


Effects of Climate Change in Agricultural Areas of Greece, Vulnerability Assessment, Economic-Technical Analysis, and Adaptation Strategies [†]

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Abstract: This pilot study aims to evaluate the impact of climate change on the critical stages of crop growth. Data from agricultural stations in Greece were analyzed to assess the effects of climate change on the country's agriculture, focusing on areas vulnerable to frost, as identified by the Hellenic Agricultural Insurance Organization. The study examined the differences in climate patterns between continental and coastal agricultural regions to determine which areas are more resilient to local climate change. The frequencies of frost events and government subsidies were analyzed. The significance of early spring temperatures and their potential consequences for plant growth and vegetation, if followed by late-frost incidents, was emphasized. The severity and impact of frost events vary depending on the location, vegetation type, and growth stage. The economic importance of frost-sensitive crops, like deciduous fruit trees, citrus, and vines, in Greek agriculture has been highlighted. Given the increasing frequency of adverse weather conditions, the study underscores the need for a resilient and sustainable approach to agriculture, focusing on prevention and adaptation to climate variations.



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1. Introduction

One of the most vulnerable regions to recent climate change is the Mediterranean, including Greece. It has already experienced extreme climatic events [1], which pose a threat to the entire agricultural sector.

Agriculture is the economic sector that is most directly exposed to the vagaries of the climate, and this is why it is considered to be most vulnerable to climate variability [2].

The seasonal variations in climate conditions, reflected by the corresponding changes in meteorological parameters (sun duration, air temperature, and rainfall), are consistent with the seasonality and periodicity in the manifestation of the biological cycle and the various developmental stages of plants. The climatic extremes threaten to disturb this periodicity in the manifestation of the phenological stages of plants.

To assess these climate extremes, various climatic and agroclimatic impact indicators have been used by climatologists, which can be easily calculated and can be applied in different parts of the world.

Reference is made to biologically effective degree days (BEDD) and frost days, especially for the assessment of late spring frost incidents. The earlier the typical spring

temperatures arrive in a year, the sooner the growing season starts. The prevalence of adverse weather conditions, in this stage of the plant life cycle, is the cause underlying the loss of agricultural income and of public subsidies to affected farmers.

2. Methods and Materials

2.1. Climate Data Acquisition

This study used data from six meteorological stations situated in representative agricultural regions throughout Greece.

Daily mean and minimum temperature data were used for the entire period of operation of each station. Three parameters were computed: daily mean temperature (T_{mean}), number of days with frost ($T_{\text{min}} < 0$), and biologically effective degree days (BEDD). The daily mean temperature was calculated using temperatures at 06:00, 12:00, and 18:00 UTC.

The number of applications for compensation due to frost, for the areas under study, was obtained from the Hellenic Agricultural Insurance Organization (ELGA).

Data analysis and visualization were carried out using Python programs.

2.1.1. Biologically Effective Degree Days

Agroclimatic indices used to quantify the rate of development crops are computed. They include simple heat units based on the accumulation of daily mean temperatures above a certain threshold temperature during the growing period.

The threshold temperature is referred to as the base temperature. The threshold temperature used for vines and other crops was 10 °C [3]. For deciduous fruit trees and apple trees grown in Edessa, a base temperature of 7 °C was used.

The BEDD index is defined as follows:

$$BEDD = \sum_{i=1}^{10} i, i = 1 \text{ if } T_{\text{daily}} > 10; 0, \text{ otherwise} \quad (1)$$

BEDDs are used due to their significance across the agricultural, phenological, and other related fields [4].

The first appearance of BEDD in each year was computed using a 10-day rolling sum. Daily mean temperatures above 10 °C or 7 °C, marking the start of the growing season for each crop, were used [4,5].

On the other hand, other environmental factors and responses of plants to similar temperatures, during various stages of their life cycle, were neglected.

2.1.2. Frost Days

The most important frosts observed in Greece are the winter and spring frosts (late frosts). Late frosts are the most destructive for the agricultural production sector [6].

The extent of the damage caused by frosts depends on the rate of temperature drop, the minimum temperature, its duration, and the vulnerability of a plant's phenological stage.

During the pink or white top stage in deciduous fruit trees, the petals begin to appear and become sensitive to temperatures of −3.3 °C. In addition, during the period of petal fall, the flowering parts are destroyed under temperature from −1 °C to −2.2 °C [4]. It is at this phenological stage that damage from late frosts occurs. When late frost conditions prevail, the air temperature is uneven.

The topography of the agricultural area and its neighboring area, along with the form of the land cover, have a significant effect and influence on the local micro-meteorological conditions [6].

Since most meteorological stations used are located near local airports, deviations from the actual conditions are considered acceptable.

In general, as the latitude and altitude increase, the start of the growing season and the onset of late frost events are expected to be delayed.

Table 1 (shown below) displays the BEDD and frost statistics from the start date taken of each station until 4 May 2023.

Table 1. BEDD and frost statistics.

Station Name and WMO No.	Argos 16,724	Edessa 16,618	Kastelli 16,760	Larisa 16,648	Serres 16,606	Tripolis 16,710
Longitude (°)	22.75978	22.04091	25.32888	22.46019	23.52938	22.39725
Latitude (°)	37.63278	40.80872	35.18882	39.64609	41.07654	37.52475
Altitude (m.)	12.0	314.8	349.2	71.2	32.1	653.0
Start date	01.01.1981	01.01.1975	01.01.1977	01.01.1955	01.01.1972	01.01.1957
Average day of 1st occurrence of BEDD = 10	93	84	74	91	89	108
Median day of 1st occurrence of BEDD = 10	92	86	81	92	90	107
Average last frost day	71	64	38	80	72	97
Median last frost day	75	67	44	81	74	98

3. Results and Discussion

3.1. Vulnerability Analysis and Topical Adaptations Strategies

ELGA subsidies due to frost for the areas under study are shown in Table 2 below.

Table 2. Annual frost subsidies in Euros.

Year	Argos	Tripolis	Heraklion	Larissa	Edessa	Serres	Total
2011	1,462,227.00	748,540.00	4,957,222.00	632,979.00	566,080.00	68,239.00	8,435,287.00
2012	783,187.00	200,628.00	254,654.00	19,319.00	1,316,929.00	133,909.00	2,708,625.00
2013	120,998.00	1,927,287.00	268,332.00	18,599.00	6,516,412.00	122,421.00	8,974,050.00
2014	13,075.00	165,251.00	270,176.00	46,792.00	173,329.00	13,932.00	684,510.00
2015	3,861,518.00	275,578.00	155,699.00	6,915,091.00	11,992,413.00	480,211.00	23,726,592.00
2016	189,127.00	1,326,044.00	382,876.00	4,146,907.00	5,103,220.00	285,729.00	11,433,904.00
2017	1,859,222.00	957,652.00	505,546.00	1,869,068.00	16,261,327.00	341,073.00	21,796,028.00
2018	1474.00	105,757.00	799,093.00	18,867.00	112,390.00	49,083.00	1,086,663.00
2019	238,059.00	75,946.00	460,025.00	99,106.00	1,420,852.00	97,837.00	2,391,826.00
2020	135,706.00	243,933.00	3236.00	15,847,819.00	9,091,742.00	602,959.00	25,925,396.00
2021	2,300,386.00	1,697,073.00	1,637,679.00	39,457,017.00	80,834,283.00	3,841,020.00	129,768,080.00
2022	15,233,920.00	798,120.00	938,924.00	4,032,204.00	14,574,006.00	2,254,411.00	37,831,586.00
Total	26,198,903.00	8,521,808.00	10,633,464.00	73,103,767.00	147,962,984.00	8,290,824.00	274,762,548.00

The day of the year of the end of the first ≥ 10 -day period with a daily mean temperature greater than 10 °C for each area are shown in Figure 1.

3.1.1. Region of Serres

For the reference period under study, there is a gradual advancement in the start of the growing season and a corresponding delay in the last day of the last frost event. This implies fewer ideal conditions, especially for vine cultivation, since if this trend continues in the future, plants will not be able to overcome the frost-prone stage of flowering. Thus, the related subsidies for this type of crop in this region could be increased.

On the contrary, the selection of earlier genetic varieties of deciduous fruit trees may work synergistically with the advancement in the start of growing season in Serres. Thus, plants will quickly overcome the frost-sensitive phenological stages before the onset of frost.

According to ELGA, 16% of annual applications for frost subsidies in 2021 were due to adverse conditions in April. A strong late frost event occurred on 9 April, where the Tmin dropped to −1.4 °C, and on 10 April, where the Tmin was marked at −1.1 °C.

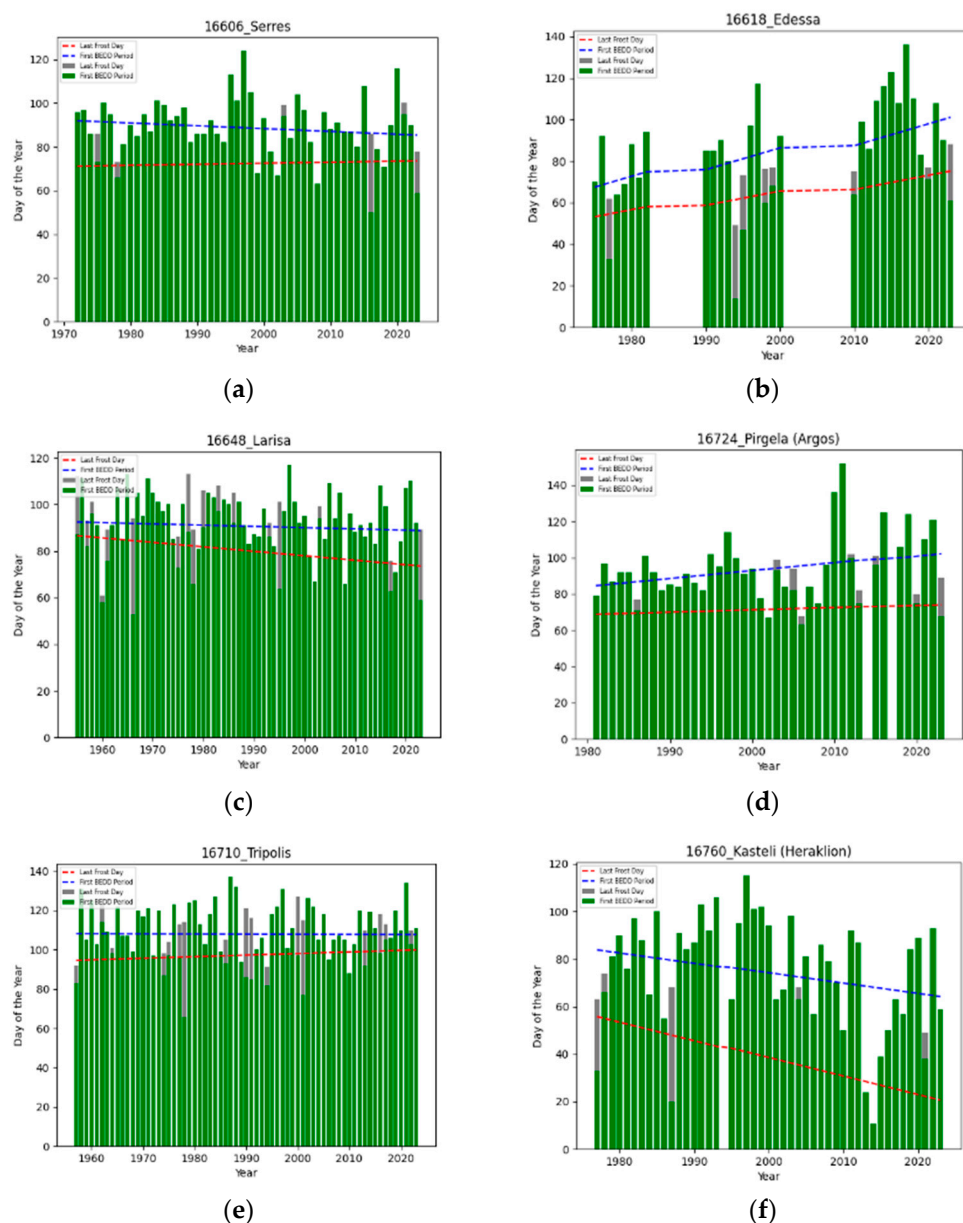


Figure 1. The day of the year of the end of the first ≥ 10 -day period with daily mean temperature $> 10^{\circ}\text{C}$: (a) Serres; (b) Edessa; (c) Larisa; (d) Argos; (e) Tripolis; and (f) Kastelli.

3.1.2. Region of Edessa

As it turns out, the region of Edessa is one of the most vulnerable areas of Greece. Furthermore, this situation seems to be getting worse.

Selecting the earlier-flowering varieties of deciduous trees can help to mitigate the consequences of late frost events. By blooming earlier, these trees can potentially avoid or minimize the damage caused by the late frosts.

On the other hand, the cultivation of vineyards in the Serres area seems to be less affected by the late frosts compared to Edessa. In the Serres area, the last day of the year with a late frost event occurs, on average, 7 days later than in Edessa. This means that vineyards in the Serres area have a slightly longer frost-free period, which can be beneficial for grape cultivation.

According to ELGA, in 2015, 99% of annual applications for frost subsidies corresponded to April (late frost events).

3.1.3. Region of Larisa

Another quite vulnerable area to late frost events is the region of Larissa, where the early onset of late frost incidents affects the early-flowering deciduous fruit crops, such as apricots and peaches.

In contrast to the previous cases, the choice of more late-flowering varieties is preferred here. The cultivation of vines does not seem to be particularly affected, except for, perhaps, a slight delay in the start of its growing season.

For the region of Larissa, ELGA data for the period of 2011 to 2022 indicates that subsidies were only provided in the years 2014 and 2017, with most of them being due to frost in April (late frost event).

3.1.4. Region of Pirgela (Argos)

From our results, it appeared that the changes observed in the Argos area favor the citrus crops.

Widening the day of the year gap between the last frost event and the onset of vegetative growth may protect both young vegetation and the frost-sensitive flowering stage from late frost events.

It should be noted that the prevalence of a strong early frost in 2022 (from the 23rd to 27th of January, with $T_{min} = -5.6$ °C) caused the complete destruction of the fruit and a large part of the trees. This is why the area obtained the highest amount of subsidies compared to the other areas under study.

3.1.5. Region of Tripolis

It is noteworthy that the day of the year when the last frost event occurs is becoming increasingly delayed, while the start of the growing season remains unchanged.

In Tripolis, the start of the growing season is the latest among the regions, primarily because the last frost event occurs later in this area compared to the other areas. The main influence on this phenomenon is mainly due to altitude. Tripolis is the most mountainous area in this study and, as such, this region becomes resistant to local climatic variability, particularly regarding the cultivation of vines, which has a clear comparative advantage.

3.1.6. Region of Kastelli (Heraklion)

The Heraklion area is not a particularly frost-prone area.

Climatic variability causes an earlier onset of late frost incidents and an earlier start of the growing season compared to the past. This affects the early-flowering of deciduous trees and vineyards to a lesser extent, since late frost events are milder and only affect plants in later phenological stages, which are no longer so frost-prone.

4. Conclusions

The use of new varieties adapted to evolving local climate conditions is crucial to mitigating the effects of climate change in agriculture.

The periods of high probability of frost incidents in typical rural areas in Greece have been identified spatially and temporally. Successful adaptation policies based on the best farming practices are typically proposed when late frost events occur.

Our study showed that the consequences of climate change on the agriculture are not limited to the warmer months of the year, e.g., with increased drought.

The adoption of local adaptation policies is the key factor for intelligent and resilient agriculture.

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