Informe de resultados/Project Report

Convenio OXFAM INTERMON-CEIGRAM

“Evaluación cuantitativa de los impactos del cambio climático en la producción de olivar y viñedo en la Franja de Gaza, Palestina”

“Quantitative assessment of climate change impact on grapevine and olive tree crop production in the Gaza Strip, Palestine”.

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1. INTRODUCTION

This study aims to provide projections of climate change impacts on grapevine and olive tree crops in the Gaza Strip. The study will deliver a preliminary diagnosis on the rough trends of impacts and uncertainties, identifying main issues that need to be addressed before conducting an accurate adaptation analysis and generating recommendations.

The first step of the study was a literature review and search of available data sources both publicly available and from previous studies. The focus was targeted on previous analyses on grapevine and olive crop including climate change conditions.

This section is a brief overview of the main literature mostly published in the last 5 years, after the last AR5 IPCC report, on the impacts and adaptation measurements of olive and grapevine crops in the Mediterranean region. Some former references were also included when they considered relevant for the study. As the publications in the Gaza Strip are scarce, studies with similar conditions were included.

Some studies stress that Mediterranean basin is especially vulnerable to changes in precipitation patterns in concurrence with high temperatures. This will have a negative impact in both olive and grapevine crop (De Ollas et al., 2019), which demand a special effort on breeding programmes for developing varieties resistant to drought and heat stress.

1.1. Previous work on olive tree crop

Existing studies on how climate change will affect olive crop, show that changes in phenological dates are expected as a consequence of the temperature increase. Specifically, flowering is expected to occur 11 days earlier in the Mediterranean in the second part of XXI century (Tanasijevic et al., 2014). In the case of the A1B scenarios, moderately optimistic (given that it implies a temperature increase of 1.8ºC), this flowering could be advanced between 3 and 7 days for Gaza (Ponti et al., 2014). There also some previous work relating flowering date and intensity with the temperature and water availability (Orlandis et al., 2014) in the Mediterranean basin. These authors report an advance of flowering between 5-7 days from 2000-2009 compared to the previous decade, with a decrease in pollen emission.

Other phenological issue to be considered is the start date of the heat accumulation period. For evaluating this aspect, one approach would be to evaluate the chilling accumulation periods. There is a large uncertainty about olive chilling requirements. However, some authors have estimated them and how they would be fulfilled in future (Aguilera et al., 2014). They conclude that the orchards in the warmest winter areas of the Mediterranean basin will exhibit rapid floral development once the chilling requirements are met. This work shows a string relationship between the both the threshold temperature to estimate chilling accumulation and the flowering date, with the latitude, and at a lesser extent with the altitude. Anyway the olive trees have been proven a large adaptive capacity for warmer conditions. On the other hand, olive tree management can be enhanced when forecasting of crop phenology
is possible. There are some advances in this sense, as for instance as shown by Oteros et al. (2014).

Water consumption is a key issue in rainfed crops. For olive trees, crop evapotranspiration is projected to increase by 8%, with more net irrigation requirements (18.5% higher), that for example, could translate into additional 140 mm in the case of Algeria (Tanasijevic et al., 2014). This could jeopardize the rainfed olive orchards in some parts of the Mediterranean area (Ponti et al., 2014; Orlandis et al., 2014). Orlandis et al. (2014) identified summer water deficit as the main limiting factor for the area, as the temperatures of the winter period can be dealt with current or adapted varieties.

There are also other factors that have not been considered here, as for instance how the climate change will affect pests and diseases. For instance, fly infestation has to be assessed, as well as new invasive pests, which may have an impact on profitability of small farms in marginal areas of the Mediterranean basin (Ponti et al., 2014). In the case of the Gaza Strip, projections indicate a slight decrease in fly abundance and in the % of fruits infested for 2041-2050, but the risk of new pests should be considered.

As a consequence of all these factors together, at the Mediterranean basin the projection of crop yield for olive trees are both positive and negative, depending on the area within the Mediterranean, the emission scenario, the period of the XXI century considered and also depending on the author. For example according to Ponti et al. (2014), the projections in the Mediterranean basin are mostly positive; however for the area of the Gaza Strip a decrease of ca. 20% in olive tree yield is expected (i.e ca. 400 kg/ha of yield decrease for 2041-2050). The predictive model by Oteros et al. (2014) projects a decrease in crop yield when temperature during winter and summer increases. These in turn will result in a decrease of crop profitability in this area, which has been estimated in ca. 100-120 euros ha⁻¹ for the area where Gaza Strip is located (Ponti et al., 2014).

Finally, previous studies have projected a swift of land suitable for olive tree cultivation to northwards and at higher altitudes. This would increase the total suitable area in the Mediterranean region by 25% in the next 50 years (Tanasijevic et al., 2014). For instance for Spain, Gabaldón et al. (2017) found that an advance in the flowering date of olive trees of 1 to 2 weeks is projected in Andalusia for 2021-2050 and 2071-2100 periods, with low uncertainty. Within Spain, the Atlantic Ocean area and South-East coast will be more vulnerable due to lack of chilling units in winter and the Northern-East region due to the high temperatures during flowering.

1.2. Previous studies on grapevine

Grapevine has the largest area and highest economic importance among the tree crop globally (Ponti et al., 2018). It is also very relevant in the Mediterranean area, where the projections on how the climate change will affect crop yield are mostly negative. This is not the case in the rest of Europe, for where it is expected moderate to important yield increases.
However, projections for Italy, Spain, Turkey and Morocco indicate yield decrease for a warming of 1-8 °C (Ponti et al., 2018). It is noticeable that these authors provide these results with a spread that includes positive yield changes; this is to say, there is a very large uncertainty in the final crop yields, with means indicating yield decrease but with some projections indicating moderated increases. The decrease is projected to affect more area when going southwards (e.g. Algeria or Egypt; Ponti et al., 2018).

This was also confirmed by Ferrise et al. (2016), who found also for this crop an faster crop development associate to the to the temperature increase as compared to the present period, which similarly to olive crop, will in turn result in a decrease in grapevine yield in the Mediterranean Basin, but for southern France and western Balkans. Other example is grapevine production in Spain, where Resco et al. (2010) found that warmer and drier temperatures during grapevine growing season will cause a yield decrease up to 60% in Córdoba (Andalusia) under future climate for different SRES scenarios (A1, A2, B1, B2), making advisable at least a change of variety. According to this author, yield quality would be also affected. However, for coastal regions as Murcia (Southeast of Spain) the impact was much less pronounced.

Water availability and management are key issues for this crop in the study. The Standardised Precipitation-Evapotranspiration Index (SPE), a common indicator for water deficit, is projected to change from dry, as in mid 21 century, to very dry by the end of the 21 Century in the Gaza Strip (Santillán et al., 2019). Heat waves and severe drought summer are expected to increase in the Mediterranean climate areas (Carvalho et al., 2018).

Also, evolution of pests and diseases under future climate conditions is also very relevant for grapevine production. Bois et al. (2017) investigated this evolution in the main productive areas of grapevine at global level, finding that mildews will remain the major phytosanitary threat in most of the regions, including Mediterranean.

Other factor to be considered is the variation of the producers-climate interactions (Santillán et al.; 2019), which can be extremely different across Mediterranean. Inadequate consideration of this interaction can lead to maladaptation unless explicitly description of the local viticulture systems and management, as well as vulnerability to climate, are included when design the adaptation plans.

Farmers at the Mediterranean already are adjusting their management techniques to the changing climate, which is pushing main crops in the area to their limits. Also, they are demanding from researchers genotypes to response to future climate conditions (Carvalho et al., 2018). In particular, there is a compelling need for varieties able to cope with stress combinations and extreme events. A better understanding of acclimatization is also needed.
2. MATERIAL AND METHODS

2.1. Climate data

Daily maximum and minimum temperatures and precipitation for the region were selected from the observational data set EOBS (v20.0e released in October 2019, Cornes et. al, 2018) for the 1976-2005 period.

Meteorological field data were retrieved from a station in Gaza located at 31.30N, 34.26E, (13m a.s.l.), which provided monthly-aggregated information of maximum and minimum temperatures and precipitation (Tmax, Tmin and Pr respectively). Information from some years (depending on the variable) from 1967 to 2018 were available.

Daily outputs of simulated daily Tmax, Tmin and Pr for the region were extracted for the Gaza Strip from 4 different EUR-11 RCM simulations (with a horizontal resolution of ca. 12 km) from the Coordinated Regional Climate Downscaling Experiment (CORDEX; Giorgi and Gutowski, 2015) for the period 1976-2005 (from the historical simulations) and for the periods 2020-2049 and 2070-2099, both under two emission scenarios or Representative Concentration Pathways (RCPs; van Vuuren et al., 2011): the RCP4.5 and RCP8.5, which consider a radiative forcing increase of 4.5 W/m$^2$ and 8.5 W/m$^2$ at the end of the century relative to pre-industrial levels respectively.

The individual members (CNRM-CM5_r1i1p1_RCA4_v1, EC-EARTH_r1i1p1_RACMO22E_v1, EC-EARTH_r12i1p1_RCA4_v1 and MPI-ESM-LR_r1i1p1_CCLM4-8-17_v1) of the 4-model outputs ensemble (hereafter ENS-11) were bias adjusted before its application.

The bias adjusting process was performed by using the climate4r R package (Iturbide et al., 2018) for applying the trend-preserving ISI-MIP bias correction approach proposed by Hempel et al. (2013). To do this, the EOBS dataset was used as observational data set for adjusting each member of the ENS-11 ensemble for the previously mentioned periods and RCPs. An additive approach was applied to minimum and maximum temperatures and a multiplicative approach was used for precipitation.

After the bias adjustment process, each member of ENS-11 was used to calculate every index proposed in this study and an ensemble result was obtained by averaging the results from its members.

An evaluation of the bias adjusted ENS-11 ensemble compared with the observed data from the station was done by selecting the CORDEX grid cell (centre at 31.25N, 34.25E) where the station is located, selecting the years from the ensemble for each variable (maximum and minimum temperatures and precipitation) from the historical period which are available at the station (i.e. 1976 to 1997 for temperatures and 1976-2000 for precipitation). Then, monthly aggregation was performed (mean for temperatures and addition for precipitation), to compare them with the station values by plotting the results. Mean temperatures (Tmean) were calculated by averaging monthly data from Tmax and Tmin for both observed and simulated and then also added to the plot.
2.2. Crop data

Phenological data (as flowering and maturity dates) and beginning and ending of evaluation periods were gathered from literature and from reported data. For instance flowering dates in present climate were estimated by reported data, expert judgement, a weighted mean between values from similar locations (e.g. Zarzis, Tunisia), and the regression found between latitude and flowering date (Aguilera et al., 2014), which provided a value of 102 days for flowering date at Gaza latitude. The final date considering these inputs was day of year (DOY) 110, this is to say, the 20th April.

2.3. Indexes

The following indicators (highlighted within the following text) have been used in this study, and their references, definitions and calculation procedure are depicted below.

The chilling accumulation was calculated. For doing so, hourly temperature was derived from the simulated Tmax and Tmin temperatures following the de Wit et al. (1978) approach. The chilling accumulation was calculated from the moment in autumn when the chill starts to increase until the moment the chill accumulation reaches the maximum value following the procedure depicted in Rodríguez et al. (2019). In this way, the end of chilling accumulation period index is calculated.

For the dynamically calculated chilling accumulation period, chilling units where calculated using the De Melo-Abreu model (De Melo-Abreu et al., 2004), specifically developed for olive, also, chilling portions were calculated by using the Dynamic model (Fishman et al., 1987a,b) and chilling hours under the 18ºC threshold were calculated. In every case the median was used for estimation for the ENS-11.

For analysing the budbreak date, in first place a base budbreak date for present was established as February 1st, and then, the growing degree days (with a base temperature of 5ºC) from January 1st until that date were calculated for the baseline period. In second place, the changes in budbreak dates are estimated by calculating the dates when the growing degree days are reached in the future periods for both RCPs. The final averaged result from the ENS-11 was gathered by using the median of the individual results.

An analogous procedure was followed for analysing the flowering date, where a base flowering date for present was set as April 20th, and the growing degree days (also with a base temperature of 5ºC) were calculated from the budbreak date, and the changes in flowering date were estimated following the same approach than for budbreak.

The number of days with temperatures above 35ºC and with temperatures above 27ºC were calculated during a two-month period (30 days before and after) centred in flowering
date and the results are shown following two approaches: 1) plotting in a map the number of days (out of 61) when the event takes place (after calculating the mean for the years of the period and the members of the ensemble) for the whole region, and 2) showing results for individual grid cells about the number of years in which those events for each day of the year (DOY) from the selected period for each of the 4 grid cells from the CORDEX grid covering the whole Gaza strip. The first approach provides a general overview for the whole region meanwhile the second one show more detailed information for each grid covering the region.

A similar procedure was followed for calculating the number of events of three consecutive days with temperatures above 35°C and with temperatures above 27°C with the only difference that the temperature threshold should have been exceeded also in the two previous days in addition to the considered.

Also, by following a similar procedure, the number of events when no rain for the last two weeks was calculated. In this case the considered period started 30 days before flowering and ended on September 1st and on October 1st (both results provided). The grid cell maps were constructed following the same procedure than for the temperature ones but for the map plots. In this case, the plotted values do not show a number of events but a percentage of the days of the period, as the periods may change for different models, calculation periods or RCMs, because the initial date changes in relation to the flowering date but the end date does not change.

For all of them, the indexes were calculated for the periods 1976-2005 (representing present), 2020-2049 (representing mid 21 century) and 2070-2099 (representing end of the 21 century), and for both RCPs (4.5 and 8.5).
3. RESULTS AND DISCUSSION

3.1. Assessment of simulated climate

Simulated data from the four ENS-11 ensemble members were compared to the observed weather for the period available as described in the previous section, to estimate the errors in future projections that can be attributed to climate models. Also, the objective was to characterise the Gaza Strip in terms of the uncertainty of climate projections and depending on the results derive recommendations for further assessments.

Thus, Figure 1 shows the comparison between Tmax, Tmin and Tmean for the last part of the 20 Century. RCMs overestimated Tmax and underestimated Tmin, while its derived Tmean had a good fit throughout the year, which probably can mitigate the effect of the errors when computing phenological crop dates.

Precipitation was underestimated during the months with any rainfall (Figure 2). This can affect the simulation of soil water content during the year. However, the most relevant parts of both olive and grapevine crops occur during the months with no precipitation the area (April to September).

The combined errors of Tmax, Tmin and precipitation, and considering that rainfed management is at stake, make advisable the use of techniques for uncertainty management in further stages of this research, as for instance, the Impact and Adaptation Response Surfaces (e.g. Pirttioja et al., 2015; Ruiz-Ramos et al., 2018). These techniques allow assessing the performance of adaptation options under a wide range of combined temperature and precipitation changes.

![Temperature (1976-1997)](image)

*Figure 1. Evaluation of simulated temperatures by RCMs as compared with observed data.*
Figure 2. Evaluation of simulated precipitation by RCMs as compared with observed data.
3.2. Impacts on chilling accumulation

Both grapevine and olive trees are reported to require an amount of chilling accumulation defined by different temperature thresholds for a successful end of dormancy and therefore to an appropriate flowering. However, both the number of chilling requirements and the thresholds are estimated with large uncertainty. Besides, chilling requirement varies with the crop variety. The commonly used varieties in the Gaza Strip have low chilling requirements, but it is important to assess if even those will be met in future.

According to field data provided, farmers from Gaza have indicated that 18°C is a suitable threshold for grapevine crop. Figure 3 shows the annual chilling accumulation over this threshold for the current climate (represented by the period 1976-2005), and the change of this accumulation for mid and end of 21 century (2020-2049 and 2070-2099, respectively), for the Representative Concentration Pathway (RCP) 4.5. (Please notice that grid cells with large sea influence not climate data were available). Figure 4 shows the same analysis for RCP 8.5. According to these plots, chilling accumulation will decrease by 20-30 % for mid 21 century, while at the end of the century the decrease could range from 40% to 80% depending on location and RCP.

Using this threshold, it is also possible to simulate the date when the chilling accumulation ends. This date is expected to be advanced from 6 to more than 12 (up to 18) days by mid century, and between one to three weeks by the end of the century, depending on location and RCP (Figures 5 and 6).

Some of the chilling accumulation methods have been specifically developed for specific crops. This is the case of the De Melo-Abreu method, developed for olive tree, crop for which has been applied. In its definition, the optimum temperature for chilling accumulation is defined at 7.3°C, matching the threshold of 7°C retrieved from the field information provided by farmers. According to this method, chilling accumulation will decrease between 20 and 60% by mid century and between 60 and 100% by the end of the century depending on location and RCP (Figures 7 and 8).

![Figure 3. Assessment of chilling accumulation using a threshold of 18°C for the Gaza Strip in present conditions and changes for future conditions for the RCP 4.5 during 21Century.](image)
Figure 4. Assessment of chilling accumulation using a threshold of 18°C for the Gaza Strip in present conditions and changes for future conditions for the RCP 8.5 during 21 Century.

Figure 5. Assessment of end date of chilling accumulation using a threshold of 18°C for the Gaza Strip in present conditions and changes for future conditions for the RCP 4.5 during 21 Century (DOY, day of year).

Figure 6. Assessment of end date of chilling accumulation using a threshold of 18°C for the Gaza Strip in present conditions and changes for future conditions for the RCP 8.5 during 21 Century (DOY, day of year).
Finally, we have used a different approach, the Dynamic method. This is a general method that can be applied to a variety of crops and it uses as chilling units the “chilling portions”. Using this method, the chilling accumulation is expected to decrease between 20 and 60% by mid century and between 60 and 100 by the end of the century (Figures 9 and 10). However there are varieties with small or no chill requirements so lack of chilling is not expected to be a major hazard for this crop ion the studied area.
Figure 9. Assessment of chilling accumulation using the Dynamic method for the Gaza Strip in present conditions and changes for future conditions for the RCP 4.5 during 21 Century.

Figure 10. Assessment of chilling accumulation using the Dynamic method for the Gaza Strip in present conditions and changes for future conditions for the RCP 8.5 during 21 Century.
3.3. Impacts on bud break reduction for grapevine

The previous analysis on chilling accumulation allowed assessing the end of the dormancy period of grapevine and the changes on bud break dates. Our analysis suggest that bud breaking would occur 5 days earlier by mid century and 10 days earlier at the end of the century, for all locations and RCPs (Figures 11 and 12).

**Figure 11.** Assessment of bud break date for the Gaza Strip in present conditions and changes for future conditions for the RCP 4.5 during 21 Century (DOY, day of year).

**Figure 12.** Assessment of bud break date for the Gaza Strip in present conditions and changes for future conditions for the RCP 8.5 during 21 Century (DOY, day of year).
3.4. Impacts on flowering

Flowering was estimated considering that April 20th is the current mean flowering date for both species. Growing degree days were calculated from this day and used to estimated future flowering dates. Thus, an advance of 10 days is projected by mid century, while for the end of the century the expected advance is up to 15 days for RCP 4.5 and 25 days for the RCP 8.5 (Figures 13 and 14). These results are in agreement with those of Tanasijevic et al. (2014).

Figure 13. Assessment of the change of flowering date for crops with current flowering at DOY 110 for the Gaza Strip, for future conditions for the RCP 4.5 during 21 Century (DOY, day of year).

Figure 14. Assessment of the change of flowering date for crops with current flowering at DOY 110 for the Gaza Strip, for future conditions for the RCP 8.5 during 21 Century (DOY, day of year).
3.5. **Impacts of extreme events**

3.5.1. **Maximum temperature with threshold 35ºC**

3.5.1.1. *Tmax in the whole Gaza Strip with threshold 35ºC*

Maximum temperatures are analysed as they can pose a major threat for flowering and fruit setting of the studied crops. The temperature threshold for crop damage during flowering has been set to 35ºC for olive tree according to literature and field information. Specifically, the number of days with Tmax over 35ºC during flowering and their changes under future conditions have been evaluated. A period of two months around flowering (DOY 110) was considered to encompass the variability and common varieties of both olive and grapevine crops. Thus, the number of days above 35ºC could be up to 4 days by mid century and also by the end of the century under RCP4.5, while for this period the number of days over 35ºC would be up to 6 or 7 days for the RCP8.5 (Figures 15 and 16). These results are in agreement with Gabaldón et al. (2017).

**Days with Tmax>35ºC (number of events)**

*During two-month period centered in flowering (RCP 4.5)*

![Figure 15. Assessment of number of days with Tmax >35ºC around flowering period, and its change, for the Gaza Strip, for future conditions for the RCP 4.5 during 21 Century (unit: number of days).](image)

**Days with Tmax>35ºC (number of events)**

*During two-month period centered in flowering (RCP 8.5)*

![Figure 16. Assessment of number of days with Tmax >35ºC around flowering period, and its change, for the Gaza Strip, for future conditions for the RCP 8.5 during 21 Century (unit: number of days).](image)
When the Tmax over 35º lasts few hours the damages and lesser than for long-lasting periods. For this reason, we have assessed the number of events of at least three consecutive days with Tmax over 35ºC, and their changes under future climate. For all periods and RCPs considered, up to one more event per year is expected to occur under future conditions (Figures 17 and 18). These results are in agreement with Gabaldón et al. (2017).

**3 consecutive days with Tmax>35ºC (number of events)**

*During two-month period centered in flowering*  
(RCP 4.5)

![Graph](image1)

*Figure 17. Assessment of number of events with at least three consecutive days with Tmax >35ºC around flowering period, and its change, for the Gaza Strip, for future conditions for the RCP 4.5 during 21 Century (unit: number of days).*

**3 consecutive days with Tmax>35ºC (number of events)**

*During two-month period centered in flowering*  
(RCP 8.5)

![Graph](image2)

*Figure 18. Assessment of number of events with at least three consecutive days with Tmax >35ºC around flowering period, and its change, for the Gaza Strip, for future conditions for the RCP 8.5 during 21 Century (unit: number of days).*
3.5.1.2. Tmax by cell with threshold 35°C

Each cell of the Gaza Strip as represented by the RCMs was analysed separately. For each cell, the new flowering dates were compared to the timing and frequency of the days with Tmax over 35°C (Figures 19 and 20). In all cases, the number of these events increased (one or two more events in 30 years under RCP 4.5 and up to 4 to 5 more days for some cells under RCP8.5 after flowering) even if the advanced phenology allowed the crop to escape from the period when these episodes were more frequent. This is more evident at the end of the century.

When events of three consecutive days with Tmax over 35°C were evaluated and compared to current and flowering dates, the results were different (Figures 21 and 22). For RCP4.5 (Figure 20), the number of events did not increase and the advanced flowering is projected to avoid this kind of events especially at the end of the century, when the frequency around flowering would decrease. The effect is less evident under RCP8.5, for compensation between advances phenology and more extreme events results in small changes on the number of events around flowering.
Figure 19. Assessment of the timing and frequency of the days with Tmax >35°C compared with mean flowering dates for current and future conditions, for the Gaza Strip and for the RCP 4.5 during 21 Century. Results are for the RCM grid cells indicated by the location maps and coordinates.
Figure 20. Assessment of the timing and frequency of the days with Tmax >35°C compared with mean flowering dates for current and future conditions, for the Gaza Strip and for the RCP 8.5 during 21 Century. Results are for the RCM grid cells indicated by the location maps and coordinates.
Figure 21. Assessment of the timing and frequency of the events of three consecutive days with Tmax >35ºC compared with mean flowering dates for current and future conditions, for the Gaza Strip and for the RCP 4.5 during 21 Century. Results are for the RCM grid cells indicated by the location maps and coordinates.
Figure 22. Assessment of the timing and frequency of the events of three consecutive days with Tmax >35°C compared with mean flowering dates for current and future conditions, for the Gaza Strip and for the RCP 8.5 during 21 Century. Results are for the RCM grid cells indicated by the location maps and coordinates.
3.5.2. Maximum temperature with threshold 27ºC

3.5.2.1. Tmax in the whole Gaza Strip with threshold 27ºC

The temperature threshold for crop damage during flowering has been set to 27ºC for grapevine according field information provided by the farmers. Specifically, the number of days with Tmax over 27ºC during flowering and their changes under future conditions have been evaluated. A period of two months around flowering (DOY 110) was consider to encompass the variability and common varieties of both olive and grapevine crops. Given that flowering is also advanced under future climate due to warming, in agreement with Ferrise et al. (2016), the number of days above 27ºC around flowering stage would not significantly increase for none of the periods nor RCPs considered (Figures 23 and 24).

**Figure 23.** Assessment of number of days with Tmax >27ºC around flowering period, and its change, for the Gaza Strip, for future conditions for the RCP 4.5 during 21 Century (unit: number of days).

**Figure 24.** Assessment of number of days with Tmax >35ºC around flowering period, and its change, for the Gaza Strip, for future conditions for the RCP 8.5 during 21 Century (unit: number of days).
When the Tmax over 27º lasts few hours the damages are lesser than for long-lasting periods of supra-optimum temperatures. For this reason, we have assessed the number of events of at least three consecutive days with Tmax over 27ºC, and their changes under future climate. Changes were small for mid century, while for the end of the century a higher number of events are expected, especially under RCP8.5, for which between 2 to 4 more events could appear as average every year (Figures 25 and 26).

3 consecutive days with Tmax>27ºC (number of events)

*During two-month period centered in flowering* (RCP 4.5)

![Figure 25](image1.png)

*Figure 25. Assessment of number of events with at least three consecutive days with Tmax >27ºC around flowering period, and its change, for the Gaza Strip, for future conditions for the RCP 4.5 during 21 Century (unit: number of days).*

3 consecutive days with Tmax>27ºC (number of events)

*During two-month period centered in flowering* (RCP 8.5)

![Figure 26](image2.png)

*Figure 26. Assessment of number of events with at least three consecutive days with Tmax >27ºC around flowering period, and its change, for the Gaza Strip, for future conditions for the RCP 8.5 during 21 Century (unit: number of days).*
3.5.2.2. Tmax by cell with threshold 27ºC

Each cell of the Gaza Strip as represented by the RCMs was analysed separately. For each cell, the new flowering dates were compared to the timing and frequency of the days with Tmax over 27ºC (Figures 27 and 28). The number of these events increased under RCP4.5, as in future periods more than 10 events in 30 years were projected. For the RCP8.5, there was little change on the number of these events due to the advance of the flowering date.

Also, events of three consecutive days with Tmax over 27ºC were evaluated and compared to current and flowering dates. These events are less frequent than the 1-day events, but the results for future periods were similar (Figures 29 and 30): For RCP4.5 the number of events were projected to increase moderately while this is not the case for the RCP8.5, for which the advanced flowering is projected to allow escaping from this kind of events.
Figure 27. Assessment of the timing and frequency of the days with T_max >27°C compared with mean flowering dates for current and future conditions, for the Gaza Strip and for the RCP 4.5 during 21 Century. Results are for the RCM grid cells indicated by the location maps and coordinates.
Figure 28. Assessment of the timing and frequency of the days with Tmax >27°C compared with mean flowering dates for current and future conditions, for the Gaza Strip and for the RCP 8.5 during 21 Century. Results are for the RCM grid cells indicated by the location maps and coordinates.
Figure 29. Assessment of the timing and frequency of the events of three consecutive days with Tmax >27°C compared with mean flowering dates for current and future conditions, for the Gaza Strip and for the RCP 4.5 during 21 Century. Results are for the RCM grid cells indicated by the location maps and coordinates.
Figure 30. Assessment of the timing and frequency of the events of three consecutive days with Tmax >27°C compared with mean flowering dates for current and future conditions, for the Gaza Strip and for the RCP 8.5 during 21 Century. Results are for the RCM grid cells indicated by the location maps and coordinates.
3.5.3. Precipitation

3.5.3.1. Precipitation in the whole Gaza Strip

Water availability during crop growth depends on the precipitation during this period and on the soil water storage that accumulates precipitation from the rest of the year. In this section, we focus on the first aspect, which will be evaluated by computing the number of events with two consecutive weeks with no rain under present and future climate. The part of the cycle was selected to encompass the flowering and important stages of fruit setting of both studied crops (Figures 31 and 32) from 1 month before flowering up to 1st October for olive tree and Figures 33 and 34 until 1st September for grapevine.

The results show that no changes are expected with regard the precipitation, for both mid and end of the century and for both RCP4.5 and 8.5, even considering changes in phenology under future conditions. The main reason is that fruit setting matches the dry part of the year in present climate, which in turn will remain under future scenarios. The precipitation in these months is so low than no further decreases are very relevant (Figures 31 to 34). These results are in agreement with Carvalho et al., (2018) and Santillán et al. (2019). Therefore, water availability will depend on how climate change affects the soil water storage of the rainfall from the rest of the year.

![Last two weeks with no rain](image)

*Figure 31. Assessment of number of events of two weeks with no rain from 1 month before mean flowering until 1st October, and its change, for the Gaza Strip, and for future conditions for the RCP 4.5 during 21 Century. Units: % of days from the considered period.*
Figure 32. Assessment of number of events of two weeks with no rain from 1 month before mean flowering until 1st October, and its change, for the Gaza Strip, and for future conditions for the RCP 8.5 during 21 Century. Units: % of days from the considered period.

Figure 33. Assessment of number of events of two weeks with no rain from 1 month before mean flowering until 1st September, and its change, for the Gaza Strip, and for future conditions for the RCP 4.5 during 21 Century. Units: % of days from the considered period.

Figure 34. Assessment of number of events of two weeks with no rain from 1 month before mean flowering until 1st September, and its change, for the Gaza Strip, and for future conditions for the RCP 8.5 during 21 Century. Units: % of days from the considered period.
3.5.3.2. Precipitation by cell

Results were analysed by CORDEX grid cell, comparing timing and frequency of events with two consecutive weeks with no rain with mean flowering dates and fruit setting, for present and future conditions. This allowed analysing the beginning and ending of the dry period and how it matches the current and future phenology.

In the two southern cells of the Gaza Strip two dry periods were detected, while in the northern cells a single extended period appeared. This pattern will remain under future conditions for both periods and RCPs (Figures 35 and 36).

No changes are projecting regarding the end of the dry periods, when compared to the 1\textsuperscript{st} October and 1\textsuperscript{st} September dates. For flowering dates, that were advanced under future conditions, a moderate increase of events is projected for RCP4.5 (Figure 34) while no changes are projected for RCP8.5 especially for the end of the century when the higher warming associated to this RCP becomes more evident and produces a greater flowering advance (Figure 35).
Figure 35. Assessment of the timing and frequency of events of two weeks with no rain from 1 month before mean flowering until 1st October, and mean flowering dates, for current and future conditions, for the Gaza Strip and for the RCP 4.5 during 21 Century. Results are for the RCM grid cells indicated by the location maps and coordinates.
Figure 36. Assessment of the timing and frequency of events of two weeks with no rain from 1 month before mean flowering until 1st October, and mean flowering dates, for current and future conditions, for the Gaza Strip and for the RCP 8.5 during 21 Century. Results are for the RCM grid cells indicated by the location maps and coordinates.
4. CONCLUSIONS

Raw simulated climate data available for Gaza Strip present important biases in Tmax, Tmin and precipitation, which make it advisable the use of techniques of bias and uncertainty management and reduction, as the use of bias corrected data (as in this study) and the impact and adaptation response surfaces (proposed for a further work). Also, a more accurate and complete observational weather database would be needed to be used as reference for future bias corrections.

A decrease of chilling accumulation is projected with low uncertainty, with higher uncertainty in the exact value of the decrease. Mean values are about an important decrease (20-40%) by mid century and a more severe one (more than 40 and up to 100%) depending on location and RCP for the end of the century. The bud break of grapevine is expected to occur would occur 5 days earlier by mid century and 10 days earlier at the end of the century.

Flowering period of both olive and grapevine are projected to occur 10 days earlier by mid century, while for the end of the century the expected advance is between 15 and 25 days. This is an important factor when considering adaptation, as for moderate warming (RCP4.5), the number of Tmax hazardous events increase for future conditions, while is not the case for a more severe warming (RCP8.5). These events were found to be more dangerous for the olive trees flowering than for the grapevine one (without considering changes in varieties, as this study did not consider adaptation). This points out how selecting varieties whose phenology allows escaping from Tmax events is an excellent tool for adaptation.

Also, the duration and intensity of dry periods during key crop stages (around flowering and fruit setting) is not projected to change. Timing of flowering has to be matched to occur before the beginning of the dry period. Given the low rainfall during this part of crop cycle, water availability will depend on how climate change affects the soil water storage of the rainfall from the rest of the year.

In general, results are in agreement with the trends reported by previous studies.

As a conclusion, warmer temperatures and dry spring and summer are projected with high confidence for the Gaza Strip, which will impose adapting crop phenology for flowering to escape from heat and water stress. Transition to new cultivars or varieties is slow and expensive in tree crops. Given the uncertainty linked to climate projections, a more accurate analysis is needed to provide specific recommendations on the chilling requirements and growing dates that the adapted varieties should have.

In this context, management techniques that modify canopy temperature and soil moisture (e.g. pruning and soil management) will be additional tools, together with supplementary irrigation (e.g. a single irrigation event to protect flowering of current varieties or of extreme years under future conditions), that will support adaptation beside adapting crop cultivars.
5. RECOMMENDATIONS FOR FURTHER WORK

Several steps are proposed to improve the accuracy of this assessment. Only when this accuracy is high, the assessment can be translated into recommendations for farmers, in terms of type of varieties and management. This is especially relevant for tree crops, for which maladaptation cannot be corrected in yearly basis, as it is the case of field crops.

Therefore some actions or steps are required to progress towards this operative stage. Some of them rely in retrieving more and better observations, while some of them require just a deeper analysis. Among them are:

- For climate data
  - An improved and standardized record of observed climate data
  - An extended search for more regional and/or global climate projections
    - A bias correction regarding a more accurate observational data base (if available)
  - Application of impact and adaptation response surfaces in case the remaining biases are still too high or not enough data are available

- For crop data
  - Characterisation of crop varieties
    - Reliable, long series of crop phenology data: description in terms of chilling units and growing degree days. If this is not possible, long series of yearly dates for beginning and ending of chilling/dormancy, flowering and maturity.
    - Records of crop yield in normal years
      - Records of yield losses linked to extreme events: this would allow modelling the % of damage

- For soil data
  - Description of soil water storage capacity for the main soil types in the Gaza Strip. This would allow to estimate the trend water available for crops during the dry period

- For management data
  - Reliable, long series of management description (actions, amounts, dates, etc)

Once part or all of these improvements are accomplished, a set of adaptation strategies could be identified and tested.
6. REFERENCES


