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# Frost and Drought Events in Çukurova's Agricultural Production: Impacts and Strategic Recommendations for Future Resilience

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**Abstract.** All agricultural activities are highly dependent on climatic conditions. Various adverse consequences of climate change—such as shifts in precipitation regimes, rising temperatures, meteorological and hydrological droughts, and an increased frequency of natural disasters—can significantly affect agricultural productivity, growth rates, and food security. Frost and drought events, which are among the most critical risks to agricultural production, represent natural hazards with economic, social, and environmental implications. These events occur when temperatures fall below or rise above the tolerance thresholds of crops, increasingly as a result of climate change. In the 2025 growing season, farmers in Türkiye, as in many other parts of the world, were confronted with a range of extreme weather and climate phenomena. This paper presents recommendations for measures and practices that can be adopted to reduce the economic impacts of future frost and drought events during agricultural production periods.

**Keywords:** Cukurova, Drought, Agricultural Frost, Agriculture, Climate Change.

## 1 Introduction

All agricultural activities are largely dependent on climatic conditions. Various adverse consequences of climate change including changes in precipitation regimes, rising temperatures, meteorological and hydrological droughts, and natural disasters—can exert significant negative impacts on agricultural productivity, growth rates, and food security.

Among the most critical risks in agricultural production are frost and drought events. These are natural phenomena with economic, social, and environmental repercussions, typically triggered when temperatures fall below or rise above crop tolerance thresholds as a result of climate change. Unlike frost, drought events are also strongly influenced by the absence of precipitation and the reduction of irrigation water availability, in addition to temperature anomalies [1]. This study outlines



recommendations for measures and management practices aimed at mitigating the economic impacts of future frost and drought events that may occur during agricultural production periods.

Cukurova is one of Türkiye's most important agricultural production centers, representing approximately 5% of the nation's total arable and cultivable land and hosting one of the most fertile plains in the World [2]. The region contributes nearly 10% of the country's total agricultural production value and supports a wide diversity of crops. However, this diversity requires different agronomic strategies due to varying crop temperature requirements and frost tolerance levels, making agricultural production management in the region complex. In the 2025 growing season, the region experienced reduced precipitation and extreme temperature fluctuations, leading to widespread drought and frost events across Cukurova.

As a result of drought, yields of major field crops such as cereals and oilseed sunflower were severely reduced. Concurrently, frost events caused extensive damage to citrus orchards (particularly lemon and orange), as well as apricot, cherry, and peach/nectarine orchards, leading not only to lower yields but also to the removal of some severely damaged orchards.

Consistent with IPCC AR6 WGII, climate change is already negatively affecting agricultural productivity in low- to mid-latitudes via heat and water-stress interactions and increasing variability. Regional strategies proposed here (phenology-aware frost protection, drought-smart irrigation, cultivar choice) align with adaptation pathways recommended for agrifood systems [13].

For annual crops such as cereals and oilseed sunflower, yield losses are confined to the affected production season; assuming no recurrence of extreme drought or frost in subsequent years, economic impacts are short-term. In contrast, perennial fruit trees are more vulnerable: frost damage often leads to reduced yields for several following years, and the re-establishment of uprooted orchards delays their contribution to the agricultural economy.

## **2 Frost and Drought**

### **2.1 Agricultural Frost and Frost Events in Türkiye**

Agricultural frost refers to a natural event that occurs when air temperature falls below or approaches 0 °C, reaching levels that can damage crops [3]. It becomes a critical meteorological hazard when it causes



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injury to plants in agricultural fields following a frost episode. Frost events are typically classified according to temperature: light frost between 0 °C and -2.2 °C, moderate frost between -2.2 °C and -4.4 °C, and severe frost below -4.4 °C. When nighttime temperatures drop below freezing, the leaves, fruits, and buds of plants can suffer serious injury, reducing crop yields and causing economic losses for farmers.

Agricultural frost can harm many crop species, with fruit trees, vegetables, and flowering plants among the most affected. Key factors that contribute to frost damage include sub-zero air temperatures, humid conditions (which exacerbate damage at low temperatures), and wind (which accelerates temperature drops). The impacts of agricultural frost manifest through yield losses, increased production costs, and negative consequences for economic sustainability. Harvest reduction, yield decline, plant stress, and ultimately economic losses typically follow frost episodes. Moreover, frost events are not limited to a single production season; they can disrupt regional economies by affecting multiple crops simultaneously.

During the 2025 production year, farmers across Türkiye encountered a variety of extreme weather and climate events. Drought, floods, hailstorms, excessive rainfall, and cold spells affected agricultural production and farmer incomes at different times of the season. This complex risk landscape places considerable pressure on both producers and consumers in the agri-food sector, which is already struggling to manage seasonal and long-term uncertainties. Recent frost events have highlighted the critical role of climate in maintaining the continuity of agricultural production in Türkiye.

Agricultural frost events are most frequent in Eastern Anatolia, Central Anatolia, and the highlands of the Black Sea region, where winter temperatures can drop to -20 °C. Such events typically occur during autumn (October–November), winter (December–February), and spring (March–April). Sudden temperature drops in spring can also cause frost damage in both highland and lowland areas.

Although frost events occur at different times and locations each year, during the 2025 production season Türkiye experienced three major and widespread frost episodes in February, March, and April. While the February and March events were relatively limited in impact, the severe frost between April 10 and 13 affected crops nationwide.

In April, temperatures fell below freezing in many regions, and initial assessments indicated that at least 36 provinces and a wide variety of crops were affected. Key damage included apricot, cherry, and apple



orchards in Central Anatolia; vineyards in the Aegean and Thrace; hazelnut in the Black Sea region; citrus (especially lemon) and watermelon in Çukurova; and almond and quince orchards in Eastern Anatolia.

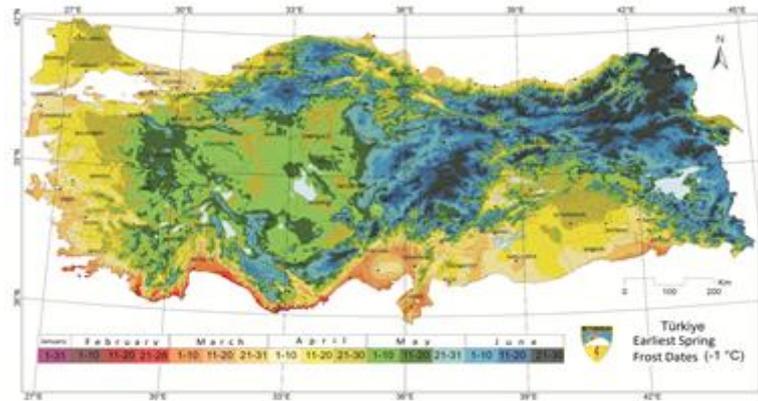


Fig. 1. Map of the latest frost dates in Türkiye ( $-1^{\circ}\text{C}$ )

## 2.2 Agricultural Frost in Cukurova

In Cukurova and Adana, severe agricultural frost events that occurred in February, March, and April of 2025 caused significant damage to agricultural crops. The frost episodes seriously affected watermelon, lemon, and other citrus crops, leading to leaf and flower burn, followed by defoliation and flower drop. Citrus trees—particularly lemon trees—shed their leaves and flowers extensively. Observations indicated that, after pruning, some trees attempted to re-sprout leaves and initiate flowering again.

However, it became clear that these trees would either fail to produce fruit during the current season or produce only limited yields. In some areas, yield reductions are also expected in the following production year due to the cumulative physiological stress caused by the frost events.

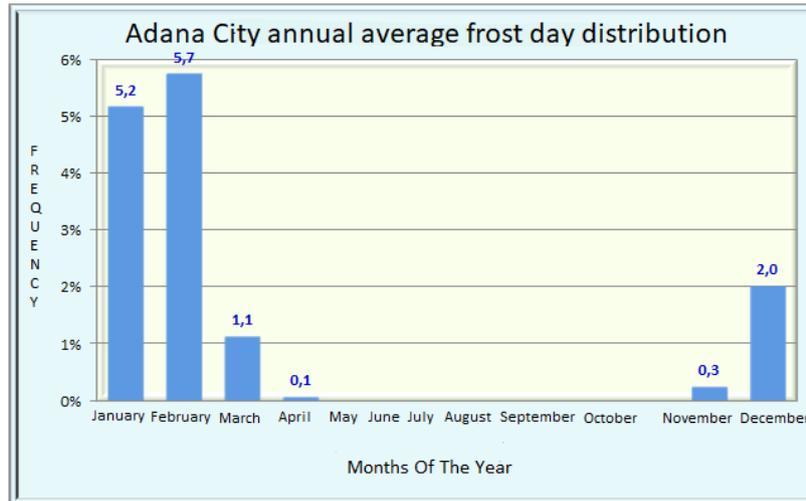


Fig.2. Annual average frost distribution in Adana province.

Although April exhibits the lowest frost frequency in Adana, the risk to agriculture remains high because many perennial crops are at their most sensitive phenophases (full bloom/fruit set). With warming winters reducing accumulated winter chill, irregular flowering and asynchronous budbreak can further heighten vulnerability. This underscores the need for regional frost-risk calendars linked to phenology rather than climatology alone [11]. As can be seen from the graph, April has the lowest frequency of frost events in Adana Province considered the heart of the fertile Cukurova region, which encompasses approximately 1.6 million hectares of total agricultural land with an occurrence rate of only 0.1%. Despite this, agricultural areas in Adana, where around 40,000 families rely on farming for their livelihoods, were severely affected by the agricultural frost event that occurred in April. This episode may mark the beginning of difficult times for both the national and household economies. In the coming years, it will be crucial to enhance economic productivity by conducting research and development to breed frost-resistant crop varieties and by developing technological solutions for frost mitigation.

Recent evidence shows that warming advances spring phenology (budburst/flowering) without a commensurate advancement of the last spring frost, thereby increasing exposure to late-spring frost—especially in fruit trees and vineyards. This phenological mismatch has been documented across Europe and East Asia and is relevant for Cukurova’s citrus, stone fruit, and grape systems where early flowering is common under warm winters. Strategic responses include selecting later-blooming cultivars, managing rest break with chill-aware models, and adjusting pruning to delay phenophases in high-risk years [7, 8, 9].



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Critical damage temperatures for citrus indicate that lemon buds/blossoms are injured near  $-2.8$  °C, small lemon fruit near  $-1.4$  to  $-0.8$  °C, and green oranges near  $-1.9$  to  $-1.4$  °C. These thresholds help set action temperatures for protection. Among active methods, under-tree microsprinklers can protect young trees during radiation frosts by releasing latent heat as ice forms; however, their effectiveness declines in advective (windy) freezes, and fruit protection is limited. System layout (nozzle placement on the N–NW side; adequate discharge) and real-time decision tools improve outcomes. For mixed-age orchards, combining microsprinklers with wind machines or heaters is recommended where inversions are strong [10].

### 2.3 Agricultural Drought and Drought in Türkiye

Drought can be broadly defined as a natural climatic phenomenon that arises from temporary imbalances in atmospheric moisture, leading to water scarcity in a given region. It can occur in virtually any climate zone from arid to humid regions although areas with arid climates are generally more vulnerable due to chronic moisture deficits and highly variable precipitation patterns [4]. Among extreme events, drought typically develops slowly, persists for long periods, and is one of the least predictable atmospheric hazards, while its impacts can be extensive.

Drought should be characterized using complementary indices that capture atmospheric demand as well as precipitation. The Standardized Precipitation Index (SPI) quantifies precipitation anomalies across time scales and is widely used operationally; the Standardized Precipitation-Evapotranspiration Index (SPEI) extends SPI by incorporating potential evapotranspiration, making it sensitive to warming-driven increases in atmospheric water demand. Utilizing SPI/SPEI concurrently enables discrimination of meteorological, agricultural, and hydrological drought linkages in Cukurova's irrigation-dependent systems [12].

Drought should not be viewed merely as a physical or natural phenomenon. Because human societies and economic activities are highly dependent on water resources, drought has wide-ranging social, environmental, and economic consequences. Prolonged dry conditions reduce atmospheric and soil moisture, deplete vegetation, forests, and water resources, and ultimately give rise to serious environmental, economic, and social challenges.

Drought is essentially a law of nature: when atmospheric moisture availability declines temporarily, it causes water shortages that negatively affect water resources, agriculture, and all living organisms. It is a slow-onset natural disaster, but its impacts are profound and far-reaching [5].

As illustrated in the map below, large parts of Türkiye are currently experiencing severe drought conditions. With the exception of parts of the Black Sea, Marmara, and Aegean regions, drought has been observed across most of the country.

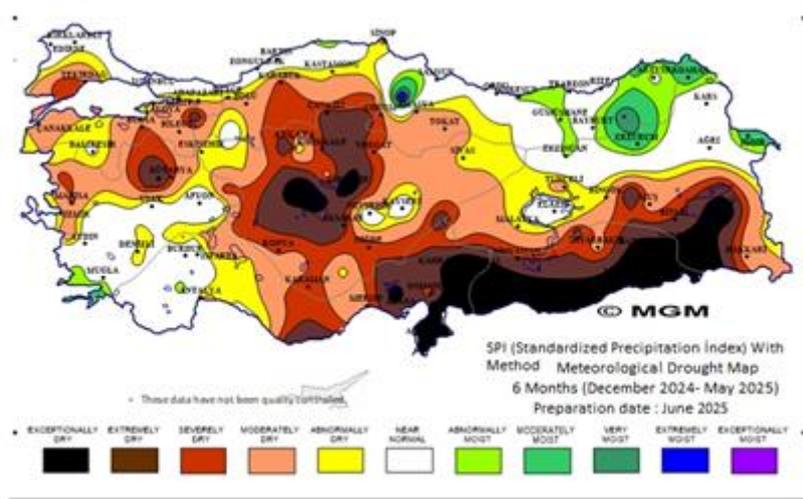


Fig. 3. Six-month drought map of Türkiye (December 2024 – May 2025)

The six-month national drought assessment by the Turkish State Meteorological Service (MGM) for December 2024–May 2025 depicts extensive areas under severe to extreme drought classifications, consistent with the observed rainfall deficits in Cukurova. Embedding SPI/SPEI maps from MGM into the regional analysis would strengthen attribution of yield losses to combined precipitation shortfalls and high evaporative demand.

## 2.4 Agricultural Drought in Cukurova

In recent years, drought has caused severe yield losses in many agricultural crops across Türkiye. Reservoir water levels have dropped below critical thresholds, raising serious concerns about the country’s future water security. If this trend continues and no effective measures are taken, Türkiye risks becoming a water-scarce country in the near future.

For example, according to meteorological data from the TİGEM Cukurova Agricultural Enterprise weather station, total precipitation between October 2024 and June 2025 was recorded at 226 mm,



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compared to the ten-year average of approximately 551 mm [6]. This clearly indicates the severity of the drought experienced in the Cukurova region. Similarly, the average wheat yield at TIGEM Cukurova over the past decade has been 455 kg per decare, but in 2025 yields dropped dramatically to 180 kg per decare.

Due to these conditions, approximately 10,000 decares of cereal fields in Cukurova were abandoned for the 2025 production season because they were not suitable for harvesting. The same situation applies to sunflower fields in rainfed areas, where significant yield losses are expected.

Given the TIGEM station totals (226 mm vs. ~551 mm 10-yr mean, Oct 2024–Jun 2025), anomalies of this magnitude would typically correspond to “severe–extreme” SPI classes at seasonal scales in many Mediterranean sites, implying substantial soil-moisture deficits during critical growth stages. To quantify expected yield penalties and evaluate mitigation, AquaCrop can be used to simulate yield response to water and to compare rainfed, supplemental, and deficit-irrigation scenarios for cereals and oilseed crops in Cukurova conditions.

### 3 Conclusions

For field crops, frost events can result in severe yield reductions or even total crop failure within the affected production year. In orchards, frost can cause tissue damage, shoot dieback, and abnormal sprouting, leading to further yield reductions over the following one to two years.

The agricultural impacts of severe frost events should be systematically assessed through “Evaluation and Mitigation of Agricultural Frost Impacts” consultation and coordination meetings to develop appropriate planning and response strategies. Additionally, climate change is causing earlier flowering in fruit trees, increasing their vulnerability to late frost damage. Therefore, cultivar and species selection, as well as orchard establishment planning, should be adjusted accordingly.

Although rising temperatures associated with climate change may initially lead to earlier harvest dates, inadequate winter chilling can later cause harvest delays and yield declines. When early ripening coincides with drought stress, agricultural losses may become severe, resulting in substantial economic impacts.



To address drought, comprehensive plans must be developed for the sustainable management of existing water resources. Excessive water consumption should be avoided, and modern pressurized irrigation systems that provide more uniform application while consuming less water should be promoted.

Society must also learn to use water resources more consciously. Drought and water scarcity policies should be strengthened, and farmers must be educated on efficient water use practices.

Moreover, national frost and drought maps should be updated to reflect changing climatic conditions, and regional cropping patterns should be revised accordingly. Farmers need to be supported and guided to adapt to these new cropping systems. This is not only a national necessity but a global one. For the Turkic world and beyond, paying close attention to these issues is essential for advancing agricultural production and sustaining agriculture-based economies.

Adaptation should prioritize pressurized irrigation with precise scheduling and consider regulated/deficit irrigation where agronomically safe. Evidence shows that well-designed deficit irrigation regimes can maintain economic yields while markedly improving water productivity, especially in perennial systems; in annuals, AquaCrop-guided scheduling helps target most sensitive growth stages to avoid disproportionate penalties.

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