to a higher number of damaged or non-commercial asparagus spears.

Regarding the comparison between treatments, the Control showed the lowest percentages in the first two cycles, indicating a better capacity for producing asparagus meeting commercial standards. However, in the last year, the percentage of non-commercial spears increased significantly in the Control, likely due to the onset of the cross-contamination mentioned earlier in relation to agricultural activities. It is also noteworthy that the largest increase in non-commercial yield occurred with the ADS treatment in 2020 due to delayed harvests, indicating that this treatment provides less flexibility for extended intervals between harvests.

3.3. Quality

Table 2 presents the results of various asparagus quality parameters, including weight, diameter, hardness, unit volume, spear density, sugar content (°Brix), and juiciness. Below, the average results for each parameter for the Control and ADS treatments, as well as comparisons across the different study years, will be discussed.

In 2019, significant differences were observed between the treatments in terms of hardness, sugar content (°Brix), and juiciness in the asparagus spears. The samples from the ADS treatment exhibited greater hardness compared to those in the Control, which is considered a negative characteristic for commercial evaluation. However, a significantly higher sugar content was found in this treatment, indicating a greater level of sweetness in the ADS asparagus (Table 2).

Table 2. Quality parameters measured in the spears harvested from plants subjected to the different treatments in the study during the years 2019, 2020, and 2021.

		Weight (g)	Intermediate Diameter (mm)	Hardness (g/cm^2)	Unit Volume (dm^3)	Spear Density (g/dm^3)	°Brix	Juiciness (%)
2019	Control	20.48	9.78	521.28	53.57	0.382	5.84	13.93
	ADS	22.21	9.38	549.97	48.79	0.396	6.70	12.21
	p-value	NS	NS	*	NS	NS	*	*
2020	Control	22.50	11.99	443.80	68.79	0.326	4.43	13.91
	ADS	22.21	11.26	402.03	66.50	0.334	5.16	11.46
	p-value	NS	NS	NS	NS	NS	*	*
2021	Control	17.40	9.42	460.92	48.87	0.356	5.00	13.90
	ADS	17.00	9.41	417.96	48.24	0.364	5.46	12.49
	p-value	*	*	*	*	**	*	*
	Multivariant analysis							
	ADS (A)	NS	NS	**	NS	**	***	***
	Year (Y)	***	***	***	***	***	***	NS
	A×Y	NS	NS	***	NS	NS	NS	NS

The differences between means were compared using Fisher's least significant difference (LSD) test. Significance levels are expressed as * $p < 0.05$; ** $p < 0.01$; *** $p < 0.001$; and NS (not significant), with $p > 0.05$.

In 2020, no significant differences were found in most of the evaluated parameters between the treatments, with similarities in weight, diameter, hardness, unit volume, and spear density. However, the ADS treatment continued to show significantly higher sugar content compared to that of the Control, suggesting a positive effect on the flavor quality of these asparagus samples. On the other hand, the Control showed higher juiciness levels, which is a favorable characteristic in terms of sensory quality [19] (Table 2).

In 2021, significant differences were found in all studied parameters between the treatments. Asparagus samples from the ADS plot showed significantly lower values for weight, intermediate diameter, and volume per spear unit. On the other hand, the Control exhibited greater hardness compared to that of ADS. Additionally, the ADS treatment showed significantly higher sugar content (°Brix), indicating greater sweetness in the asparagus, with both parameters being favorable from a qualitative standpoint for ADS. However, it is important to note that the Control treatment showed lower spear density compared to that of ADS, which could influence the overall quality of the asparagus (Table 2).

The results of the multivariate analysis highlight that the ADS factor significantly influenced spear hardness, spear density, °Brix, and juiciness, while other parameters such as weight, intermediate diameter, and unit volume showed no statistical significance. The year factor had a highly significant effect on all parameters, except for juiciness, indicating substantial inter-annual variability. The interaction between ADS and year was significant only for spear hardness, suggesting that the impact of ADS on this parameter may vary depending on the year (Table 2). These results underline the complex interplay between biotic stress caused by ADS and environmental or management conditions associated with specific years, particularly in relation to spear hardness and metabolic traits such as °Brix and juiciness.

In summary, the results indicate that the Control and ADS treatments had differentiated effects on the asparagus quality parameters. The Control treatment exhibited a larger spear weight and diameter in 2021. These parameters are the most valued from a commercial perspective. The effect of ADS on hardness cannot be clearly established, since it varies according to the year and can be higher, lower, or without differences with respect to spears from a plot without decay. On the other hand, the effects on sugar content and juiciness are clear, since the °Brix increased due to ADS, while juiciness decreased in all years of the trial.

The reduction in juiciness observed in asparagus from fields affected by ADS is likely a consequence of water stress experienced by these plants. Water stress can decrease tissue water content, diminishing turgor and sap flow, which directly impacts juiciness, as reported in various crops under drought conditions [20,21]. Additionally, the syndrome may impair root functionality, reducing water uptake and transport efficiency. This physiological dysfunction mirrors findings in stressed fruits, where cell wall degradation and increased permeability lead to water loss [22]. Such structural and metabolic disruptions not only compromise juiciness but may also have sensory and commercial implications, as juiciness is a critical quality attribute influencing consumer acceptance of asparagus [19].

The observed increase in Brix levels in spears from fields affected by ADS suggests a physiological response to stress conditions potentially linked to changes in water content and carbohydrate metabolism [23]. Stress conditions such as reduced water availability often concentrate soluble solids, including sugars, due to decreased water uptake and the increased mobilization of carbohydrates to aboveground tissues as part of a survival mechanism [20,21]. This accumulation of soluble sugars can enhance Brix levels, as has been documented in other crops under abiotic stress [24].

While an increase in Brix levels can enhance sweetness and flavor, it may also affect overall quality. Thus, ADS, may improve taste but at the cost of juiciness. Reduced juiciness could result in a drier texture that may be less appealing to consumers, as juiciness is a critical factor in perceived freshness and overall enjoyment of asparagus [25,26].

3.4. Correlation Analysis

The correlation analysis revealed significant relationships between various physiological and agronomic traits, providing insights into the impact of ADS on spear quality and yield. A strong positive association was observed between weight, diameter, and volume, indicating that spear morphology is tightly linked to biomass accumulation (Table 3). However, thicker spears tended to have lower hardness, density, and soluble solids (°Brix), suggesting a trade-off between spear size and quality parameters. This observation aligns with findings in other horticultural crops, where increased size often correlates with reduced textural firmness and sugar content [27]. In addition, harder spears were found to be denser, sweeter, and juicier, reflecting their superior quality, while softer spears were more frequently classified as non-commercial. This highlights the role of mechanical resistance as an indicator of spear marketability, consistent with studies emphasizing the importance of textural properties in regards to consumer acceptance of vegetables [28]. Density and °Brix were also strongly correlated, with denser spears containing higher soluble solids, further emphasizing their higher commercial value. Conversely, spears with lower density and °Brix were more likely to fall into the non-commercial category, particularly under the stress conditions associated with ADS. Likewise, the strong negative relationships between non-commercial yield and traits such as hardness, density, and °Brix underscore the detrimental effects of ADS on spear quality. These findings suggest that ADS impacts key physiological processes, leading to a higher proportion of lower-quality spears that are less marketable [16]. Additionally, the positive associations among hardness, density, and °Brix suggest that these parameters could serve as reliable indicators of spear quality in commercial production systems. Monitoring these attributes could aid in the early detection of quality decline, allowing for timely interventions to mitigate the effects of ADS.

Table 3. Linear correlation coefficients between the analyzed parameters.

	Weight	Diameter	Hardness	Volume	Density	°Brix	Juiciness	Commercial Yield	Non-Commercial Yield
Weight		**0.67 ****	0.07	**0.72 *****	−0.20	−0.08	−0.28	−0.18	0.26
Diameter	**0.67 ****		**−0.48 ***	**0.98 *****	**−0.70 *****	**−0.58 ****	−0.17	0.35	**0.55 ****
Hardness	0.07	**−0.48 ***		**−0.43 ***	**0.78 *****	**0.50 ***	**0.45 ***	−0.32	**−0.72 *****
Volume	**0.72 *****	**0.98 *****	**−0.43 ***		**−0.69 ****	**−0.55 ****	−0.20	0.30	**0.54 ****
Density	−0.20	**−0.70 *****	**0.78 *****	**−0.69 ****		**0.82 *****	0.25	**−0.58 ****	**−0.87 *****
°Brix	−0.08	**−0.58 ****	**0.50 ***	**−0.55 ****	**0.82 *****		−0.14	**−0.78 *****	**−0.71 *****
Juiciness	−0.28	−0.17	**0.45 ***	−0.20	0.25	−0.14		0.33	**−0.43 ***
Commercial Yield	−0.18	0.35	−0.32	0.30	**−0.58 ****	**−0.78 *****	0.33		0.37
Non-Commercial Yield	0.26	**0.55 ****	**−0.72 *****	**0.54 ****	**−0.87 *****	**−0.71 *****	**−0.43 ***	0.37	

The differences between means were compared using Fisher's least significant difference (LSD) test. Significance levels are expressed as * $p < 0.05$, ** $p < 0.01$, and *** $p < 0.001$. Statistically significant correlations are marked in bold.

3.5. Impact of Climatic Variability on Asparagus Growth, Mortality, and Quality

Temperature appears to play a significant role in the development and productivity of asparagus. Asparagus is a perennial crop that requires a cool to moderately warm growing season for optimal growth, with high temperatures (>25 °C) potentially leading to stress and reduced yield. For instance, during the summer months (June, July, and August), when average temperatures ranged from 21 °C to 27 °C, the asparagus plants may have experienced physiological stress, potentially reducing plant vigor, increasing susceptibility to pests and diseases, and negatively impacting harvestable yield. Furthermore, high temperatures could accelerate the senescence of spears, leading to a shortened harvesting window and potentially lower-quality spears.

Precipitation is another crucial climatic factor that impacts asparagus cultivation. The crop is known to be sensitive to water stress, especially during the growing season. Notably, there were periods of very low precipitation (e.g., in July 2018, with only 0 mm of precipitation) (Figure 1), which could have induced drought stress, particularly in the absence of irrigation. Drought conditions might have led to poor spear development, reduced yield, and even increased plant mortality. On the other hand, heavy rainfall events, such as those recorded in April 2019 (102 mm) (Figure 1), could have led to waterlogging, root damage, and a decline in plant health, which may also contribute to increased mortality rates and reduced harvests.

Relative humidity has a complex influence on asparagus cultivation. High relative humidity (e.g., in November and December 2019, with values over 80%) might have contributed to fungal diseases, such as rust or mildew, which are known to affect asparagus plants. The increased humidity, combined with high rainfall, creates favorable conditions for disease outbreaks, which can lead to reduced plant longevity and lower-quality spears. Conversely, lower humidity during drier months may have reduced disease pressure, but also potentially stressed the plants by exacerbating water loss.

In summary, the climatic conditions observed at the IFAPA Camino de Purchil weather station likely had a significant impact on asparagus cultivation, influencing factors such as plant growth, mortality, and harvest quality. High temperatures, particularly during the summer, and fluctuations in precipitation, ranging from drought to excessive rainfall, would have influenced the timing of harvest, spear quality, and overall yield. These findings highlight the importance of adapting asparagus cultivation practices to local climatic conditions to optimize productivity and mitigate climate-induced stress. Future research should focus on the development of irrigation and disease management strategies that can buffer the effects of climatic extremes.

4. Conclusions

This study underscores the significant impact of ADS on asparagus production and quality, with soils affected by the syndrome showing reduced yields and a higher proportion of non-commercial spears, thus compromising the crop's economic viability. ADS not only diminished quality parameters such as spear weight, diameter, and juiciness but also revealed trade-offs, as thicker spears contributed to total yield, while exhibiting reduced quality attributes that may affect marketability. These findings highlight the persistent challenges of replanting in affected areas and the importance of implementing targeted agronomic practices to mitigate the syndrome's effects. Moreover, understanding the physiological mechanisms underlying the correlations between yield and quality parameters offers a pathway for developing management strategies to enhance both productivity and spear marketability. By addressing these challenges, this research provides valuable insights for improving the sustainability of asparagus cultivation and highlights the need for continued studies to refine mitigation strategies and secure the future of this economically important crop.

Author Contributions: Conceptualization, T.S. and J.M.R.; methodology, F.J.L.-M., S.A.-C., E.d.l.L., F.J.L.-M. and E.N.-L.; data curation, F.J.L.-M. and E.N.-L.; writing—original draft preparation, F.J.L.-M. and E.N.-L.; writing—review and editing, J.M.R. and T.S. All authors have read and agreed to the published version of the manuscript.

Funding: This work has been developed within the project RTA2015-00008-C02, with INIA and ERDF 2014-2020 funding, in the Intelligent Growth Operational Program, and by a 2017 grant awarded to F.J.L.M. for pre-doctoral contracts for the training of doctors contemplated in the State Training Subprogram of the State Program for the Promotion of Talent and its Employability, at the IFAPA, grant number [BES-2017-080123], co-financed by the ESF. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Data Availability Statement: The data presented in this study are available on request from the corresponding author due to institutional restrictions and confidentiality agreements.

Acknowledgments: We would like to express our sincere gratitude to our colleagues from the University of Granada (UGR) and the Institute of Agricultural and Fisheries Research and Training (IFAPA) for their invaluable support and collaboration throughout the development of this project. Their commitment and dedication were essential for the planning, execution, and successful completion of the trials that underpin this work. This article would not have been possible without their effort and professionalism.

Conflicts of Interest: The authors declare no conflicts of interest.

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