# Proactive Producer and Processor Networks for

# Troodos Mountains Agriculture

# 3PRO-TROODOS

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| **Authors** | *Adriana Bruggeman, Marinos Eliades, Hakan Djuma, Ioannis Sofokleous, Christos Zoumides* |
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# Contents

## Introduction

This report presents the results of the irrigation monitoring and irrigation scheduling analysis on farmers' fruit treee terraces in the Troodos Mountains, during 2019-2022. We cooperated with farmers in Galata (nectarines), Alona (apples), Platanistasa (cherries) and Dymes (plums). All farmers were interested in the monitoring technologies and were happy to host the monitoring stations and allow the researchers access to their terraces. However, the farmers are reluctant to change their irrigation practices. The terraced orchards are also small (ranging between 0.14 and 0.49 ha) and extremely heterogeneous, with different terrace lengths, widths, tree spacings as well as different types and varieties of fruit trees. These settings were not suitable for experimental research. Therefore, irrigation treatments were only tested for the medicinal and aromatic plants in the experimental station in Saittas (see D6.5), where we installed a new soil moisture monitoring station with 20 sensors.

The objectives of this research to monitor farmers' irrigation practices, analyze potential water savings and derive crop coefficients for fruit tree production in the Troodos Mountains. We also tested the developed software and logger for irrigation scheduling advice, as presented in D6.1. The monitored terraced orchards are a diverse sample of the highly heterogeneous terraced fields in the Troodos Mountains.

## Methods

The 3PRO-TROODOS project did not allocate funding for the acquisition and installation of soil moisture and irrigation observation stations. We used three monitoring stations that were installed for monitoring under the Water-JPI INNOMED Project (completed Dec 2020) and the ERANETMED ISOMED Project (completed October 2021). In addition, we installed a small meteorological station on the cherry terraces in Platanistasa in December 2021. A new soilmoisture and meteorological station, which was developed and tested during the 3PRO project by Sigint Solutions LTD (PA8), was installed in May 2022 in Dymes.

The equipment at the four terraced farmers' fields are summarized in Table 1 and their locations are shown in Figure 1. Pictures of the stations can be found in Appendix 1. All soil moisture sensors measure the dieletric constant (permittivity) of moist soil, which is converted to volumetric soil water content with the Topp equation (Topp et al., 1980). Here we use the term soil moisture for the volumetric soil water content.

We used the the observed rainfall and meteorological data to compute daily water balances, using the soil moisture observations at midnight. For days with rain or irrigation, we used a Kc-max of 1.20, based on local, average relative humidity and wind speed, following Allen et al. (1998). We derived crop coefficients of the fields, using only dry days and days without soil moisture stress. We minimized the difference between the actual evapotranspiration computed from the water balance components and the evapotranspiration computed from the crop coefficient and the reference evapotranspiration. Daily reference evapotranspiration was computed with the Penman-Monteith of the Hargreaves equation (Allen et al., 1998).

We computed irrigation schedules by filling up the soil to field capacity when the soil moisture at midnight had reached water stress, computed with the depletion factor for each terraced system. The wilting point and field capacity were derived for each terraced field from the soil moisture observation time series. Field capacity was taken when soil moisture change at night, when evapotranspiration is zero, was minimal had stopped after a heavy irrigation or rainfall event. Likewise, wilting point was identified when soil moisture at the lower soil depths had reached its lowest level. The soil moisture level at which water stress occurs, as described by the depletion factor, was derived from the changes in the slope of the soil moisture change over time.


Figure 1. Location of the four fruit tree terraces (nectarine, apple, cherry, plums) with sensors for irrigation monitoring and scheduling in the Troodos Mountains in Cyprus.

Table 1. Soil moisture, meteorological sensors and dataloggers at the four terraced fields; the Alona meteorological station is located 560 m from the monitored apple terraces.

| Station | Soil moisture sensors | Meteorological sensors | Rain gauge | Data logger |
|---|---|---|---|---|
| Galata | 5TM<br>METER Group, Muenchen, DE<br>2 profiles, 6 and 7 depths: 10-cm depth interval | WS500-UMB<br>Lufft, Fellbach, DE | Lambrecht 15189<br>Lambrecht GmbH, Goettingen, DE | netDL500<br>OTT Hydromet GmbH, Kempten, DE |
| Platanistasa | SMT100<br>Truebner GmbH, Neustadt, DE<br>5 profiles 3 depths each:<br>10, 30, 45 cm | Atmos14<br>METER Group, Muenchen, DE | Lambrecht 15189<br>Lambrecht GmbH, Goettingen, DE | TrueLog100 with TrueCon100<br>Truebner GmbH, Neustadt, DE<br><br>CR300<br>Campbell Scientific, Logan, UT, USA |
| Alona | SMT100<br>Truebner GmbH, Neustadt, DE<br>3 profiles, 2 depths each:<br>10, 30 cm | WS300-UMB<br>Lufft, Fellbach, DE | Davis 6466M<br>Hayward, CA, USA | TrueLog100 with TrueCon100<br>Truebner GmbH, Neustadt, DE<br><br>netDL500<br>OTT Hydromet GmbH, Kempten, DE |
| Dymes | SMT100, Truebner GmbH,<br>Truebner GmbH, Neustadt, DE<br>2 profiles, 3 depths each:<br>10, 25, 50 cm | Atmos14<br>METER Group, Muenchen, DE | Davis 6466M<br>Hayward, CA, USA | Argus<br>Sigint Solutions LTD, CY |

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## Results and discussion

The farmers usually irrigate between April and October, with the start and end of the irrigation season depending on the weather. Occasionally one or two irrigations are still given in first half of November. Most farmers follow approximately a weekly irrigation schedule. Sometimes more frequent irrigations are given in summer and less frequent and reduced amounts in the beginning and end of the seasons.

The water balance components with and without sensor-based irrigation scheduling for the nectarine terrace in Galata, for the four monitored years, are summarized in Table 2. The soil moisture, precipitation, irrigation and drainage of the last two seasons are shown in Figure 2. Sensor-based irrigation scheduling could have saved the farmer on average 8% of the applied water (51 mm) during the four-year monitoring period. In 2020, the savings would have amounted to 19% of the applied irrigation (150 mm). During the very wet year 2019 and the wet year 2021, irrigation scheduling support would not have resulted in water savings for the farmer. However, the sensor-based scheduling would in all years reduce the numbers of days on which the trees experienced water stress, ranging from 38 days in 2019 to 64 days in 2021. The scheduling would also almost completely prevent irrigation drainage losses from the 80-cm rootzone. This could also result in the reduced losses of nutrients. The required smaller and more frequent irrigations do, however, result in higher evaporation losses, which was estimated as 102 mm per year, on average.

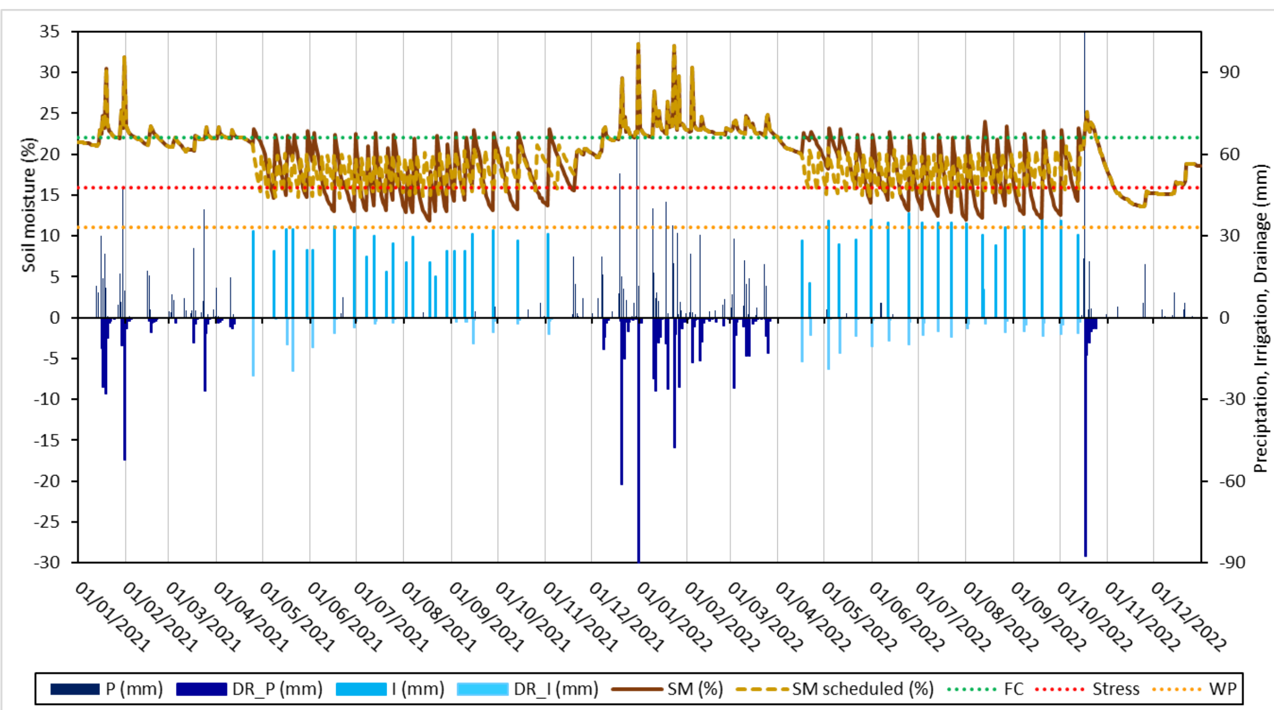

Figure 2. Observed and computed precipitation (P), irrigation (I), drainage (DR), observed soil moisture (SM) and the soil moisture resulting from a sensor-based schedule in the 80-cm rootzone of two nectarine trees in Galata, during 2021 and 2022; the soil moisture level at field capacity (FC), wilting point (WP) and tree water stress are also shown.

Table 2. Water balance components and irrigation requirements computed for the observations on the nectarine terraces in Galata and for a sensor-based irrigation schedule.

| **Water balance observed** | **2019*** | **2020** | **2021** | **2022** |
|---|---|---|---|---|
| Precipitation (mm) | 698 | 631 | 682 | 655 |
| Irrigation (mm) | 536 | 796 | 615 | 617 |
| Drainage from precipitation (mm) | 438 | 423 | 414 | 482 |
| Drainage from irrigation (mm) | 115 | 249 | 113 | 161 |
| Soil moisture change (mm) | 12 | -40 | 18 | -40 |
| Evapotranspiration (mm) | 669 | 794 | 752 | 668 |
| Reference evapotranspiration (mm) | 879 | 1016 | 1043 | 978 |
| Irrigation demand (KcETo) (mm) | 594 | 606 | 612 | 525 |
| Irrigation demand (Kc/Kc_w ETo) (mm)** | 628 | 659 | 657 | 620 |
| Number of irrigations | 19 | 28 | 23 | 20 |
| Number of days with stress | 38 | 46 | 64 | 56 |
| **Water balance with scheduled irrigation** | | | | |
| Irrigation (mm) | 535 | 646 | 620 | 575 |
| Drainage from precipitation (mm) | 437 | 423 | 414 | 482 |
| Drainage from irrigation (mm) | 0 | 2 | 0 | 12 |
| Soil moisture change (mm) | 19 | -39 | 18 | -42 |
| Evapotranspiration (mm) | 777 | 891 | 870 | 777 |
| Irrigation demand (Kc/Kc_w ETo) (mm)** | 680 | 773 | 784 | 733 |
| Number of irrigations | 32 | 39 | 37 | 35 |
| Water savings (fraction of observed irrg.) | **0.00** | **0.19** | **-0.01** | **0.07** |

* Started 23 March 2019; ** irrigation demand including evaporation losses on irrigation days (Kc = 1.20).

In Galata the crop coefficient for the nectarine trees during mid-season was 0.74 and the crop coefficient with a wetted area fraction of 0.31. During the leafless stage, when weeds are growing freely, the crop coefficient was 0.56. Both were derived for dry days without water stress. The mean absolute errors for the fitting of the crop coefficients, expressed as observed minus estimated evapotranspiration, was 1.1 mm/d (424 days) during the green stages of the trees and 0.4 mm/d (123 days) for the leafless stage. These errors are partially due to differences in the timing of the green-up, development and maturing of the trees, which is sensitive to the weather. We used the same stage lengths as observed in the field (60 days development, 135 days mid stage, 35 maturing). The management of the weeds (understory) in the field also results in changes in the crop coefficients within and between years. Eliades et al. (2022) measured the Leaf Area Index of the trees on these terraces with a canopy analyzer and related this to the crop coefficient pattern. They found a maximum crop coefficient of 0.75 during full tree canopy cover and 0.69 for the winter period (2019-2021). The depletion factor at which trees started to experience water stress was determined from the reduction in soil moisture uptake (p=0.55, SM=16%).

The water balance components of the apple terraces are presented in Table 3. As can also be seen in Figure 3, the apple farmer applies his irrigations very judiciously (approximately 10 mm per week). Thus, no irrigation water savings can be obtained here. On the contrary, the computed sensor-based irrigation schedule for fulfilling the water demand of the trees would triple the applied irrigation volume. The soil moisture observations indicated that the trees experience currently, on average, 64 water stress days per year. However, these terraces are extremely stony and we could not install sensor below the 30-cm depth. For the water balance computations we assumed a rootzone of 35-cm, but the trees are likely to take up water from the rocky lower layers. Thus, plant water stress observations (leaf or stem water potential) should be made to obtain a better understanding of the water status of the trees.

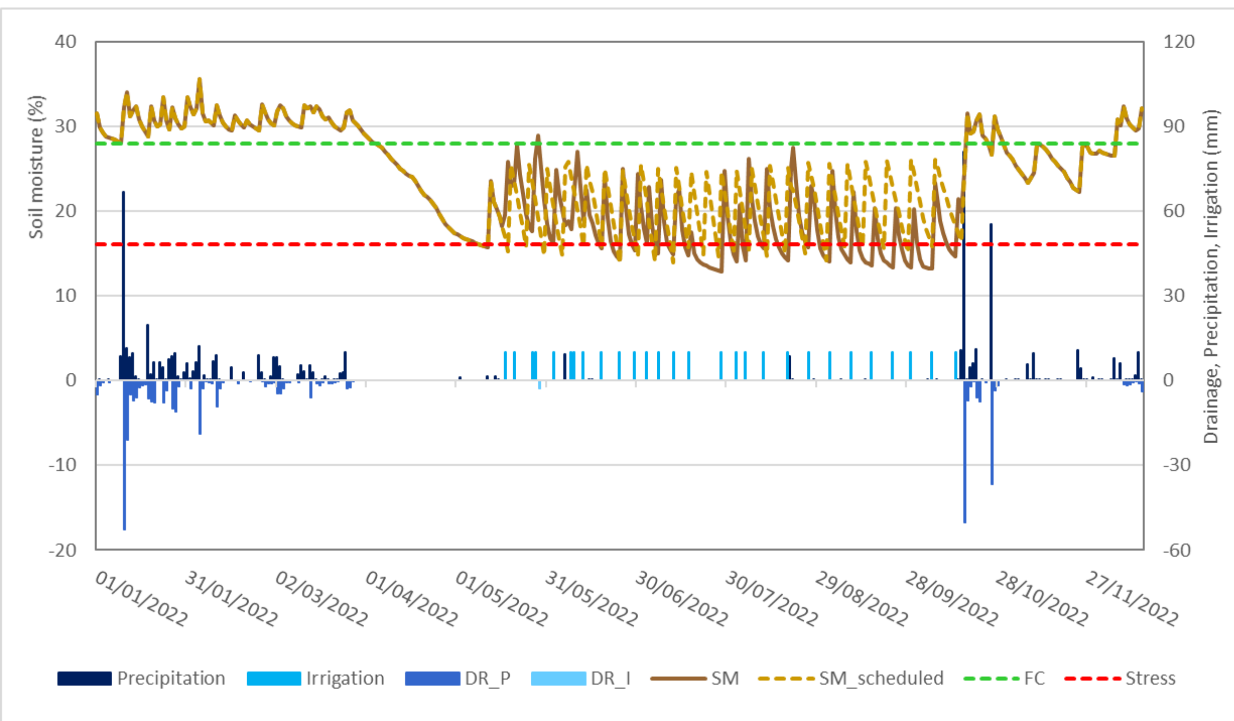


Figure 3. Observed and computed soil moisture, water balance components and soil moisture resulting from sensor-based irrigation scheduling for the apple terraces in Alona in 2022 (see Figure 2 for abbreviations).

The crop coefficient for the apples during mid-season was 0.80 with a wetted area fraction of 0.50 (micro-sprinklers). For the rainfed, leafless stage the crop coefficient was 0.63, which was slightly higher than the

0.56 for the nectarines. The mean absolute error for the crop coefficients was 1.2 mm/d (319 days) for the green stages of the trees and 0.5 mm/d (129 days) for the leafless stage.

Table 3. Water balance components and irrigation requirements computed from the observations and for a sensor-based irrigation schedule for the apple terraces in Alona.

| **Water balance observed** | **2019** | **2020** | **2021** | **2022*** |
|---|---|---|---|---|
| Precipitation (mm) | 855 | 416 | 480 | 565 |
| Irrigation (mm) | 190 | 270 | 210 | 280 |
| Drainage from precipitation (mm) | 440 | 255 | 258 | 362 |
| Drainage from irrigation (mm) | 0 | 0 | 0 | 3 |
| Soil moisture change (mm) | 24 | -10 | 24 | -11 |
| Evapotranspiration (mm) | 580 | 441 | 409 | 491 |
| Reference evapotranspiration (mm) | 1147 | 1209 | 1119 | 1057 |
| Irrigation demand (KcETo) (mm) | 865 | 914 | 843 | 724 |
| Irrigation demand (Kc/Kc_w ETo) (mm)** | 903 | 968 | 884 | 852 |
| Number of irrigations | 19 | 27 | 21 | 28 |
| Number of days with stress | 42 | 83 | 87 | 43 |
| **Water balance with scheduled irrigation** | | | | |
| Irrigation (mm) | 668 | 818 | 734 | 652 |
| Drainage from precipitation (mm) | 450 | 255 | 252 | 361 |
| Drainage from irrigation (mm) | 0 | 0 | 5 | 0 |
| Soil moisture change (mm) | 24 | -11 | 22 | -9 |
| Evapotranspiration (mm) | 1049 | 991 | 935 | 865 |
| Irrigation demand (Kc/Kc_w ETo) (mm)** | 994 | 1059 | 972 | 922 |
| Number of irrigations | 25 | 30 | 27 | 24 |

* Ended 15 Dec 2022; ** irrigation demand including evaporation losses on irrigation days (Kc = 1.20).

The water balance components and soil moisture conditions of the cherry terraces are presented in Table 4 and Figure. The loam soil of these terraces has good water holding capacity. The cherry trees are very densely planted (approximately 1.5 by 2 m spacing) with one or two drippers per tree. Ample irrigation water is applied and the trees did not experience water stress. However, the numbers in Table 4 have some uncertainties. In 2021, the soil moisture observations showed that the rainfall from the nearest rain gauge in Alona (2 km distance) did not represent the daily rainfall at the cherry terraces very well. It is obvious that in such a mountainous environment the rain can be highly variable. This was resolved with the installation of a small meteo station in December 2022. There were also instances of large drainage losses due to problems with the irrigation system in 2022, which are not added to the numbers in the table. In 2021, water savings could have been up to 60%, which should however be considered within light of the above uncertainties. In general, the data show that there is an opportunity for improving the irrigation schedule.

The crop coefficient for the mid-season for the cherry field was 0.80 (mean absolute error 1.5 mm/d), assuming a wetted area of 1.0. The crop coefficient for the rainfed season was 0.69 (mean absolute error 0.4 mm/d).

Table 4. Water balance components and irrigation requirements computed from the observations and for a sensor-based irrigation schedule for the cherry terraces in Platanistasa.

| **Water balance** | **2021** | **2022** | **2021** | **2022** |
|---|---|---|---|---|
| | **observed** | | **scheduled** | |
| Precipitation (mm) | 493 | 492 | | |
| Irrigation (mm) | 1248 | 750 | 493 | 492 |
| Drainage from precipitation (mm) | 316 | 347 | 785 | 783 |
| Drainage from irrigation (mm) | 276 | 47 | 316 | 347 |
| Soil moisture change (mm) | 26 | -12 | 0 | 0 |
| Evapotranspiration (mm) | 1123 | 861 | 26 | -12 |
| Reference evapotranspiration (mm) | 1323 | 1277 | | |
| Irrigation demand (KcETo) (mm) | 953 | 839 | | |
| Irrigation demand (Kc/Kc_w ETo) (mm) | 1058 | 995 | 1037 | 1003 |
| Number of irrigations | 41 | 30 | 16 | 16 |

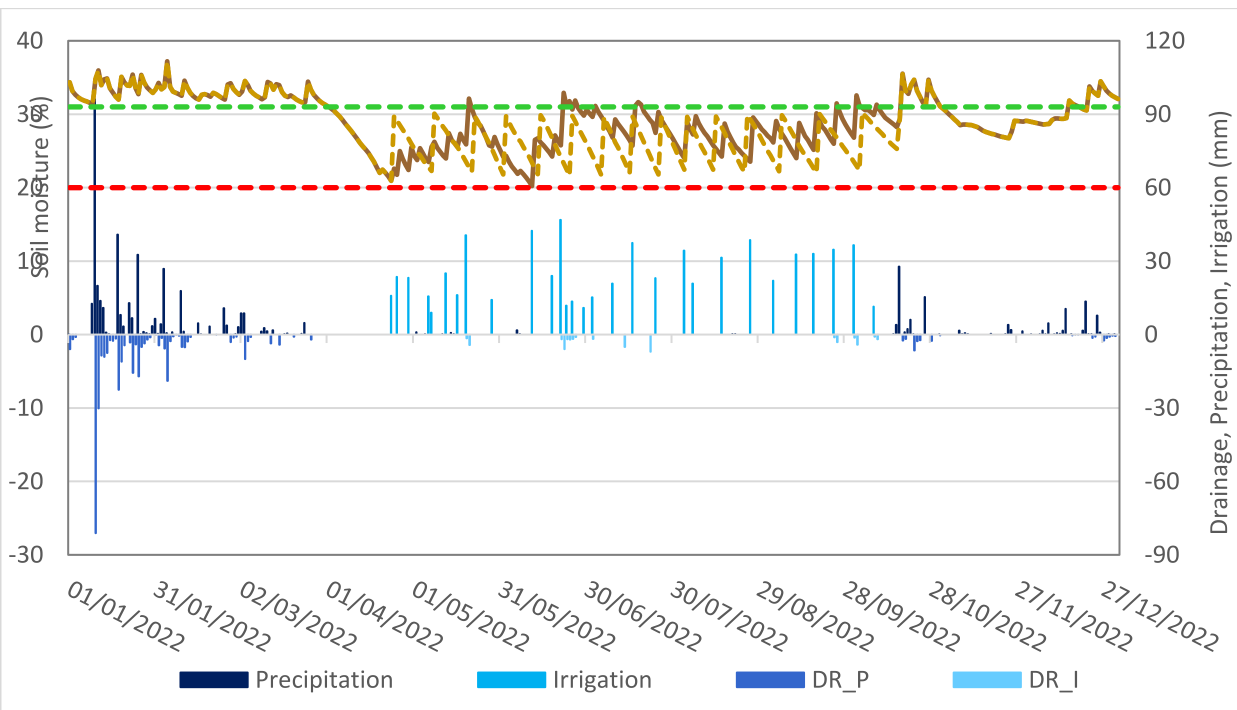

Figure 4. Observed and computed soil moisture, water balance components and soil moisture resulting from sensor-based irrigation scheduling for the cherry terraces in Platanistasa in 2022 (see Figure 2 for abbreviations).

In Dymes, the farmer received access to the software developed by project. The soil moisture of the two monitored soil profiles, average of 10, 25, and 50-cm depth each are presented in Figure 5 for the 30-minute data. The data show rapid water leaching after irrigation and high variability between the two neighboring profiles in between two trees. This may have been caused by the relocation of the micro-sprinklers. The farmer also understood that he needs to irrigate smaller amounts with relatively short time intervals.

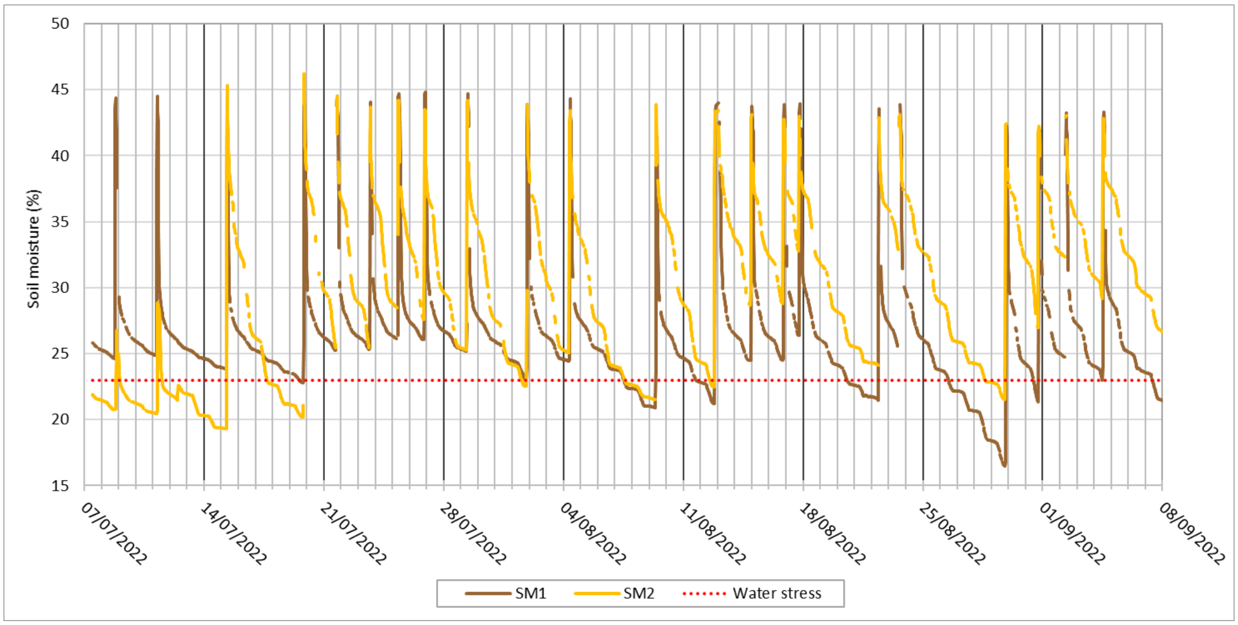


Figure 5. Soil moisture with a 30-min time interval in two profiles (SM1, SM2) in the plum terrace in Dymes.

## Conclusion

The monitoring, analysis and irrigation schedule analysis at the four fruit tree terraces showed a mixed picture. Sometimes farmers irrigate too much, sometimes not enough. The farmers welcomed the irrigation information, but they are somewhat reluctant to change their practices. The observations data showed relatively high crop coefficients during the rainy winter season, related to the weeds growing on the terraces. Further research funding will be sought to expand the research with plant water stress observations, such as stem water potential and leaf conductance to obtain a better understanding of the of the plant water status, as well as with investigations in fruit growth and quality, in relation to water stress.

# References

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Eliades, M., Bruggeman, A., Djuma, H., Christofi, C., Kuells, C. 2022. Quantifying evapotranspiration and drainage losses in a semi-arid nectarine (*Prunus persica var. nucipersica*) field with a dynamic crop coefficient (Kc) derived from Leaf Area Index measurements. Water, 14, 734. https://doi.org/10.3390/w14050734

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# Appendix 1: Location of mountain terrace stations

Monitoring stations on the nectarine terraces in Galata (top) and the apple terraces in Alona (bottom).

Monitoring stations in the cherry terraces in Platanistasa (top) and the plum terraces in Dymes (bottom).