Investigating soil–plant relationships for sustainable management of irrigation with saline water in a Sicilian vineyard

G. Crescimanno[1], K. B. Marcum[2], C. Reina[1] & A.Versaci[1]
[1]*Università di Palermo, Dipartimento ITAF – Sezione Idraulica, Italy*
[2]*Centre for Urban Greenery and Ecology, National Parks Board, Singapore*

Abstract

Water demand is increasing worldwide. In regions affected by water scarcity such as those located in the Mediterranean basin, water supplies are already degraded, or subjected to degradation processes, which worsen the shortage of water. In such regions, competition for scarce water resources among users will inevitably reduce the supplies of freshwater available for crop irrigation. Detailed studies and experimental projects are needed to develop management scenarios aimed at preventing desertification and conflicts for use of the increasingly limited water resources and cultivable land. This paper illustrates soil-plant responses to irrigation with saline water in a Sicilian vineyard located in a wine production area (Mazara del Vallo, Trapani, TP). Two irrigation treatments of different salinities, R and L, having electrical conductivities of 0.6 and 1.6 dS m^{-1}, respectively, were applied at several dates, using a drip system, in a silty-clay soil. Soil measurements were taken to monitor water content (θ) and EC of saturated extract (EC_{sat}). Plant responses to water and salinity conditions were explored by measuring crop transpiration (T) and stomatal conductance (G_s) at several dates during the irrigated season. Results showed that significantly lower T and Gs values were measured in field sites with lowest and highest EC_{sat}.

Keywords: soil, plant, irrigation, salinization.

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1 Introduction

Many Mediterranean countries exhibit water availability below the threshold of 1000 m^3/person/year. In addition, lower availability than the benchmark of water scarcity is also observed in certain regions within countries such as Spain, Greece and Italy UN Population Division [14]. Higher temperatures and population growth will increase the demand for water in most Mediterranean countries. Higher rates of evaporation due to climate change is concurrently causing rising salt concentrations in surface water bodies. Under these conditions, freshwater resources available for agriculture are declining quantitatively and qualitatively (Crescimanno et al. [7]). Therefore, the use of lower-quality supplies, such as saline waters, is inevitably practiced for irrigation purposes (Crescimanno and Garofalo [5]). Use of saline water for irrigation, coupled with adverse climatic conditions, makes the Mediterranean region vulnerable to salinization and desertification (Szabolcs [13] UNEP [15]). Salinity acts on plants through non-specific and specific mechanisms. The non-specific effect is due to decreased osmotic potential of the soil solution that impedes transpiration and photosynthesis (Munns and Termaat [10]; Shannon and Grieve [12]). Grapes have been defined as moderately sensitive to salinity (Maas [9]). Conclusions concerning vine response to salinity are largely based on short-term studies in hydroponic growing conditions or in potting media, and there have been few studies on mature grapevines over time. Sicily is located within a susceptible Mediterranean region where conditions of water scarcity and drought, as well as use of saline water for irrigation, are going to expand (Crescimanno and Garofalo [5]). Management options preventing salinization, while maintaining acceptable levels of crop productivity, need to be developed and applied (Crescimanno and Garofalo [4]). This paper reports results of an investigation carried out from 25 June 2008 to 30 July 2008 in a vineyard located in Sicily within the frame of the three-year Project: "*Evolution of cropping systems as affected by climate change* "(CLIMESCO), funded by three Italian Ministries (University, Agriculture and Environment). CLIMESCO (2007-2009) has the objective of developing management scenarios for optimizing the use of limited water resources while concurrently minimizing salinization and the risk of desertification (Crescimanno and Marcum [6]).

2 Materials and methods

2.1 Field and irrigation description

Investigations were carried out at Foraci Farm (http://www.cantineforaci.com/), a vineyard producing high quality wines located in the Mazaro basin region of Sicily (Fig. 1). Two different irrigation treatments were established (L and R) to monitor soil and plant responses to irrigation water salinity. Irrigation treatment L used irrigation water from a lake having EC_w= 1.6 dS/m; irrigation treatment R used water from a well having EC_w= 0.6 dS/m. Vine rows, named r_L and r_R, were selected in each of the two treatments for measurements of crop transpiration (T) and stomatal conductance (G_s). Four soil profiles (E, F, G and

H) were selected along each of the two rows for hydraulic characterization and for monitoring soil moisture and salinity levels. E and F were located along the r_R row, G and H along the r_L row. Irrigation scheduling was established according to a water balance model taking into account climatic data, soil hydraulic parameters (field capacity and wilting point) and crop parameters. Table 1 reports the irrigation scheduling applied during the 2008 irrigation season. Irrigation in the R plot was performed one day before irrigation in the L plot. Irrigation amount was 15 mm depth per event. Reference evapo-transpiration, ETo, was calculated by using the Hargreaves equation (Hargreaves and Samani [8]).

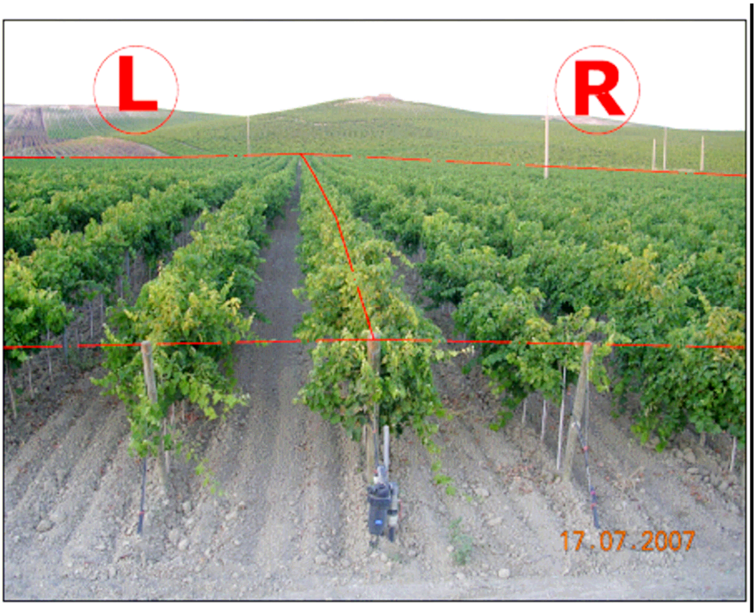

Figure 1: Foraci Farm (Mazaro basin, Sicily, Italy): location of the two treatments (L and R).

2.2 Soil physical and hydraulic parameters

Replicated soil cores having different sizes according to the physical and hydraulic characteristics to be measured were sampled from the different horizons in the E, F, G and H profiles. Soil shrinkage curve was determined by measuring vertical and horizontal shrinkage (Crescimanno and Provenzano [2]). Soil hydraulic parameters were determined by inverse method based on multi-step (MSTEP) outflow experiments (Crescimanno and Garofalo [3]). Parameter estimation was performed by representing the soil water retention curve by the equation proposed by Brutsaert [1]. Parameter estimation was performed by fixing the saturated water content, θ_s, at the measured value. Optimized parameters were therefore the residual water content θ_r, α', and n' (Crescimanno and Garofalo [3]).

Table 1: Irrigation scheduling and measurements during the 2008 irrigation season.

Irrigation (L)	Measurements (L)	Irrigation (R)	Measurements (R)
25 June	26 June	24 June	25 June
1st July	2 July	30 June	1st July
8 July	9 July	7 July	8 July
16 July	17 July	15 July	16 July
29 July	30 July	28 July	29 July

2.3 Soil and physiological measurements in four selected profiles (E, F, G, H)

Gravimetric water content, U, was determined on undisturbed soil cores sampled at different depths (15, 30, 60 cm and 80 cm) in the E, F, G and H profiles at the same dates at which the physiological measurements were performed. Bulk density (ρb) was determined from the measured shrinkage curves; U and (ρb (U)) were used to calculate volumetric water content θ, which therefore accounted for a variable soil volume. Soil saturated extracts were prepared using the soil collected in the E, F, G and H profiles; soil electrical conductivity, EC_{sat}, was measured by a conductivimeter (Crison, Micro CM 2002; Rhoades et al. [12]). θ and EC_{sat} were measured at the same dates. Crop transpiration (T) and stomatal conductance (G_s) measurements were taken on three recently matured leaves per plant) located in the E, F, G and H sites, using a CIRAS-2 portable infrared gas analyzer (PP-Systems). Crop transpiration (T) and stomatal conductance (G_s) were also measured on a total of ten plants per row going from plant n. 1 to plant n. 100 along the r_L and r_R rows, taking three measurements per plant.

3 Results and discussion

3.1 Soil physical and hydraulic parameters

Table 2 reports some soil physical characteristics of the four profiles, together with their pedological classification. Table 3 reports the hydraulic Brutsaert parameters Crescimanno and Garofalo [3] obtained for the four profiles.

Figure 2 illustrates the water retention curves (h, θ) obtained for the E, F, G and H profiles. The Figure shows differences in water retention between the four profiles, with H profile showing the lowest retention capacity.

Table 2: Classification and physical properties of the considered soils.

Soil profile	Classification	Horizon	Depth [cm]	Clay [%]	Silt [%]	Sand [%]
E	Typic Chromoxerert	Akp2	30-60	55	37	9
F	Typic Chromoxerert	Akp2	30-60	54	36	10
G	Typic Chromoxerert	Akp2	30-60	52	37	11
H	Typic Chromoxerert	Akp2	30-60	33	34	33

Table 3: Hydraulic parameters determined for the E, F, G and H four soil profiles.

Soil profile	Horizon	Depth [cm]	α' [cm^{-1}]	n' [cm^{-1}]	θr [$cm\ cm^{-3}$]	θs [$cm\ cm^{-3}$]
E	Akp2	30-60	0.001	0.202	0.240	0.500
F	Akp2	30-60	0.005	0.557	0.257	0.450
G	Akp2	30-60	0.001	0.363	0.250	0.450
H	Akp2	30-60	0.026	0.516	0.200	0.420

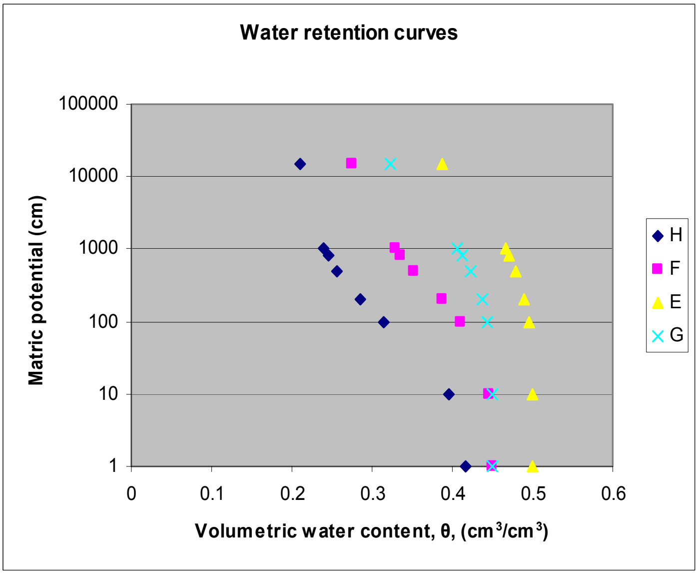

Figure 2: Water retention curves (h, θ) obtained for the E, F, G and H profiles.

3.2 Water content

Figure 3 illustrates the volumetric water content (θ) at 60 cm depth of soil profiles measured after irrigation. The θ values measured in the H profile were generally lower than θ values measured in the E, F and G profiles. This is consistent with the water retention curve measured in the H profile, and proves that a variability of the soil hydraulic properties occurred in the plots. Instead, differences in θ values measured in profiles E, F and G were less relevant.

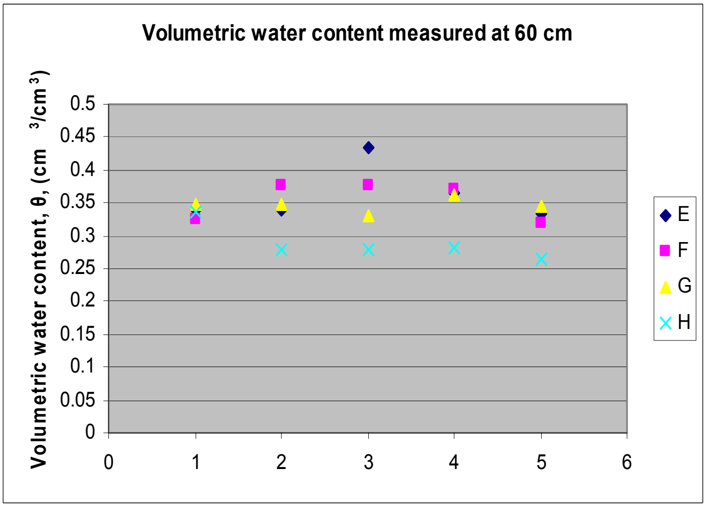

Figure 3: Volumetric water content (θ) measured at the depth of 60 cm in the four profiles.

3.3 Electrical conductivity of saturated extract

Figure 4 illustrates the electrical conductivity (EC_{sat}) measured after irrigation in the four profiles at the depth of 60 cm. The highest EC_{sat} were generally measured in the G and H profiles; lower EC_{sat} values were found in the E and F profiles. EC_{sat} values measured at 15, 30 and 80 cm, not reported, showed a similar behaviour.

3.4 Transpiration and stomatal conductance

Figure 5 illustrates transpiration (T) values measured after irrigation events in the E, F, G and H profiles. A paired t-test proved that significantly higher T values were measured in the E and F profiles (r_R row) compared to values measured in the G and H profiles (r_L row). The same t-test performed on all the T measurements performed along the r_R and r_L rows confirmed that statistically significant higher T values were measured in the r_R row compared to T values measured in the r_L row.

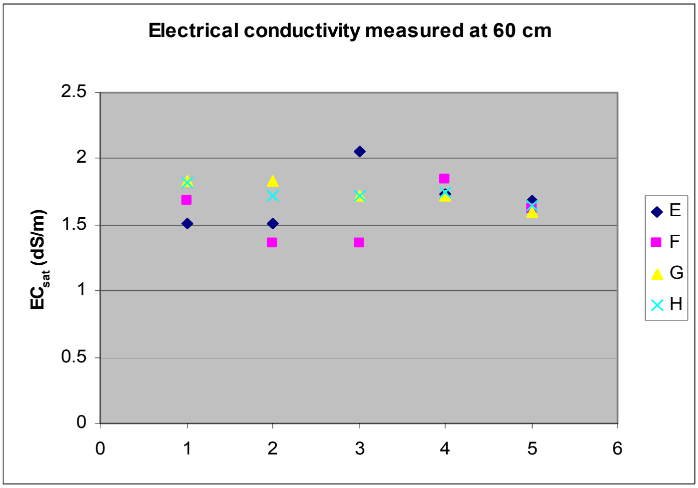

Figure 4: Electrical conductivity (EC_{sat}) measured after irrigation at the depth of 60 cm in the four profiles.

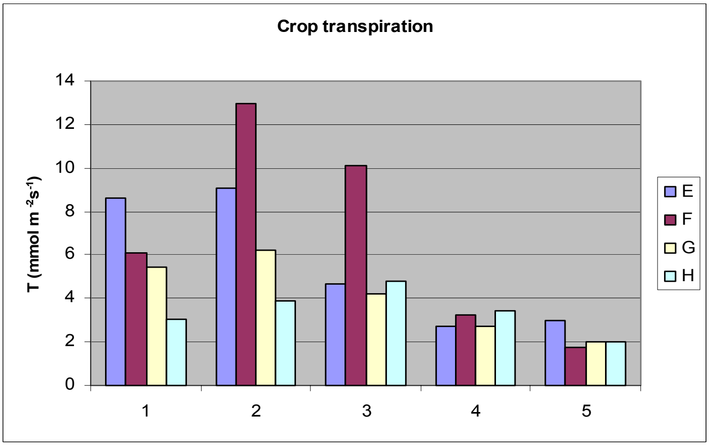

Figure 5: Transpiration (T) values measured after irrigation events in the E, F, G and H field-sites.

Consistently with the higher T, statistically significant higher G_s values were measured in the E and F profiles, compared to those measured in the G and H (Fig. 6); significance of these differences was also confirmed by analyzing all G_s measured along the r_R and r_L rows. Figure 7 illustrates the relationship between the T and G_s values measured after irrigation events in the R and in the L profiles. In Figure 7, T and G_s values measured in E and F profiles were grouped and indicated with R, T and G_s values measured in G and H profiles were grouped and indicated with L. A significant linear regression equation predicting T from G_s was found for the R treatment.

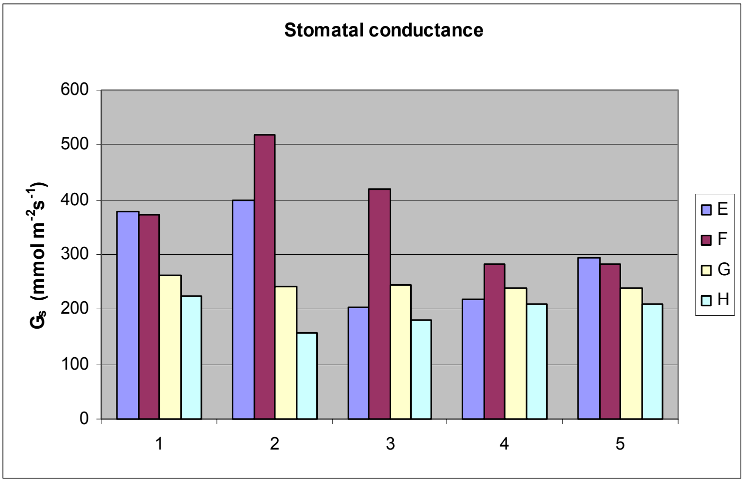

Figure 6: Stomatal conductance (G_s) measured after irrigation events in the E, F, G and H field-sites.

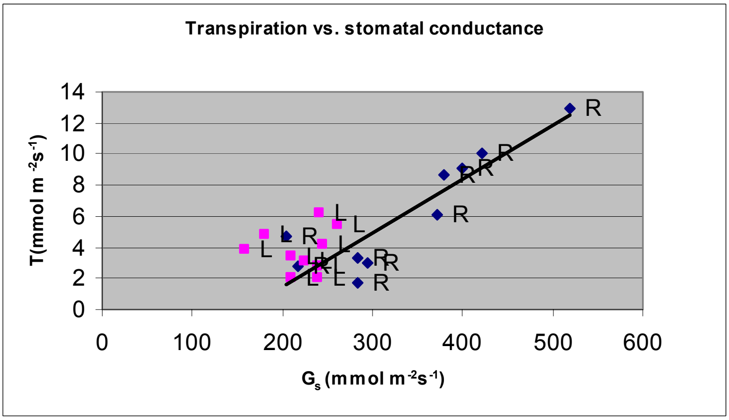

Figure 7: Transpiration (T) vs. stomatal conductance (G_s) measured after irrigation events in the R and L field-sites.

Instead, no correlation was found between T and G_s for the L treatment. Figure 8 illustrates the Crop Water Stress Index, CWSI (CWSI=1-T/Eto) calculated for E and F (R) and for G and H (L). Lower CWSI, which were consistent with the higher measured T and G_s, were found for the E and F profiles after irrigation events compared to those measured in the G and H profiles. Differences between CWSI measured in the E, F, G and H sites under non-irrigated conditions were less relevant. Figure 9 illustrates T vs. water available for crops, AW (AW= θ-θr) for the E, F, G and H profiles. The figure shows that the higher T values were measured in profiles having the highest AW;

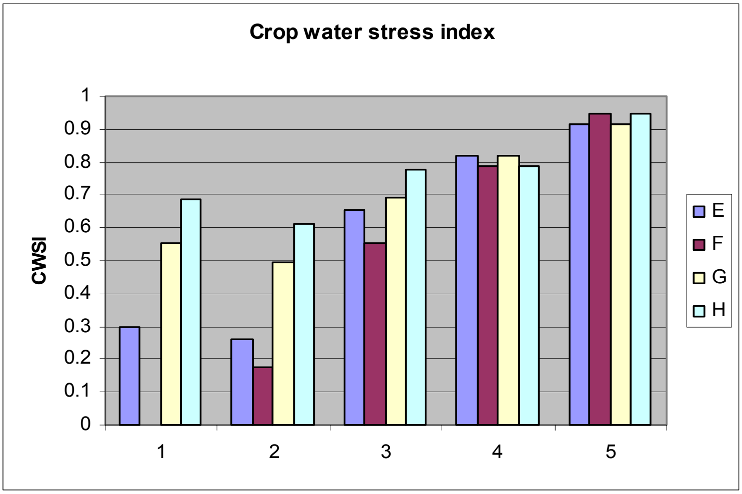

Figure 8: Crop water stress index (CWSI=1- T/Eto) calculated for E, F, G and H field-sites.

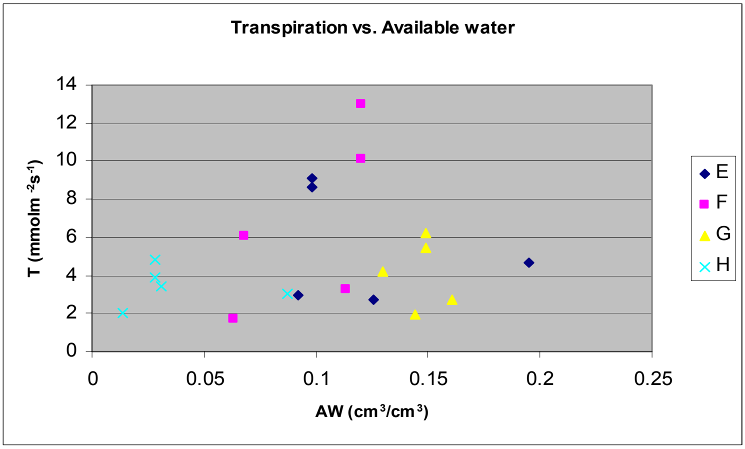

Figure 9: Transpiration (T) measured after irrigation events vs. water available for crops (AW) in the E, F, G and H field-sites.

instead the lowest T values were measured in the H profile, and corresponded with the lowest AW values. The lower AW values measured in the H profile depended on the soil hydraulic properties measured in this profile. This result indicates that soil hydraulic properties may considerably affect crop response to irrigation, determining different levels of transpiration under the same climatic and irrigation conditions. Figure 10 illustrates T vs. EC_{sat} measured in the E, F, G and H profiles; in Figure 10, T measured in profiles belonging to the R or L plot were grouped together. A statistically significant linear regression equation

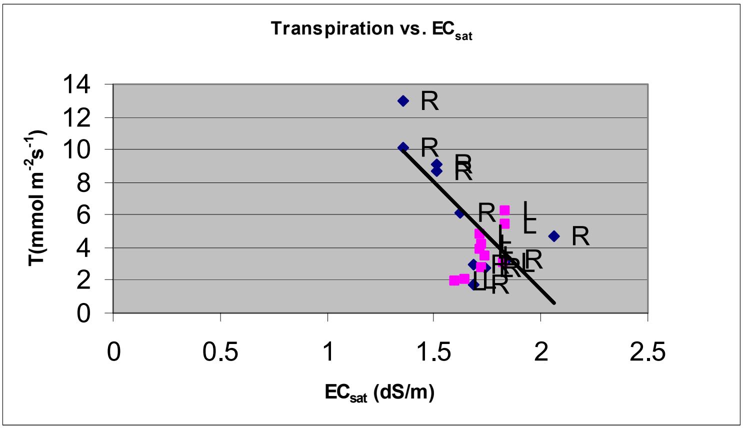

Figure 10: Transpiration (T) measured after irrigation events vs. electrical conductivity (EC_{sat}) measured at 60 cm in the R and L soil profiles.

predicting T from EC_{sat} was found for the R profiles. This result proved that T depended on EC_{sat}. Instead, no relationship predicting T from EC_{sat} was found for the L data.

4 Conclusions

Crop transpiration (T) and stomatal conductance (G_s) measured in grapevines irrigated with water of different salinity proved to be significantly affected by soil salinity conditions, expressed by electrical conductivity of soil saturated extract. Significant reductions in T and Gs were measured in plants in the treatment irrigated with water having EC_{sat}=1.6 dS/m compared to T and G_s values measured in the plot irrigated with water having a salinity of 0.6 dS/m.

In addition, in the plot irrigated with the more saline water (L), T and G_s proved to be significantly affected by the amount of water available for crops, AW, which in turn depended on spatially variable soil hydraulic properties. In conclusion, T and G_s levels proved to be dependent on soil hydrological and salinity conditions. Determining soil hydraulic parameters is therefore essential to develop proper irrigation strategies, particularly when saline waters are used for irrigation. Further investigation is underway to determine the extent to which crop yield and wine quality were affected by water and saline stress in the two irrigated plots.

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