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Evaluating Food Production, Cooling Potential, and Gardener Perspectives in Urban Allotment Gardens of Valladolid, Spain

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Abstract: The renaissance in urban agriculture is driven by its contributions to fostering more sustainable, healthy, and renaturalized cities. While urban gardens are usually designed to improve food security or serve social purposes, they also offer additional benefits. The aim of this research is to study the urban allotment gardens in Valladolid, Spain, highlighting their capacity to support low-income populations and their potential contribution to urban cooling. As a result of research in twelve plots across four gardens, we found that crop selection in Valladolid aligns with broader urban gardening trends in the Global North, with production adapted to limited plot space and varying significantly by season. In addition, we observed that urban allotment gardens provide more stable and cooler temperatures compared to urban gray spaces, although not as significantly as urban parks. The cooling effect was most pronounced during the summer, a season with the highest number of crops and the warmest temperatures. The study identified that greater crop cover above soil had a more significant cooling effect at the plot level. Surprisingly, crop abundance and crop diversity showed a weak correlation with cooling benefits. As a complement, survey questionnaires conducted with gardeners revealed their awareness of climate change and its perceived direct threat to their crops, health, and city. The future concerns of gardeners regarding the availability of water for both crop growth and the development of urban allotment gardens are emphasized. The findings provide results on self-produced food, urban cooling, and the opinion of gardeners, underscoring the multifunctional contributions of urban gardens to cities.

Keywords: urban agriculture; urban garden; allotment garden; urban adaptation; climate change

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1. Introduction

Urban areas are home to over half of the global population, and that percentage is projected to exceed 70% by 2050 [1,2]. Rapid urban growth is linked with complex factors that intersect across food security, resource scarcity, social inequality, poverty, and climate change [3–7]. Historically, urban agriculture initiatives stand out because they can contribute to food security and supply through the cultivation of crop plants, ornamental plants, and medicinal plants [8,9]. Urban agriculture can be defined as the production of crops and livestock within the confines of a city and encompasses initiatives like community gardens, allotment gardens, and home gardens, among others [10–12]. Despite their historical significance, there is a renaissance of interest in urban gardens for food production [13]. The current interest in integrating these practices into cities is coupled with a renewed focus on research, particularly in the climate change context, which imparts unique characteristics to the 21st century. Understanding urban agriculture as a multifaceted space that addresses social, environmental, and economic dimensions, this manuscript provides empirical data that contribute to its comprehension and its role in urban development.

Climate change impacts are exacerbated in urban areas through the so-called 'urban heat island' effect [14,15], which can affect urban thermal comfort and urban public health and disrupt urban ecosystem functions [4,16–19]. Urban areas, though covering less than 3% of the Earth's surface, contribute significantly to climate change by producing 78% of global greenhouse gas emissions [20], and cities must play a crucial role in adaptation, mitigation, and resilience strategies [1,7,21]. International recommendations call for an urban transformation towards more sustainable, resilient, inclusive, renaturalized, and healthy cities [4,7]. As urban temperatures rise, the urban heat island effect underscores the need for adaptation actions, making urban green spaces crucial for enhancing thermal comfort and reducing the impacts [21].

Urban green spaces, including grasslands, parks, forests, street green belts, and also urban agricultural systems, are recognized as nature-based solutions that offer ecosystem services such as microclimate regulation [10,22–24]. In this study, we focused on urban allotment gardens, where land is subdivided into individual plots cultivated by a household or individual [25]. While allotment gardens are frequently studied for their health and well-being benefits [26–28], there remains a lack of case studies that provide empirical data on the dual benefits of allotment gardens focused on food production as productive space to combat urban heat exacerbated by climate change [29].

We fill this gap in research on food production and the potential urban cooling benefits of urban allotment gardens in the city of Valladolid, Spain. Spain exemplifies urbanization trends, with 80% of its population in 2018 as urban, a number expected to rise to 88% by 2050 [6]. Valladolid's urban initiatives, size, and climate make it an ideal location for research on urban sustainability issues and nature-based solutions. In our study system, urban allotment gardens are developed in public urban spaces and focused on organic crop production for low-income city residents, making them a social asset that contributes to food security [30,31]. By assessing crop system characteristics, collecting temperature data in gardens as well as reference built (gray) and park systems, and surveying gardeners about their activity and perspectives on climate change, this research explores the potential benefits that urban allotment gardens can provide to cities, complementing their often reported social role [26–28,32,33]. Regarding the cooling potential of urban gardens, this study contributes new research on allotment gardens (with their respective characteristics), analyzes data over extended periods (beyond a single season), and introduces a new study city (with its corresponding climate) to the existing research [23,34–36]. As research questions (RQs), we asked:

- RQ1: What is the crop diversity and estimated food production contribution of urban allotment gardens in Valladolid?
- RQ2: How does temperature vary in the gardens in relation to crop system characteristics, and are there significant cooling benefits in comparison to non-vegetated "gray" spaces as well as to other urban parks in the city? Do the crop system characteristics influence the microclimatic temperature variables in the garden plots?
- RQ3: How do gardeners perceive the benefits of allotment gardens for their city as well as the impacts of changes in weather patterns to their gardening practices?

2. Materials and Methods

2.1. Study Places

Valladolid is in Spain, situated in the northwestern quadrant of the Iberian Peninsula [37]. Valladolid is a medium-sized city with a population of 295,639 as of 1 July 2022 [37,38]. Its climate is categorized as Mediterranean-Continental, with an average temperature slightly above 12 °C and an annual rainfall of 400 mm/year (Table 1) [37,39]. Climate models for Valladolid, according to the RCP-8.5 and RCP-4.5 emissions scenarios, indicate a decrease in minimum temperature, extreme minimum temperature, frost days, and heating degree days, along with an increase in maximum temperature, extreme maximum temperature, thermal amplitude, warm days, heat wave days, and cooling degree days [37].

Table 1. Climate profile of Valladolid (1981–2010): monthly and annual mean values. Legends: “T” for average temperature; “MT” for mean of daily maximum temperatures; “Mt” for mean of daily minimum temperatures; “P” for average precipitation; “RH” for relative humidity; “FD” for average number of frost days; and “S” for average sunshine hours. Source of data: AEMET.

Months	T (°C)	MT (°C)	Mt (°C)	P (mm)	RH (%)	FD (Days)	S (Hours)
January	4.2	8.2	0.2	40	83	15.9	101
February	5.9	11.2	0.7	27	72	12.8	147
March	9.0	15.2	2.8	22	62	6.7	215
April	10.7	16.9	4.6	46	62	2.3	232
May	14.5	21.0	7.9	49	60	0.3	272
June	19.3	27.0	11.6	29	52	0.0	322
July	22.3	30.7	14.0	13	45	0.0	363
August	22.1	30.1	14.1	16	48	0.0	334
September	18.5	25.6	11.3	31	56	0.0	254
October	13.2	18.9	7.6	55	70	0.5	182
November	7.9	12.4	3.5	52	79	5.8	117
December	5.0	8.6	1.3	53	84	12.4	89
Year	12.7	18.8	6.6	433	64	56.2	2624

Valladolid is focused on initiatives related to climate change adaptation, carbon neutral cities, smart cities, and renaturing cities [6,37,40–43]. Valladolid is firmly committed to addressing its current environmental challenges, such as the lack of connectivity between green areas, the urban heat island effect, low air quality, and flood risks. This has been demonstrated in recent years by implementing cycle and pedestrian green routes, community composting areas, green roofs, green covering shelters, vertical gardens, green glitter areas, floodable parks, and rain gardens, among others [40]. Specifically, the city has incorporated nature-based solutions, including planting and renewing urban trees, selecting cooling tree species, providing shade trees, and creating green resting areas [40].

In this context, the local government manages four urban allotment gardens (Table 2): *Jardín Botánico* (JB), *Valle de Arán* (VdA), *Parque Alameda* (PA), and *Los Santos Pilarica* (LSP). The urban allotment gardens are dedicated mainly to unemployed residents and for organic food production [30,31].

After contact with the local government, three plots (henceforth “research plots”) in each urban allotment garden were authorized by government officials and the individual gardeners to collect data for this research. The authorization allowed access to obtain crop and temperature information using environmental stations placed within the research plots. In addition, the placement of two environmental stations (S14; S15) was also authorized in a traditional urban forested park named *Campo Grande* (CG) as a comparison reference site. *Campo Grande* has 101,376 m^2 of total surface area and is the park with the highest density of trees in Valladolid [44].

Once the environmental stations in the urban gardens and a forest park were placed, a collaboration with the local government was established due to the interest in urban microclimate. The government decided to collaborate with the research by providing data on temperatures from its urban environmental stations located in five inner-city urban gray spaces—*Puente Poniente* (PP), *San Miguel* (SM), *Catedral* (Cat), *Don Sancho* (DS) and *Dos de Mayo* (DdM). These stations offered a comparison to the gardens and parks to assess potential cooling benefits. In sum, temperature data were collected in four urban allotment gardens, in one urban forested park, and five urban gray spaces (Figure 1).

Table 2. Urban allotment gardens in Valladolid, Spain, managed by the local government, that were the subject of this research. Provided are characteristics such as the total surface area, the number of allotment plots in the entire garden, as well as the number of individual allotment plots that were volunteered for research. We assigned the plots randomized numbers as unique identifiers. Source of data: Government of Valladolid.

Name	Location	Characteristics	Id. Number of Research Plots
Jardín Botánico	Lat: 41°40′6.18″ N Long: 4°44′0.62″ O	Total surface area: 2600 m^2 (33 plots of 50 m^2 each)	S2; S11; S11
Valle de Arán	Lat: 41°40′3.32″ N Long: 4°42′58.67″ O	Total surface area: 4620 m^2 (50 plots of 50 m^2 each; one plot for community work of 800 m^2)	S1; S4; S6
Parque Alameda	Lat: 41°37′9.64″ N Long: 4°44′47.45″ O	Total surface area: 3300 m^2 (48 plots of 50 m^2 each; one plot for community work of 300 m^2)	S3; S7; S8
Los Santos Pilarica	Lat: 41°39′5.51″ N Long: 4°42′0.44″ O	Total surface area: 5200 m^2 (50 plots of 50 m^2 each; one plot for community work of 800 m^2)	S5; S9; S13

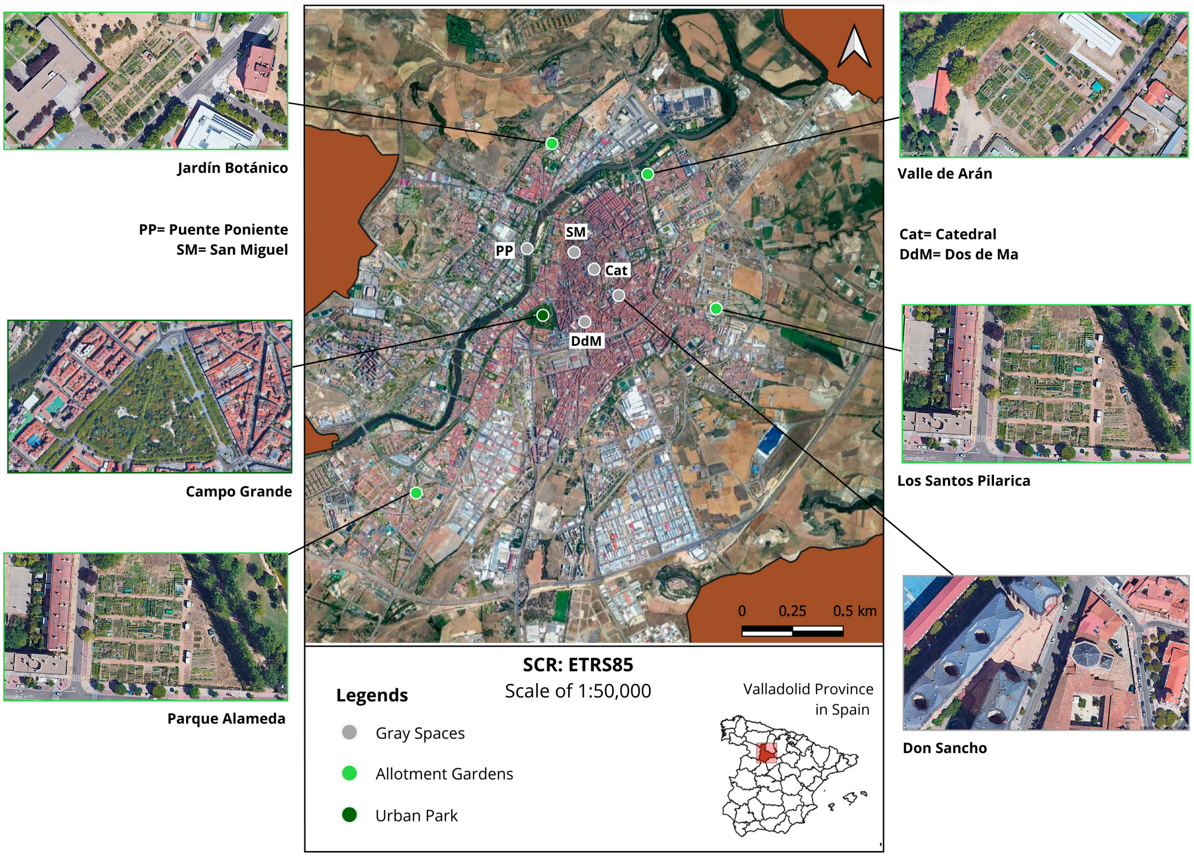

Figure 1. Spatial orientation of the research sites in Valladolid, Spain. The locations of the four urban gardens are identified in light green, *Campo Grande* (park) in green, and the gray spaces in gray. Satellite images show the layout of the plots and the general vegetation structures between some spaces of interest. Source of images: Google Earth.

2.2. Crop Data

We obtained crop characteristics in the four urban allotment gardens (*Jardín Botánico*, *Valle de Arán*, *Los Santos Pilarica*, and *Parque Alameda*). The objectives were to obtain information about crop abundance, crop plant diversity, crop height, and crop plant cover over soil, as crop choice and cultivation methods vary among gardeners [34]. Due to the characteristics of urban allotment gardens in Valladolid, only vegetable crop plants were considered in the assessment, and not aromatic, ornamental, or medicinal plants because, upon initial preliminary visits, we found that the non-crop plants represented a very low percentage of the vegetation. To obtain the crop data, 11 days of field work rounds were carried out between 29 June 2022 and 14 May 2024. Four rounds were in 2022, five in 2023, and two in 2024 (Table 3). Greater focus was placed on the summer season.

Table 3. Field work rounds and the respective seasons and dates for collecting crop data.

Field Work Rounds	Season of the Year	Day (DD MM YYYY)
Field Work N°1	Summer	29 June 2022
Field Work N°2	Summer	20 July 2022
Field Work N°3	Summer	12 September 2022
Field Work N°4	Autumn	8 November 2022
Field Work N°5	Winter	10 February 2022
Field Work N°6	Spring	18 June 2022
Field Work N°7	Summer	19 July 2023
Field Work N°8	Summer	16 August 2023
Field Work N°9	Autumn	26 October 2023
Field Work N°10	Winter	8 February 2024
Field Work N°11	Spring	14 May 2024

For crop data, we followed and adapted methodologies already used in other studies [23,35]. We recorded crop abundance, crop plant diversity, and the estimated average height (measurements taken of five plants, averaged per crop) in three research plots (5×10 m) of each allotment garden. Moreover, three 1×1 m subplots were randomly distributed in each research plot for crop plant cover data (%) and ground cover data (% bare soil; % grass; % straw; % mulch; % rock). Both the plots and subplots were monitored during the different field work rounds to assess their progress (Figure 2). We understand the concepts of the crop's metrics analyzed as follows:

- Crop Abundance: Total number of individual crop plants within each plot.
- Diversity: Total number of crop plant species within each plot.
- Height: The average height of crop plants within each plot (considering five random crop plants' measurements).
- Crop Plant Cover: The proportion of soil covered by crop plants within each subplot.
- Ground Cover: The proportion of soil covered by bare soil, grass, straw, mulch, and rock within each subplot.

Furthermore, the Shannon–Wiener Index (a biodiversity index) was calculated by first determining the proportion of each crop's abundance relative to the crop diversity (i.e., the relative abundance). This proportion was then multiplied by the natural logarithm of the proportion. The index was computed by summing these values for all crops in the dataset and taking the negative of that sum. Analyses were performed using the *vegan* package in the R Statistical Environment, where the *diversity()* function was employed to compute the Shannon–Wiener Index by inputting a community data matrix, with rows representing field work rounds and columns representing crops. The function applied the formula $H' = -\sum(pi \times ln(pi))$, where pi was the proportion of crop species diversity i in the dataset.

Figure 2. Evolution of crops plants in urban allotment gardens: (**a**) Seasonal changes at plot level (S7) between winter and summer in *Parque Alameda*; (**b**) Growth progression of *Cucurbita* spp. at subplot level (S3) in *Parque Alameda*; (**c**) Seasonal changes at plot level (S2) between winter and summer in *Jardín Botánico*; (**d**) Growth progression of *Fragaria* spp. at subplot level (S11) in *Jardín Botánico*. Source of images: The authors.

2.3. Temperature Data

Remote sensors as environmental stations were used to research the influence of urban gardens on urban temperatures at the habitat scale [23,34–36]. This methodology is a technique verified in the last decade through studies carried out in Melbourne (Australia), California (United States), Rosario (Argentina), and Munich (Germany) [10,23,34–36]. In Valladolid, we placed 14 environmental stations in the study sites. There were Onset HOBO UA-002-64 data loggers (5.8 cm × 3.3 cm × 2.3 cm in size) with an operating range of −20 to 70 °C (accuracy of ±0.53 °C from 0 to 50 °C), 1.5 m above the ground with a plastic shield (Figure 3). Three environmental stations were placed in each allotment garden (n = 12) in the center of each research plot, and two stations were placed in the center of the urban park (*Campo Grande*).

Our records started on 21 June 2022 at 00:00 h in S1, S4 S2, S5, S9, S3, and S8 research plots, and in *Campo Grande* (S14; S15). The stations S11, S12, and S13 started on 25 June 2022 at 00:00 h, while S6 started on 19 July 2022 at 10:00 h. All the records ended on 14 May 2024 at 23:00 h. The stations were configured to collect average maximum hourly temperature, average minimum hourly temperature, average hourly temperature (measured and averaged every hour), intraday variation of average hourly temperature, maximum average hourly radiation, minimum average hourly radiation, average hourly radiation (measured and averaged every hour), and intraday variation of average hourly radiation. However, for the analysis, we selected the hourly average temperature (°C), calculated from temperature measurements taken each hour.

Figure 3. Environmental stations in *Jardín Botánico*, *Parque Alameda*, and *Campo Grande*. Source of images: The authors.

In addition, temperature data were collected from government environmental stations located in five reference urban gray spaces. These records were obtained from 21 June 2022 to 18 December 2023, but data gaps were evident between the periods, especially in *Dos de Mayo* and *San Miguel* locations. Since the nature of the government stations was different from that of the HOBO stations, a process of standardization was carried out. For standardization, sensors of different types were placed in the same location for 84 h—starting at 00:00 h on 21 June 2022 and finishing at 11:00 h on 24 June 2022. An additional step was implemented to homogenize the data obtained from both datasets. This homogenization was achieved by applying a scaling factor, defined as the ratio between the average hourly value recorded at the HOBO stations and the average hourly value recorded at the government environmental stations at each calibration location. Consequently, individual scaling factors were calculated for each of the five calibration sites (for *Puente Poniente* = 0.95; for *San Miguel* = 0.95; for *Catedral* = 0.97; for *Don Sancho* = 0.96; for *Dos de Mayo* = 0.97). These scaling factors were subsequently applied to each dataset collected in the urban gray spaces. With the results obtained, we used scale factors for each set of data obtained from the government stations to standardize these government data with the HOBO data.

2.4. Crop–Temperature Relationship

We analyzed correlations between crop characteristics and temperatures variations to assess correlations between crop characteristics and temperature variations across 11 field work rounds during the summer seasons—21 June 2022 to 23 September 2022, and 21 June 2023 to 23 September 2023. The summer crop data (abundance, diversity, Shannon–Wiener Index, height, and cover) and summer temperature data were analyzed using linear regression models to test how each crop characteristic influenced daily average and maximum temperatures. The 12 combinations of variables used in the models were as follows: Average Daily Temperature (°C) vs. Crop Abundance; Average Daily Temperature (°C) vs. Crop Diversity; Average Daily Temperature (°C) vs. Shannon–Wiener Index; Average Daily Temperature (°C) vs. Average Height (cm); Average Daily Temperature (°C) vs. Crop Cover (%); Average Daily Temperature (°C) vs. Ground Cover (%); Maximum Daily Temperature (°C) vs. Crop Abundance; Maximum Daily Temperature (°C) vs. Crop Diversity; Maximum Daily Temperature (°C) vs. Shannon–Wiener Index; Maximum Daily Temperature (°C) vs. Maximum Height (cm); Maximum Daily Temperature (°C) vs. Crop Cover (%); and Maximum Daily Temperature (°C) vs. Ground Cover (%). Additionally, we employed visualization techniques to illustrate the main findings. All analyses and visualization were performed in the R statistical environment. The analysis was conducted collectively by spaces of interest to identify general trends. Using these relationships, we identified whether crop characteristics at the plot and subplot level influence the microclimate during the summer seasons.

2.5. Survey Data

To understand gardeners' perceptions of the benefits of allotment gardens for the city, as well as the impacts of climate changes on their gardening activity, we conducted survey questionnaires with volunteer gardeners. We organized surveys into three components: personal information, horticultural activity, and the relationship between urban allotment gardens and climate change. The first section gathered personal information on participants' ages, backgrounds (urban/rural), and general experience with crop cultivation. The second section focused on horticultural activities, aiming to identify the gardeners' primary goals and behavior patterns in garden management. For its part, the third section examined urban gardeners' thoughts, beliefs, and attitudes toward climate change.

To carry out the questionnaires, we adapted surveys from other studies on the social benefits of gardens and management practices by gardeners to ask about climate-related challenges [23,35,45]. In total, 15 closed questions were asked in paper format: 10 with the possibility of a single answer and five with two answer options. Surveys were conducted from June 2022 to September 2023. The survey locations were inside the gardens. The people surveyed were mainly the official gardeners of the plots, but there were also family members or temporary assistants who were in the gardens at the time of the surveys. Although family members and assistants are not officially responsible for working on the assigned plot, they act as helper gardeners, as it is common for multiple people to collaborate on a single plot to provide assistance, better manage time, or simply share the gardening experience. The survey data were reviewed, cleaned, and quality-checked before the analysis of the results.

3. Results

3.1. Contributions of Urban Allotment Gardens as Sources of Food Crops

The 11 field work rounds across 2 years in the research plots from the four allotment gardens documented a total of 21,843 individual plants of 26 different crops. Tomatoes (*Solanum* spp.; n = 5213 individuals), peppers (*Capsicum* spp.; n = 3386), and onions (*Allium* spp.; n = 3369) were the most abundant. We also found lettuces (*Lactuca* spp.; n = 2464), garlic (*Allium* spp.; n = 1174), cabbages (*Brassica* spp.; n = 1085), strawberries (*Fragaria* spp.; n = 898), beans (*Phaseolus* spp.; n = 584), raspberries (*Rubus* spp.; n = 568), broad beans (*Vicia* spp.; n = 567), zucchinis (*Cucurbita* spp.; n = 495), cucumbers (*Cucumis* spp.; n = 448), carrots (*Daucus* spp.; n = 386), pumpkins (*Cucurbita* spp.; n = 276), chards (*Beta* spp.; n = 201), eggplants (*Solanum* spp.; n = 181), kales (*Brassica* spp.; n = 112), sunflowers (*Helianthus* spp.; n = 94), melons (*Cucumis* spp.; n = 89), beets (*Beta* spp.; n = 78), cauliflowers (*Brassica* spp.; n = 55), peas (*Pisum* spp.; n = 53), corns (*Zea* spp.; n = 46), broccoli (*Brassica* spp.; n = 12), watermelons (*Citrullus* spp.; n = 6), and spinach (*Spinacia* spp.; n = 3). *Los Santos Pilarica* garden showed the most crop units, followed by *Valle de Arán*, *Parque Alameda*, and *Jardín Botánico*, respectively. The crop accumulation curve showed a rapid initial increase in observed crop plant diversity, followed by a slower growth trend over time, indicating a stabilization (Figure 4). No significant differences were found in crop diversity among the gardens. The highest abundance and diversity were shown during summer and spring (Figure 5). The crop plant cover over the soil at the subplot scale was also higher in summer and spring.

The Shannon–Wiener Index showed the crop abundance and crop diversity at the research plot scale in *Valle de Arán*, *Jardín Botánico*, *Parque Alameda*, and *Los Santos Pilarica* (Figure 6). Plots were included in the analysis only if they exhibited some presence of crop plants. Through the 11 field work rounds, plot S8 (*Parque Alameda*), plot S13 (*Los Santos Pilarica*), and plot S1 (*Valle de Arán*) were the research plots with higher crop abundance, while plot S3 (*Parque Alameda*), plot S7 (*Parque Alameda*) and plot S12 (*Jardín Botánico*) were the research plots with lower crop abundance (Table 4). Plot S8 in the field work round N°2 was identified with the highest crop abundance (n = 468) and diversity (n = 12).

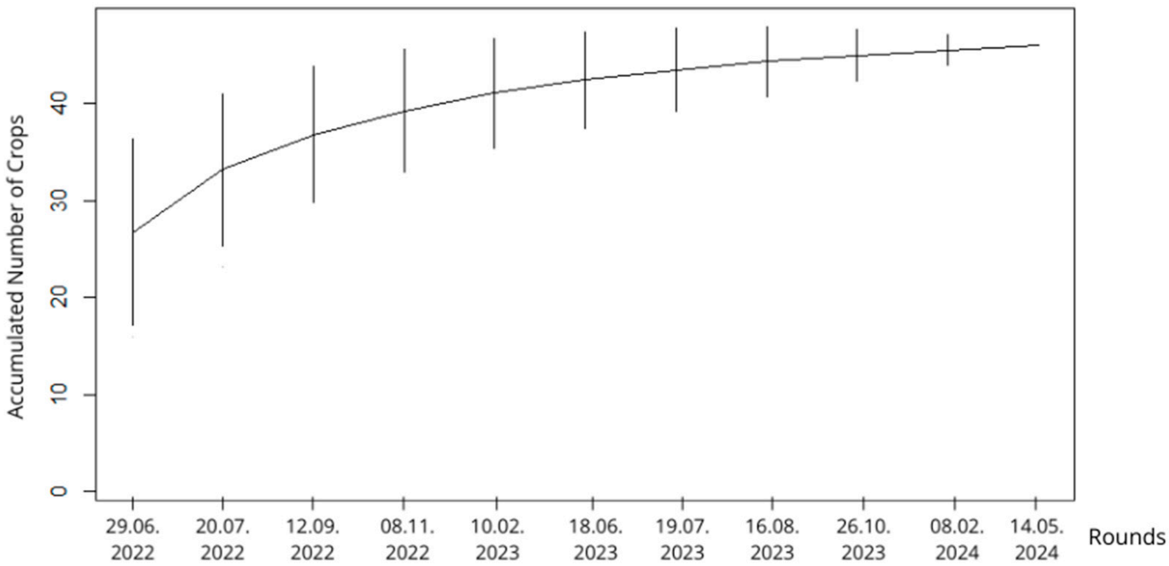

Figure 4. Crops accumulation curve over the rounds of field work.

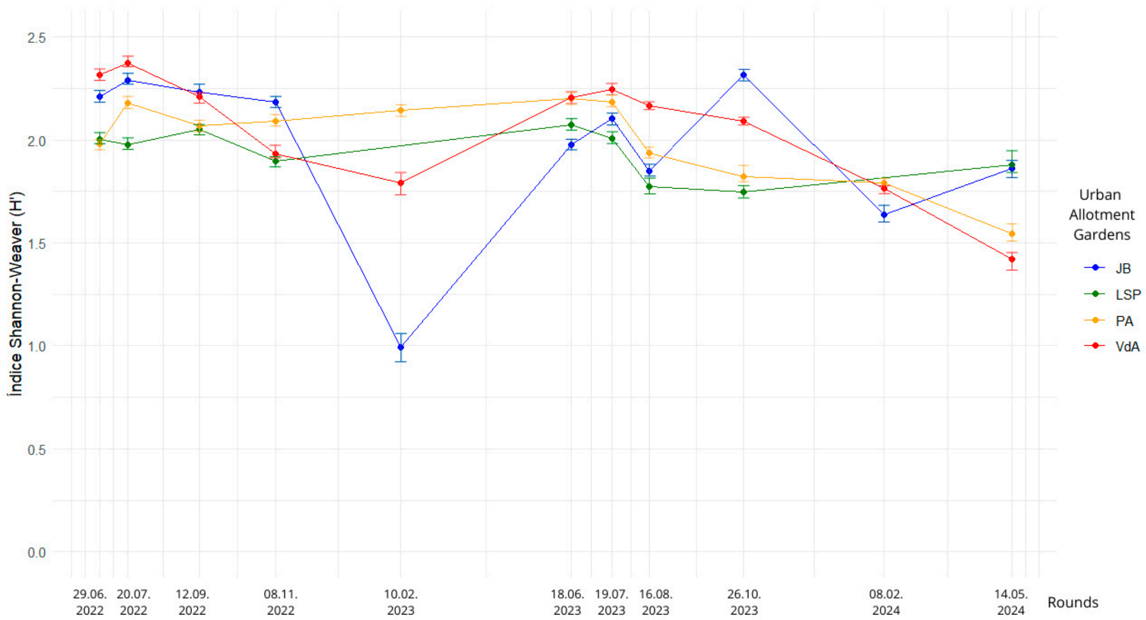

Figure 5. Shannon–Wiener Index over sampling rounds at allotment gardens level. Legends: "VdA" for *Valle de Arán*, "JB" for *Jardín Botánico*, "PA" for *Parque Alameda*, and "LSP" for *Los Santos Pilarica*.

At the subplot scale, crop plant cover over soil varied between the gardens and between the research plots. The subplot results revealed an average crop plant cover of 44% considering all research plots in all rounds, but it was 51% in the summer sessions. The crop cover ranged from 0% to 98%. Within the uncultivated ground covers, a predominance of bare soils and grass was identified—over straw, mulch, and rock—considering all rounds. Variations were identified in bare soil between 2% and 88%, straw soil from 0% to 93%, mulch from 0% to 40%, and rock from 0% to 22%.

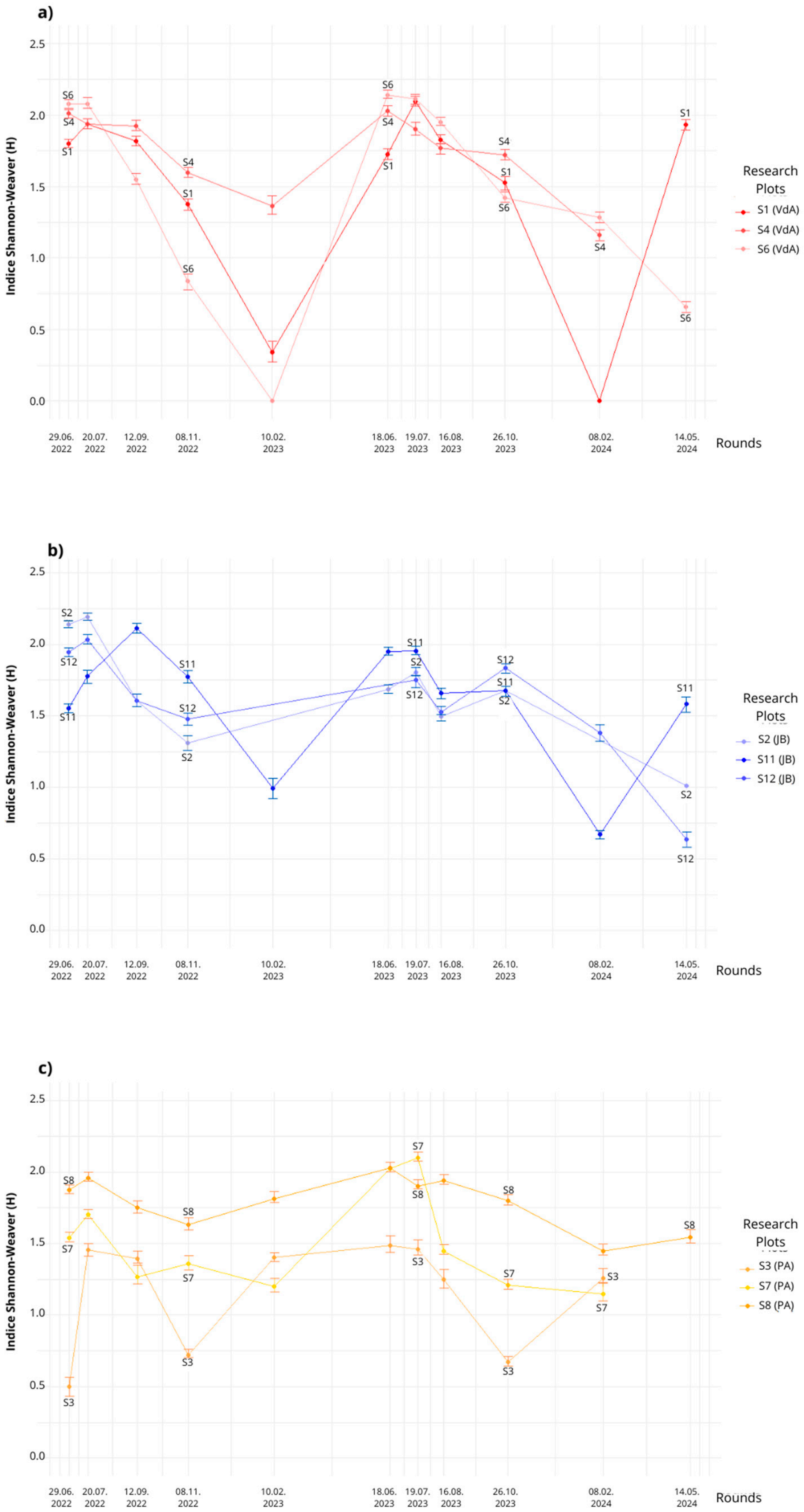

Figure 6. *Cont.*

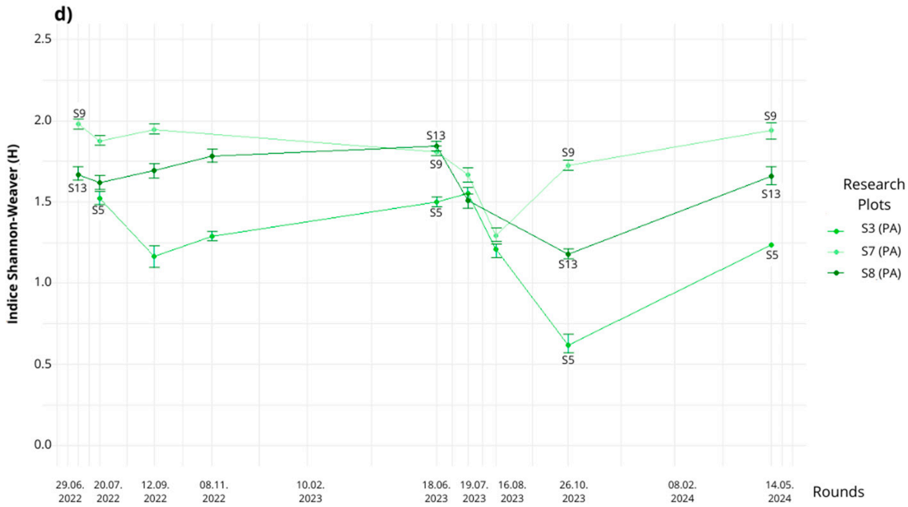

Figure 6. Shannon–Wiener Index over sampling rounds at plot level in the four allotment gardens. (**a**) *Valle de Arán*, (**b**) *Jardín Botánico*, (**c**) *Parque Alameda*, and (**d**) *Los Santos Pilarica*.

Table 4. Crop abundance and crop species diversity (in parentheses) according to the field work rounds.

Field Work Round		Research Plots in *Valle de Arán*			Research Plots in *Parque Alameda*		
		S6	**S1**	**S4**	**S3**	**S7**	**S8**
(1)	29 June 2022	161 (10)	421 (11)	319 (9)	10 (2)	156 (7)	422 (11)
(2)	20 July 2022	161 (10)	258 (9)	287 (10)	33 (5)	166 (8)	468 (12)
(3)	12 September 2022	101 (6)	131 (8)	263 (9)	42 (5)	66 (5)	270 (8)
(4)	8 November 2022	59 (3)	58 (6)	166 (6)	24 (3)	74 (5)	146 (6)
(5)	10 February 2023	20 (1)	28 (2)	164 (5)	36 (5)	18 (5)	171 (7)
(6)	18 June 2023	181 (10)	381 (10)	295 (11)	150 (6)	184 (10)	423 (11)
(7)	19 July 2023	214 (11)	390 (12)	251 (10)	143 (6)	180 (11)	397 (10)
(8)	16 August 2022	104 (8)	221 (10)	194 (10)	66 (3)	128 (6)	350 (11)
(9)	26 October 2023	52 (5)	78 (6)	175 (10)	10 (2)	74 (4)	256 (10)
(10)	8 February 2024	41 (5)	18 (1)	15 (4)	63 (5)	122 (6)	293 (8)
(11)	14 May 2024	333 (2)	237 (9)	No crops	No crops	No crops	363 (6)
		Research Plots in *Jardín Botánico*			**Research Plots in *Los Santos Pilarica***		
		S11	**S2**	**S12**	**S13**	**S9**	**S5**
(1)	29 June 2022	338 (8)	243 (11)	180 (11)	351 (8)	403 (14)	273 (6)

Table 4. *Cont.*

Field Work Round		Research Plots in *Valle de Arán*			Research Plots in *Parque Alameda*		
		S6	**S1**	**S4**	**S3**	**S7**	**S8**
(2)	20 July 2022	262 (8)	205 (11)	192 (12)	256 (7)	346 (12)	258 (6)
(3)	12 September 2022	218 (10)	100 (7)	253 (9)	221 (7)	277 (11)	132 (5)
(4)	8 November 2022	108 (5)	77 (5)	81 (5)	233 (8)		146 (4)
(5)	10 February 2023	83 (4)					
(6)	18 June 2023	206 (8)	161 (7)		383 (8)	251 (8)	220 (6)
(7)	19 July 2023	206 (8)	232 (8)	232 (8)	320 (6)	226 (7)	196 (7)
(8)	16 August 2022	128 (6)	131 (7)	199 (7)	229 (5)	148 (6)	146 (5)
(9)	26 October 2023	51 (6)	50 (6)	130 (9)	215 (6)	60 (6)	26 (2)
(10)	8 February 2024	74 (4)	No crops	83 (7)			
(11)	14 May 2024	138(7)	226 (3)	10 (2)	234 (8)	338 (8)	286 (4)

Empty boxes mean no data due to weather incidents or problems of access to the gardens.

3.2. Temperature Comparison Across Urban Allotment Gardens, Urban Parks, and Urban Gray Spaces

The warmest season across all monitored spaces was the summer of 2022, particularly in the gray spaces (Table 5). By contrast, the minimum seasonal temperatures highlighted an exceptionally cold winter in Valladolid, with winter 2022 standing out, particularly the value observed in Los Santos Pilarica at −6.28 °C. Furthermore, the largest differences between maximum and minimum temperature records during the same season were observed across the four urban allotment gardens in autumn 2023, exceeding 35 °C. Among the monitored locations, Campo Grande consistently recorded the coolest temperatures throughout all seasons. On the other hand, Parque Alameda emerged as the garden with the highest temperatures among the urban allotment gardens, particularly evident in the summer of 2022 and autumn 2023. Meanwhile, Puente Poniente showed the lowest seasonal temperature records compared to the other gray spaces, as demonstrated across the seasons of 2022 and in spring 2023. Shifting from seasonal to monthly and daily analysis, the average monthly temperature revealed that July 2022 had the highest temperature. Moreover, the highest numbers of days with hourly records exceeding 35 °C were observed at *Catedral* (46 days) and *Puente Poniente* (44 days). The highest average daily temperature was recorded on 17 July 2022—as evidenced at eight out of the 10 monitoring spaces.

The highest hourly temperatures recorded in each space ranged from 38.86 °C to 42.42 °C, occurring between 14 July 2022 and 17 July 2022, and between 16:00 and 19:00 h. Considering the average hourly temperature from 21 June 22 to 18 December 2023—the last date with records in the gray spaces—the results showed that *Campo Grande* (CG) had the lowest temperatures compared to urban gardens and urban gray spaces (Table 6). In this case, the gray spaces showed a higher temperature difference than the urban gardens compared to *Campo Grande*.

Table 5. Seasonal average, minimum, and maximum temperatures (°C) across selected urban spaces. Legends (seasons of the year): "Sum." for Summer; "Aut." for Autumn; "Win." for Winter; "Spr." for Spring.

Season of the Year		Sum. 2022	Aut. 2022	Win. 2022	Spr. 2023	Sum. 2023	Aut. 2023	Win. 2023	Spr. 2024
Valle de Arán (allotment garden)	Avg (°C)	23.13	11.76	6.45	15.78	22.44	11.68	7.19	10.61
	Min (°C)	8.81	−3.13	−4.34	−0.26	7.65	−2.32	−3.42	2.71
	Max (°C)	40.24	29.09	22.61	32.03	38.94	32.93	22.38	26.51
Jardin Botanico (allotment garden)	Avg (°C)	23.08	11.49	6.28	15.60	22.35	11.45	6.99	10.46
	Min (°C)	8.61	−3.65	−4.76	−0.92	7.05	−2.25	−4.41	1.93
	Max (°C)	40.67	28.73	22.66	32.22	39.15	32.79	22.75	26.27
Los Santos Pilarica (allotment garden)	Avg (°C)	23.19	11.75	6.21	15.58	22.56	11.54	7.00	10.49
	Min (°C)	8.55	−3.96	−6.28	−0.59	7.68	−2.61	−3.75	1.80
	Max (°C)	40.34	29.75	22.26	31.77	38.81	32.87	22.01	26.12
Parque Alameda (allotment garden)	Avg (°C)	23.63	11.97	6.66	16.15	22.97	11.91	7.33	10.90
	Min (°C)	9.92	−2.98	−3.62	0.66	7.52	−2.38	−3.21	1.54
	Max (°C)	40.98	29.21	22.45	32.23	39.35	33.33	23.03	26.84
Campo Grande (park)	Avg (°C)	22.31	11.34	6.29	15.26	22.09	11.29	7.00	10.55
	Min (°C)	10.06	−2.43	−3.11	0.62	8.17	−1.68	−3.26	1.99
	Max (°C)	38.26	26.04	21.62	30.61	37.51	29.26	22.16	25.61
Puente Poniente (gray space)	Avg (°C)	23.24	11.49	7.04	14.66 *	22.87	12.15		
	Min (°C)	8.92	−2.75	0.03	0.14 *	7.74	−0.93		
	Max (°C)	41.24	29.71	23.21	31.61 *	41.02	33.78		
Sin Miguel (gray space)	Avg (°C)	23.51	13.38	8.82 *	16.42	22.00	10.63 *		
	Min (°C)	9.96	1.53	0.08 *	2.73	9.67	2.20 *		
	Max (°C)	40.36	25.13	21.60 *	31.52	37.41	17.01 *		
Catedral (gray space)	Avg (°C)	23.74	13.04	8.88	16.83	22.73	13.97		
	Min (°C)	9.96	0.24	0.06	3.37	10.32	1.68		
	Max (°C)	42.42	27.65	22.95	31.80	38.19	32.59		
Don Sancho (gray space)	Avg (°C)	23.68	13.45	9.68 *	16.63	21.97	13.48		
	Min (°C)	9.85	1.53	1.10 *	4.25	10.58	2.76		
	Max (°C)	41.04	25.28	21.10 *	29.92	36.49	29.29		
Dos de Mayo (gray space)	Avg (°C)	23.68	14.60 *	12.37 *	16.28	21.90	14.52 *		
	Min (°C)	10.04	3.99 *	6.30 *	4.00	10.66	2.20 *		
	Max (°C)	38.86	24.35 *	19.76 *	29.96	34.09	27.84 *		

* Values obtained from hourly data—less than 75%—corresponding to each season.

Table 6. Average hourly temperature (°C) differences between *Campo Grande* (park) and the other studied spaces (21 June 22 to 18 December 2023): allotment gardens shown in light green, and gray areas shown in gray. Higher values indicate a higher temperature difference compared to the park, and thus relative cooling benefit of the site compared to the park, where cooling benefits are high. Legends: "CG" for *Campo Grande*; "PP" for *Puente Poniente*; "SM" for *San Miguel*; "Cat" for *Catedral*; "DS" for *Don Sancho*; "DdM" for *Dos de Mayo*; "VdA" for *Valle de Arán*; "JB" for *Jardín Botánico*; "LSP" for *Los Santos Pilarica*; and "PA" for *Parque Alameda*.

	CG	*PP*	*SM*	*Cat*	*DS*	DdM	VdA	JB	LSP	PA
Average temperature (°C)	14.76	15.24	15.79	16.53	16.48	17.23	15.21	15.04	15.14	15.55
Difference with *Campo Grande* (°C)		+0.48	+1.03	+1.77	+1.72	+2.46	+0.44	+0.28	+0.38	+0.79

Considering the average daily temperatures (21 June 22 to 18 December 2023), the records for the urban park stand out, as it had a lower mean, median, and variability compared to the gray spaces and the gardens. The gray spaces showed the highest mean and median temperatures (Figure 7). The gardens displayed the greatest temperature variability, ranging from 0 to 32 °C. Analyzing the average daily temperatures individually, it was noteworthy that the gardens had almost similar trends among them, while the gray space records varied significantly between the different locations. Among the gray spaces, *Catedral* had the highest mean and median, while *Puente Poniente* showed the greatest temperature variability. Additionally, *Parque Alameda* was the garden with the highest mean and median records among the allotment gardens.

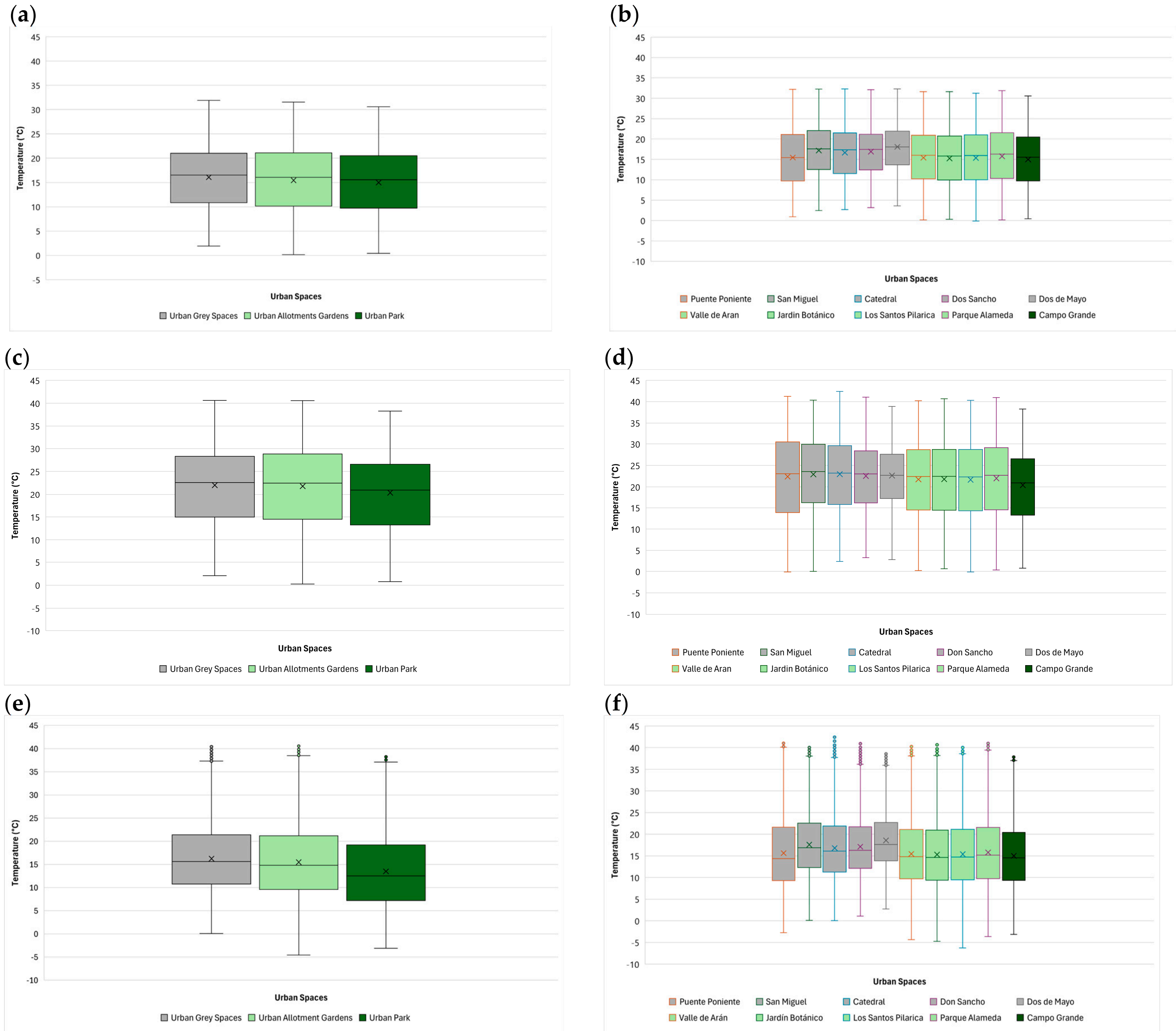

Figure 7. Analysis of temperatures in the urban spaces of interest: (**a**) Grouped average daily temperature; (**b**) Individual average daily temperature; (**c**) Grouped maximum daily temperature; (**d**) Individual maximum daily temperature; (**e**) Grouped hourly temperature; (**f**) Individual hourly temperature.

On the other hand, an analysis of the maximum daily temperatures (21 June 22 to 18 December 2023) showed that *Campo Grande* park recorded the lowest temperatures and the least variability. The behavior of daily maximum temperatures in the allotment gardens and gray spaces was quite similar: means and medians ranged between 22 to 23 °C, and their variability included values exceeding 40 °C. The graph of individual records by location (Figure 7) highlighted the highest variability of daily maximum temperatures in *Puente Poniente*, and the lowest in *Dos de Mayo*. In this case, *Don Sancho* was the garden with the highest mean and median compared to *Valle de Arán*, *Jardín Botánico*, and *Los Santos Pilarica*, which showed similar patterns. Finally, in the temperature analysis according to the hourly records obtained, the predominance of outliers above 35 °C in the gray spaces stood out—especially in *Catedral* and *Don Sancho*.

Another analysis was conducted considering only the data from summer records: summer 2022 (21 June 2022 to 23 September 2022) and summer 2023 (21 June 2023 to 23 September 2023). The daily average records identified *Campo Grande* as the location with the lowest temperatures. The grouped analysis of average daily temperatures indicated that gray spaces and urban gardens exhibited similar behaviors but with a lower median in urban gardens. The analysis of individual spaces with their average daily temperatures highlighted *Parque Alameda* with the highest temperatures among urban gardens, while *Puente Poniente* and *Catedral* was the hottest space among the gray spaces (Figure 8).

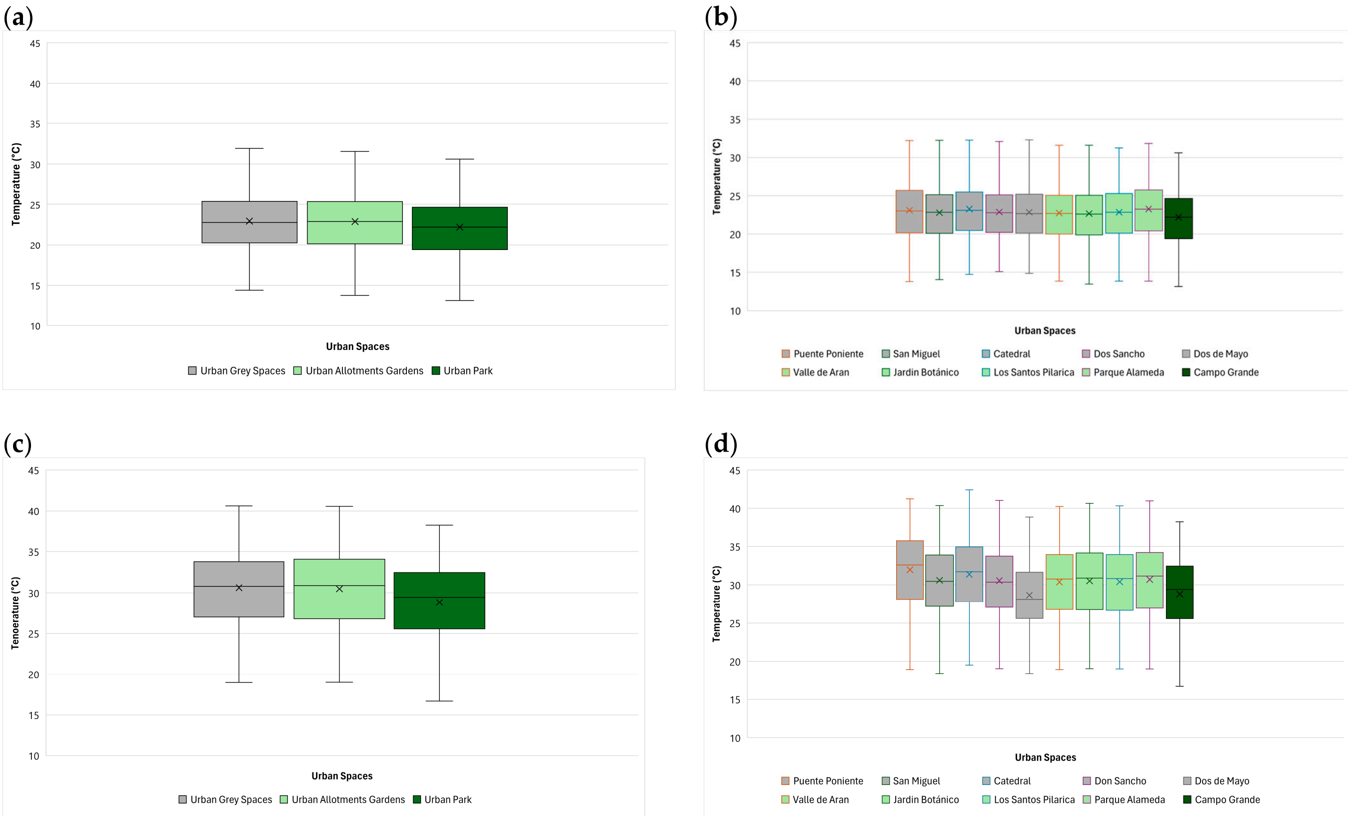

Figure 8. Analysis of summer temperatures in the urban spaces of interest: (**a**) Grouped average daily temperature in summer; (**b**) Individual average daily temperature in summer; (**c**) Grouped maximum daily temperature in summer; (**d**) Individual maximum daily temperature in summer.

Alternatively, an analysis of the maximum daily temperatures during the summer season revealed similar patterns between gray spaces and gardens when grouped, with *Campo Grande* showing the lowest maximum temperatures. *Catedral* and *Puente Poniente* had the highest maximum daily temperatures among the gray spaces, whereas *Dos de Mayo* had the lowest. Among the urban gardens, *Parque Alameda* stood out with the highest maximum temperatures, while *Valle de Arán* and *Los Santos Pilarica* had the lowest maximum temperatures (Figure 8).

3.3. Influence of Crop Characteristics on Summer Temperature Records

The findings suggested that certain crop characteristics have a measurable impact on summer temperature dynamics in the urban allotment gardens. The most significant relationships found were between the temperature and the crop plant cover, showing moderate correlations with summer temperatures. While crop plant cover was positively correlated with daily average and maximum temperatures, ground cover demonstrated exactly opposite trends. Additionally, average plant height was found to have a positive relationship with daily average and maximum temperatures (Figure 9). The crop abundance and the crop diversity did not show significant relationships with temperature and revealed greater uncertainties: only a weak positive relationship was identified between daily maximum temperatures and both crop abundance and diversity.

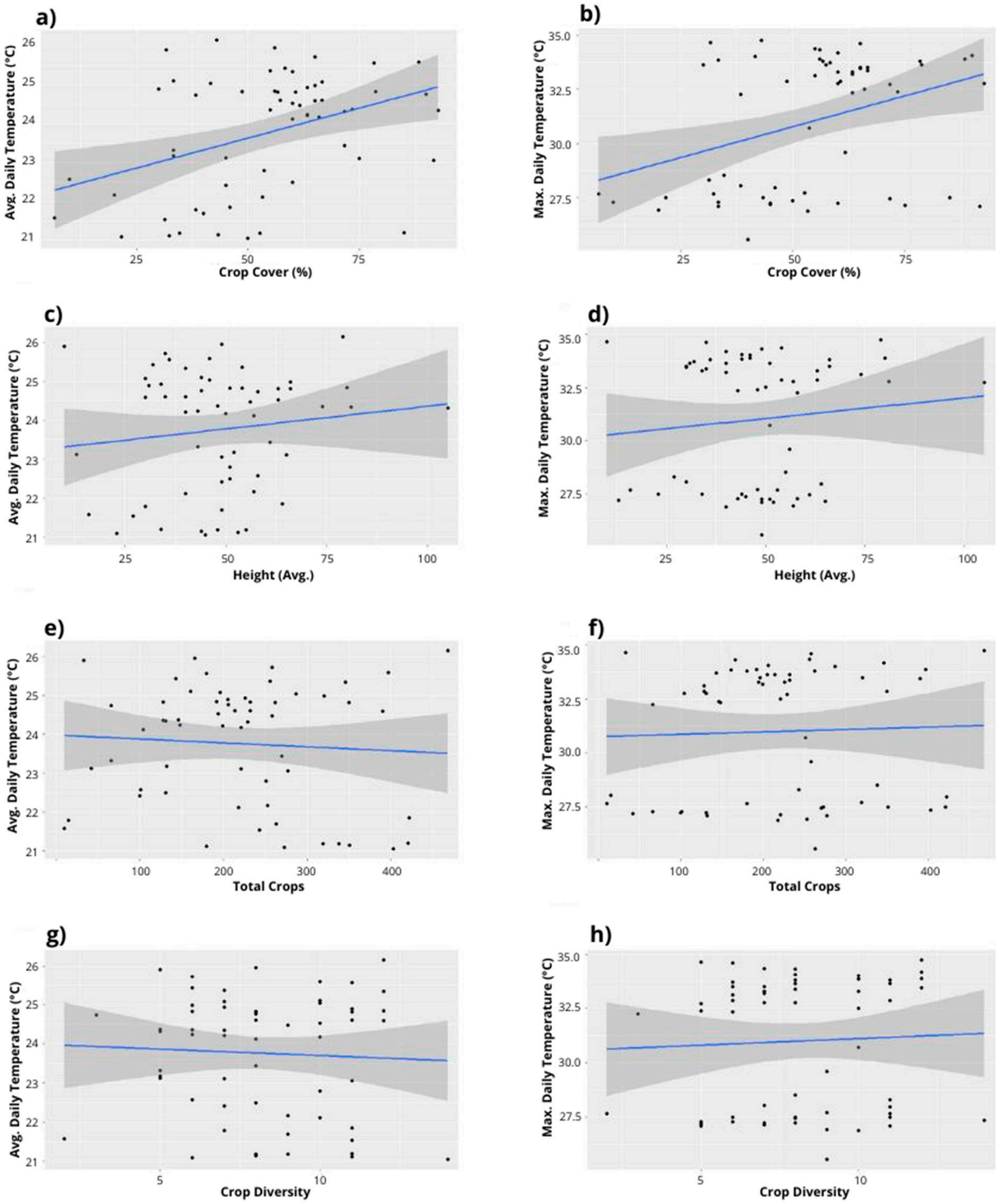

Figure 9. Relationships between crop characteristics and temperature during summer seasons: (**a**) Crop cover vs. Average daily temperature; (**b**) Crop cover vs. Maximum daily temperature; (**c**) Crop height vs. Average daily temperature; (**d**) Crop height vs. Maximum daily temperature; (**e**) Total crop plants vs. Average daily temperature; (**f**) Total crop plants vs. Maximum daily temperature; (**g**) Crop diversity vs. Average daily temperature; (**h**) Crop diversity vs. Maximum daily temperature.

3.4. Perceptions of Urban Gardeners About Climate Change

A total of 128 people were surveyed in the allotment gardens (21 people in *Jardín Botánico*, 34 in *Valle de Arán*, 35 in *Parque Alameda*, and 38 in *Los Santos Pilarica*). In most cases, people were between 55–64 years old (34%), followed by 45–54 (20%), and 65–74 (17%). The majority were perceived as coming from urban areas (70%), with 30% from rural areas. Approximately 25% of the people surveyed, had no previous experience in food cultivation practices before their activity in the urban allotment gardens. Currently, the main reasons for cultivating in Valladolid were personal and family food (28%), recreation and hobby (23%), economic benefit (14%), connection with nature (13%), health benefits (11%), aesthetic beauty of the neighborhood (7%) and socialization (4%).

Regarding their horticultural activity, a preference for summer was demonstrated as the season when the people have most work in the gardens. Work was demonstrated for more days of the week and more hours *per* day during summer, when gardeners often work three or more times a week. On the other hand, in winter, there was a preference for working one time or less *per* week.

Most gardeners thought that climate change was a current phenomenon (74%), while 17% believed that it was not (9% did not take a position). It was found that 71% perceived that their health was affected by the weather patterns of recent years, while 68% perceived that their city was affected. About the possible contributions of urban allotment gardens to cities in the climate change context, people mainly perceived that this kind of urban space can mitigate extreme temperatures (21%), can regulate the urban microclimate (18%), and can infiltrate rainwater, preventing flooding (14%) (Figure 10).

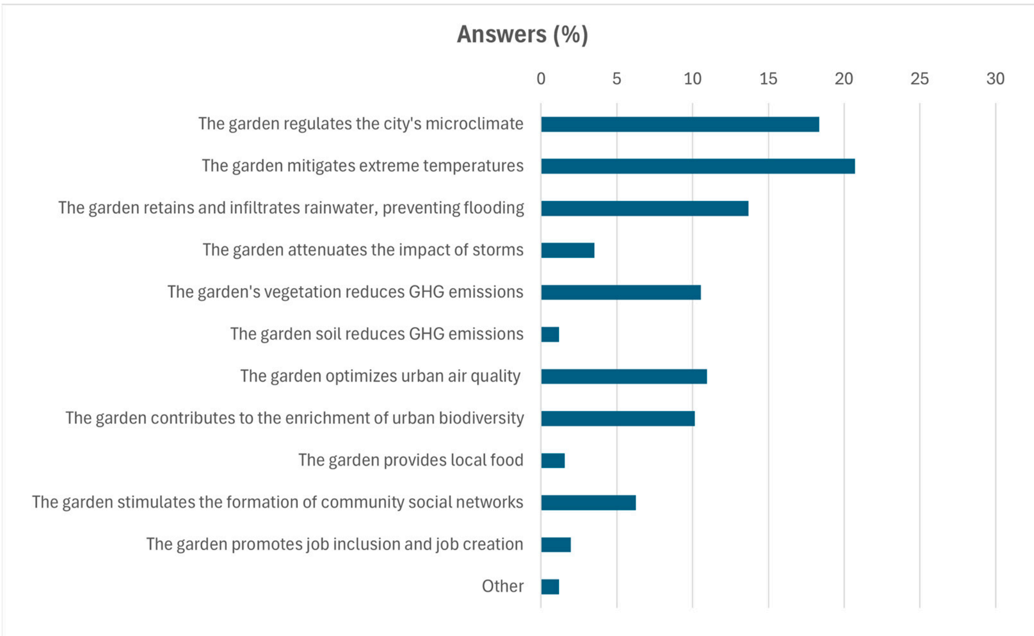

Figure 10. Gardeners' perceptions of contributions of allotment urban gardens to the city in climate change context, presented as percentage of respondents.

Relating weather patterns to urban farming practices, people identified that their crops were slightly affected (39%), severely affected (34%), not affected (10%), and also slightly benefited (3%), while 14% did not take a position. Among the perceptions about climatic or environmental considerations that affect the urban crops, greater concern was identified for heat waves, temperature increases, and daily temperature changes. Subsequently, concerns emerged regarding water, drought, rainfall, storms, and frost. Based on perceptions of climate change and gardening practices, it was identified that gardeners were currently adopting certain practices including irrigation, monitoring, and even changes in planting strategies (Figure 11). However, they believed that for the future, it will be important to increase water application, more frequently monitor crops for more controlled gardening, and add shade protection for crops in the plots. More details on the survey results can be found in the Supplementary Materials.

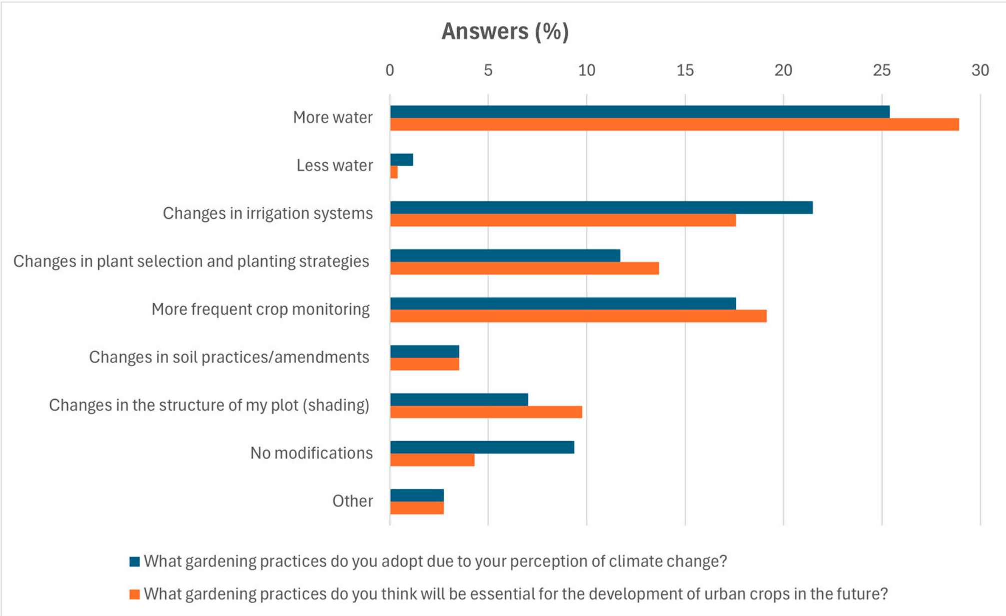

Figure 11. Urban gardening practices and climate change: current and future perspectives reported from the gardeners, presented as percentage of total respondents (%).

4. Discussion

This research brings attention to a specific type of urban garden—urban allotment gardens, which have been understudied and possess unique characteristics regarding their functioning, characteristics, and benefits. The results highlight the role that allotment gardens play for low-income populations in Valladolid. Although the primary objective of these spaces is food provision, this research reveals other ecosystem services such as cooling potential, and additional values through the perspectives of the gardeners. These analyzed capacities are three contributions to consider urban allotment gardens as an urban climate strategy [46].

The crops observed—particularly tomatoes, peppers, and onions, representing 24%, 16%, and 15% of total crop abundance, respectively—highlight a strong preference for commonly consumed crops in the urban allotment gardens of Valladolid. Despite the influence of varying climates on the types of crops grown in urban gardens around the world, the crops identified in Valladolid align with broader urban gardening trends in the Global North [23,45,47–50]. Additionally, leafy greens like lettuces and alliums (garlic and onions) showed significant presence, emphasizing the urban gardener's inclination towards vegetables that support multiple harvests or have extended shelf lives. Peak yields in summer suggest urban gardeners align crops with optimal weather conditions, demonstrating adaptability to maximize production in limited spaces (plots). Since some crops have higher water requirements than others (for example, *Solanum* spp., *Capsicum* spp., or *Cucumis* spp. require more water than *Brassica* spp. or *Allium* spp.), in the future, they will require the application of adaptive gardening practices [12,35]. This includes adjusting planting dates, selecting suitable crops, enhancing soil health, and implementing efficient irrigation practices [12,35,51]. Ground covers, especially straw and mulch, improve soil health, reduce evaporation, enhance water retention, and increase water use efficiency in urban gardens, particularly helpful during warm periods [50–52]. Although their use requires labor and costs, their long-term benefits to soil health make them valuable in the climate change context [51]. Moreover, the crop diversity observed reflects the role of the gardens as spaces with productive vegetation. Unlike other urban green spaces, the urban gardens prioritize crops that cast less shade than trees.

Considering that urban planning is shifting from traditional prescriptive approaches to adaptive planning and resilience frameworks [11], urban gardens can play a key role by emphasizing their multiple benefits. For example, in Rosario (Argentina), the urban gardens contribute to both social and environmental resilience by serving as spaces that help combat flooding and offer meaningful employment opportunities to address poverty [53]. In New York (United State), urban gardens played a vital role in building resilience after the Hurricane Sandy [54], while in Melbourne (Australia), they foster community participation and contribute to urban cooling [23]. In our case in Valladolid, we highlight the importance of urban allotment gardens for promoting social resilience (through community building), economic resilience (by reducing food costs), and environmental resilience (by urban cooling). The potential of urban gardens to mitigate urban heat underscores their value as assets in city planning for climate resilience. By incorporating more green spaces that combine food production with cooling benefits, cities could strategically reduce urban heat stress and improve overall livability. These spaces can be particularly valuable in neighborhoods facing food insecurity, limited green spaces, and heightened vulnerability to heat stress.

The effectiveness of green infrastructure in reducing urban heat has already been proven through measurements (field measurements, scale models, thermal remote sensing), and computer simulation [55]. The cooling potential of green spaces, such as parks and gardens, is directly linked to factors like evapotranspiration, vegetation cover, shaded areas, their influence on air movement, and heat exchange [55,56]. In this context, urban parks are expected to have a higher cooling potential than urban gardens. However, this assumption is one of the key motivations in our study, as it aims to quantify the extent of this difference. Our results demonstrate the significant influence of urban parks in cooling cities, while also showing that allotment gardens maintain more stable and lower thermal conditions than gray spaces. This effect is most pronounced in summer, particularly when considering the maximum temperature records. It is important to note that temperature variability at the scale of urban gardens is driven mainly by regional context, and the cooling effect must be qualified according to the type of climate, culture, traditions, and region-scale urbanization [11,23]. In this regard, the cooling effect of these spaces must be understood in relation to the type of climate, cultural practices, traditions, and the level of urbanization at the regional scale [36].

Surprisingly, we did not find consistently strong relationships between crop abundance and diversity and the cooling effect in the research plots. This unexpected result opens the debate that temperature may not be a determining factor for the abundance and diversity of crops in spaces that have highly managed systems where irrigation is allowed. The most notable effects were observed from crop plant cover over the soil, which can be attributed to the evapotranspiration activity, creating a cooling effect from the ground up. This result supports other studies that declare that greater crop cover is associated with lower temperatures [23,34,36,53,57]. In urban allotment gardens, which are often smaller and intensively managed, evapotranspiration may have a more immediate cooling effect than shading, as crops are irrigated regularly and create micro-scale humidity that offsets ambient temperatures. On the other hand, height, which was identified with a slightly positive cooling relationship, is considered to have greater influence if the crops can provide more shade, for example, by encouraging taller and vertical planting. The incorporation of trees with greater canopy cover ensures shade in the garden, thus providing greater cooling potential and a cool place for gardeners to rest.

The surveys conducted provide additional social data, complementing the field work and data from environmental stations. Sometimes, people's perspectives can carry more weight than empirical data for decision-makers. Regarding gardeners' perceptions, a general awareness of climate change is evident. In Spain, this issue is currently part of popular discourse and has even become somewhat politicized. However, we found that gardeners perceive climate change in Valladolid as a direct threat to their crops, based on recent experiences where extreme heat, frosts, or water restrictions have negatively impacted their gardens. This is in line with the perception of urban gardeners in other cities [23,57]. Water and irrigation will become increasingly important concerns as temperatures rise and crops require more water for their growth. This could become a significant challenge when planning new allotment garden spaces. The source of the water used, restrictions especially in cities facing drought conditions, and irrigation techniques are vital aspects that must be considered. Adaptive irrigation techniques, such as rainwater harvesting, the use of drought-resistant crop varieties, soil mulching, crop combinations, and optimized irrigation schedules, will become increasingly valuable [12,51]. A study in California (United States) focused on adaptive irrigation in urban gardens has revealed that the combination of education, rules and regulations will improve the sustainability of garden systems in times of climate change [35]. As climate pressures increase, such as with more frequent heatwaves and water shortages, the social dynamics around allotment gardens may shift, with gardeners likely forming stronger collaborative networks to share resources and knowledge on adaptive practices. These evolving dynamics could enhance the resilience of these spaces, fostering a collective approach to managing climate-related challenges. In particular, the technical support provided by the government for the gardens—such as in the case of the allotment gardens in Valladolid—will be crucial for enabling adaptive gardening practices in the future [34].

Despite existing studies, more information is needed to understand temperature variability at the local scale of urban gardens and how temperatures change over time in these spaces [36,57]. This study allowed the incorporation of a new city with a different climate than the existing ones. Additionally, urban gardens can be better highlighted if evaluated for their socio-environmental benefits rather than individually. In terms of their individual potential for urban cooling, these spaces could have a more significant impact if they incorporated more trees and shrubs that provide food and consistent shade. For a more comprehensive socio-environmental assessment of allotment gardens, carbon sequestration rates in the soil could be measured, biodiversity indices evaluated, and the floral richness and functional ecology of bees analyzed. Air quality could also be assessed, and even residents could be surveyed about their perceptions of the urban garden in their neighborhood. As future steps and for further enhancement of this type of research, the methodologies used could be complemented by other technologies, such as the use of unmanned aerial vehicles (UAVs) to measure garden vegetation [58] or even satellite imagery and artificial neural networks (ANNs) for estimating urban temperatures in the urban spaces of interest [59,60]. Research on this topic should seek to transfer knowledge to those responsible for public policies in order to give greater priority to urban gardens as a climate strategy, considering the food self-provisioning as a strategy for both mitigation and adaptation to climate change [61].

5. Limitations

The effective collaboration between the research group and the Valladolid government proved highly beneficial but also revealed certain limitations in the temperature data. Notably, temperature data from environmental stations in urban gray spaces—provided by the government—exhibited gaps during the study period, were discontinuous, and ended before the data collected in urban allotment gardens and *Campo Grande*. Consequently, comparisons across locations had to be constrained to specific dates. These gaps, particularly the missing records from the urban gray spaces, could have affected the study's findings by limiting the ability to compare the full range of temperature variations across all study locations. For example, missing data from periods of extreme temperatures might have resulted in an underestimation of the heat stress experienced in gray spaces, potentially affecting the results regarding their urban cooling effect. Additionally, the uneven distribution of temperature stations—twelve in four gardens, two in one urban park, and five in five gray urban spaces—further complicated direct comparisons of cooling effects across spaces. Another limitation identified in the temperature data was the difference in the characteristics of the environmental stations used by the government compared to those installed by the research team in the allotment gardens and *Campo Grande* (HOBO loggers). This discrepancy required a standardization process for the sensors over 84 h. Although extending this standardization period might have been preferable, further intervention was not authorized by the local government. Furthermore, the individual scaling factors used for standardization worked well for average temperatures but dampened the extreme temperatures (both higher and lower) recorded in gray spaces. This discrepancy had impacts on the analysis of gray space results, potentially obscuring the results in these areas. Nevertheless, the standardized data still revealed that urban gray spaces exhibited the highest temperatures, which might have been even higher when considering the raw data (unstandardized data). Future research would benefit from more extensive spatial and temporal coverage by incorporating additional environmental stations across a broader geographical urban area and over longer periods of time. This would enable a more comprehensive assessment of the temperature variations throughout different seasons, as well as provide a more accurate comparison of the urban cooling effects of various urban spaces. A more diverse dataset would improve the robustness of findings and allow for better extrapolation of the results to different urban environments with varying climate conditions.

Possibilities for improvement were also identified in relation to the crop data. There were some data gaps in the field work rounds: weather incidents restricted data collection during field work session N°5 (10 February 2023) in plot S2 and in plot S12 *Jardín Botánico*, as well as in plots S13, S9, and S5 of *Los Santos Pilarica*. This weather barrier recurred also during field work session N°10 (8 February 2024), affecting only the data collection in the plots of *Los Santos Pilarica.* Additionally, the lack of data for plot S9 in *Los Santos Pilarica* during field work N°4 (8 November 2022) and the plot S12 in *Jardín Botánico* during field work N°6 (18 June 2023) was due to restricted access to the gardens. Over a nearly two-year period of temperature recordings, more continuous monitoring, with additional field work rounds and a determined frequency, could have provided more comprehensive information, particularly in capturing seasonal variations in plant growth, yield, and response to temperature changes. For instance, more frequent observations would allow for a better understanding of how crops adapt to fluctuating conditions throughout the growing seasons, providing more insights into their resilience to extreme weather events. Additionally, increasing field work would improve the identification of crop species and their detailed characteristics, ensuring that the botanical classification of plants was more precise. Three research plots *per* garden, though informative, are insufficient to fully represent the diversity of crops grown in each garden, yet these were the only plots authorized for the study. However, the crop characteristics obtained do provide valuable insights into the plants chosen by gardeners and the composition of plots throughout different seasons. As a result, these proposed improvements in data collection could significantly enhance the depth and accuracy of the study, offering more nuanced insights into the socio-environmental impacts of urban allotment gardens.

6. Conclusions

Urban allotment gardens hold potential for addressing climate change challenges through their socio-environmental dimensions. While these spaces are initially designed as public places to help people grow their own food, they also offer additional benefits such as urban cooling. In the case study of Valladolid, Spain, this research identified crops that align with urban gardening practices in the Global North (such as tomatoes, peppers, or garlics), showing higher productivity during the summer months, which helps low-income populations. As particular urban spaces, the allotment gardens offer more stable and cooler temperatures compared to urban gray spaces; however, they do not exhibit the same pronounced cooling potential as urban parks. It is important to note that cooling effects are largely dependent on the urban spatial context at the neighborhood scale, influenced by factors such as infrastructure, vegetation, location, and structure, among others. The presence of crops, especially those that provide greater ground cover, can influence the internal microclimate at plot scale (microclimate). However, to improve the cooling capacity of an urban allotment garden, the results suggest that it should have greater crop cover over the soil, a higher species diversity, and even taller crops. If urban cooling is the primary goal of a garden, incorporating trees (as part of an urban forest) could be an optimal strategy for new designs. Beyond their contributions to cooling, gardeners in Valladolid perceive urban allotment gardens as environmentally beneficial in a climate-threatened context. As temperatures continue to rise due to climate change, urban gardeners will need to implement adaptive gardening measures such as adjustments in planting schedules, crop selection, management practices, and irrigation methods, to obtain more abundant and improved crops in the future. Water management is the threat that most concerns gardeners when considering the survival and future development of these urban productive spaces. The results show that urban gardens can contribute to the sustainable and climate-resilient planning of cities, where their integration can foster more resilient, adaptable, green, and healthy urban spaces. Researching these practices in different cities is valuable because they vary in their forms, characteristics, and management. However, the results obtained should be considered by decision-makers in taking action, and exemplary cases—such as Valladolid—can serve as references for other cities. Sustainability evaluations of urban gardens should not focus on a single benefit; rather, it is advisable to evaluate their multifunctional contributions, including social, environmental, and economic dimensions.

Supplementary Materials: The following supporting information can be downloaded at: https://doi.org/10.6084/m9.figshare.26954461.v1 (accessed on 18 November 2024).

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