Irrigation Science
https://doi.org/10.1007/s00271-023-00901-7

REVIEW

Single and basal crop coefficients for estimation of water use of tree and vine woody crops with consideration of fraction of ground cover, height, and training system for Mediterranean and warm temperate fruit and leaf crops

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Received: 30 May 2023 / Accepted: 8 November 2023

Abstract

This paper reviews the research on the FAO56 single and basal crop coefficients of fruit trees and vines performed over the past twenty-five years and focus on Mediterranean and warm temperate trees and vines. Two companion papers (López-Urrea et al., (2023) Single and basal crop coefficients for estimation of water use of tree and vine woody crops with consideration of fraction of ground cover, height, and training system for temperate climate fruit crops. Irrig Sci (submitted); Paredes et al. (2023) Single and basal crop coefficients for estimation of water use of tree and vine woody crops with consideration of fraction of ground cover, height, and training system for tropical and subtropical fruit crops. Irrig Sci (submitted)) are dedicated, respectively, to Temperate and to Tropical and Subtropical trees and vines. The main objective of the paper is to update available information on single (K_c) and basal (K_{cb}) standard crop coefficients, and to provide for updating and completing the FAO56 tabulated K_c and $K_{cb.}$ The K_c is the ratio between non-stressed crop evapotranspiration (ET_c) and the grass reference evapotranspiration (ET_o), while K_{cb} is the ratio between crop transpiration (T_c) and ET_o. The selection and analysis of the literature were performed considering only studies that adhere to the FAO56 method, thus computing ET_o with the FAO Penman–Monteith ET_o equation, the ASCE grass ET_o, or another equation that could be properly related with the former, and ET_c, or T_c, was obtained using properly accurate field measurements on crops under pristine or eustress conditions. The crops considered refer to Mediterranean (grapes and olive) and warm temperate areas (avocado, citrus, persimmon, loquat, and tea) fruit and leaf crops. Papers satisfying the above conditions were selected to provide for standard K_c and K_{cb} data. Preferably, studies should report on the crop cultivar and rootstock, planting density or plant spacing, fraction of ground cover (f_c), crop height (h), crop age and training systems. Additional information was collected on pruning and irrigation method and strategy. The ranges of reported K_c and K_{cb} values were grouped according to crop density in relation with $f_{c,}$ h, and the training system, namely vase, hedgerow, or trellis systems. Literature collected K_c or K_{cb} values were compared with previously tabulated K_c and K_{cb} values, namely in FAO56, to define the standard K_c and K_{cb} values for the referred selected crops. The tabulated values are, therefore, transferable to other locations and aimed for use in crop water requirement computations and modeling, mainly for irrigation planning and scheduling, and for supporting improved water use and saving in orchards and vineyards.

Abbreviations

A&P	Allen and Pereira (2009) approach
AGC	Active ground cover
Avg.	Average
BC	Bilateral cordon
BREB	Bowen ratio energy balance
BS	Bare soil
Capacit.	Capacitance sensors
DI	Deficit Irrigation
DL	Drainage lysimeters
DPS	Density of plants and spacing
EBL	Equilibrium boundary layer of air
EC	Eddy covariance
FAO-PM-ET_o	Grass reference ET_o computed with full data
FAO-PMT	Grass reference ET_o computed with temperature
FDR	Frequency domain reflectometry
FI	Full irrigation
GDC	Geneva double curtain
grav.	Gravimetric method

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HWC	High-wire cordon
IS-APP	Irrigation scheduling app
LAI	Leaf area index
Lys.	Lysimeter
Med	Mediterranean
METRIC	Energy balance model for mapping evapotranspiration with internalized calibration
Micro-spr	Micro-sprinkler or micro-sprayer
ML	Mini or micro lysimeters
n/r	Not reported
NDVI	Normalized difference vegetation index
OPEC	Open-path Eddy-covariance
PM-eq.	Penman–Monteith combination equation
PRD	Partial rootzone drying
PT	Priestley–Taylor equation
QCT	Quadrilateral cordon trained
RDI	Regulated deficit irrigation
Reflec	Reflectometer
RS	Remote sensing
RS-SEB	Remote sensing surface energy balance
Scintil.	Scintillometer
SDI	Sustained deficit irrigation
SEB	Surface energy balance
SF	Sap flow
Spr.	Sprinkler
SR	Surface renewal
SW	Shuttleworth and Wallace double source model
SWB	Soil water balance
TDR	Time domain reflectometer
Tens.	Tensiometers
TREL	Trellis systems
TTS	Training and/or trellis systems
VI	Vegetation index
VSP	Vertical shoot positioning
WL	Weighing lysimeter

List of symbols

ET_c	Crop evapotranspiration under standard conditions [mm d^{-1} or mm h^{-1}]
$ET_{c\ act}$	Actual crop evapotranspiration, i.e., under non-standard conditions [mm d^{-1} or mm h^{-1}]
ET_o	(Grass) reference crop evapotranspiration [mm d^{-1} or mm h^{-1}]
f_c	Fraction of soil surface covered by vegetation [-]
f_{IPAR}	Fraction of the intercepted PAR [-]
F_r	Adjustment factor relative to stomatal control [-]
G	Soil heat flux density [MJ m^{-2} d^{-1}]
h	Crop height [m]
H	Sensible heat flux [MJ m^{-2} d^{-1}]
K_c	(Standard) crop coefficient [-]
$K_{c\ act}$	Actual crop coefficient (non-standard conditions) [-]
$K_{c\ avg}$	(Standard) average crop coefficient [-]
$K_{c\ ini}$	Crop coefficient during the initial growth stage [-]
$K_{c\ mid}$	Crop coefficient during the mid-season stage [-]
$K_{c\ end}$	Crop coefficient at end of the late season stage [-]
K_{cb}	Standard basal crop coefficient [-]
$K_{cb\ act}$	Actual basal crop coefficient (non-standard conditions) [-]
$K_{cb\ ini}$	Basal crop coefficient during the initial stage [-]
$K_{cb\ mid}$	Basal crop coefficient during the mid-season stage [-]
$K_{cb\ end}$	Basal crop coefficient at end of the late season stage [-]
K_s	Water stress coefficient [-]
M_L	Multiplier relative to the canopy transparency [-]
r_a	Aerodynamic resistance [s m^{-1}]
r_s	Bulk crop–soil surface resistance [s m^{-1}]
R_n	Net radiation at the crop surface [MJ m^{-2} d^{-1}]
T_c	Crop transpiration [mm d^{-1} or mm h^{-1}]
λET	Latent heat flux [MJ m^{-2} d^{-1}]

Introduction

Orchards and vineyards are increasingly irrigated. Knowing their water requirements is essential to estimate their irrigation requirements, planning and management of crop water use, assessing water resources availability and demand at basin level, as well as developing hydrologic studies. Accuracy in evapotranspiration (ET) estimates is necessary, mainly when water scarcity prevails, and because sustainable irrigation requires not exceeding crop demand to break the trend for water over-use (Pereira et al. 2009; Wada and Bierkens 2014; Müller Schmied et al. 2016). In addition, related challenges are becoming more difficult due to a continuously increased demand for food to nourish an ever-growing population, increasing drought occurrences, and climate change. As recently reviewed by Pereira (2017), high water use performance and productivity, as well as water conservation and saving in irrigation, require solutions that need improved knowledge of crop evapotranspiration and water use.

The application of water conservation and saving, in addition to the knowledge of water needs and their relations to growth and yield, also require institutional interventions, sectoral policies and new technologies that support improved irrigation management and performance by farmers and sustainable, eco-friendly use of water for food production (Pereira et al. 2009). Literature on management of fruit trees and grapevines is quite extensive, namely relative to water management, and particularly aimed at defining deficit irrigation (DI) strategies.

The concept of standard crop coefficient implies its determination in the absence of water stress, or other stress conditions. However, research on tree and vine crops is demonstrating that the best crop management does not correspond to the full satisfaction of crop water demand, but to the adoption of controlled water deficit at given periods, or in selected modes during the crop cycle aiming that yields are less affected (Chaves et al. 2010; Rallo et al. 2017; Romero et al. 2022) and quality is improved (e.g., López-Urrea et al. 2012). The concept of eustress may better describe such conditions than deficit irrigation (Paço et al. 2019; Rallo et al. 2021). Expanding basic and accurate information on crop water needs is paramount to improve water use and irrigation management, particularly of fruit trees and vines.

Crop evapotranspiration (ET_c) is typically computed or modeled using the well-known FAO56 calculation procedure (Allen et al. 1998), which uses the simple K_c–ET_o approach to compute ET_c, or alternatively K_{cb}–ET_o to compute crop transpiration (T_c), i.e., the product of a crop coefficient (K_c) by the grass reference evapotranspiration (ET_o), or the product of a basal crop coefficient (K_{cb}) by ET_o. The latter represents the actual evaporative demand of the atmosphere, while K_c (ratio ET_c/ET_o) represents an integration of the effects of the main characteristics that distinguish, in terms of the energy balance, the grass reference crop from the crop under study (Allen et al. 1998; Pereira et al. 1999). Adopting the K_c–ET_o approach is simple but requires the application of accurate measurements and computations, particularly when deriving K_c values for a crop using field observations (Allen et al. 2011; Pereira et al. 2021a, b).

Standard, transferable crop coefficients must be obtained from accurate ET_c field measurements under non- or eustress conditions, and ET_o computed with the FAO-PM ET_o (Allen et al. 1998), or the ASCE-PM ET_o (Allen et al. 2005). Other equations whose results relate well to those of the FAO-PM ET_o equations may also be used. Adopting fixed grass parameters for aerodynamic and surface resistance in FAO-PM ET_o equation provides for the crop coefficients to be crop specific parameters that express consistently the relation between the aerodynamic and surface resistances of the considered crop with those of the grass reference crop (Pereira et al. 1999). This is particularly challenging for vines and fruit trees due to their canopy architecture and incomplete ground cover.

Accurate standard, transferable, and updated K_c values obtained from the current literature review require that related ET_c data collection, models and related model calibrations, as well as experimental set-ups were exempt of biases caused by experimental flaws (Allen et al. 2011). Following the methodology adopted in studies focused on vegetable and field crops (Pereira et al. 2021a, b), the selected references were checked to ensure that sufficient descriptions of ET_c measurement practices, crop management, and related production environment were provided. They were also checked to detect possible computational flaws and shortcomings in data handling, as well as in model calibration and validation. In addition, the possible influence of advection was considered (e.g., Wang et al. 2019) since related K_c/K_{cb} values are then of local value only, thus not transferable. Nonetheless, for several crops, the collected information was scarce.

Few studies reports on tabulated standard K_c/K_{cb} of trees and vine crops. The first is FAO56 guidelines (Allen et al. 1998), whose K_c/K_{cb} values continue to be the main reference for trees and vine crops. Later, Allen and Pereira (2009) suggested the A&P approach to determine K_c/K_{cb} from the fraction of ground cover and height and tabulated the related values. Jensen and Allen (2016) tabulated again K_c/K_{cb} for woody perennials. The A&P approach was tested for more crops and the resulting K_c/K_{cb} were reported to support further use of the A&P approach (Pereira et al. 2020b, 2021c). Finally, K_c/K_{cb} updated values were tabulated by Rallo et al. (2021). Excellent K_{cb} and K_c results were predicted from the field observed fraction of ground cover and height (Allen and Pereira 2009; Pereira et al. 2020b, 2021c). The A&P approach is particularly interesting for woody and incomplete cover crops, e.g., fruit trees and vines.

The K_c–ET_o method is the most common in practice but not in research. The selected literature reports numerous applications of the K_c–ET_o method using the soil–water balance (SWB) based on a variety of soil water content (SWC) sensors, which accuracy was reviewed by Evett et al. (2012a) and computation procedures, including a diversity of calibrated models, were recently reviewed (Pereira et al. 2020a). Diverse field measuring approaches of actual ET_c or T_c ($ET_{c\,act}$ and $T_{c\,act}$) are reported such as weighing, drainage, and water-table lysimeters (WL, DL, and WTL), as reviewed by Allen et al. (1991) and Evett et al. (2012c, 2016), the eddy covariance systems (EC, Cammalleri et al. 2013a), the Bowen ratio energy balance systems (BREB, Hu et al. 2014), sap-flow (SF, Fernández et al. 2008), and remote sensing vegetation indices (RS-VI, Pôças et al. 2020). Allen et al. (2011) and Evett et al. (2012a) reviewed these methods for accuracy in $ET_{c\,act}$ measurements, and various authors also compared diverse methods for accuracy (Sánchez et al. 2019). Methods not requiring K_c nor ET_o are also often used such as remote sensing surface energy balance algorithms (RS-SEB, Karimi and Bastiaanssen 2015), the Penman–Monteith combination equation (PM-eq, Monteith 1965), that uses actual aerodynamic and canopy resistances, the two-source

Shuttleworth–Wallace method (SW, Shuttleworth and Wallace (1985), that also relies on those resistances, or the Priestley–Taylor equation (PT, Priestley and Taylor (1972), which uses specific coefficients different of K_c. These methods may provide for K_c when ET_o is reported in addition to $ET_{c\ act}$.

Recent advances in sensors, communications and information technologies did allow the implementation of tools to support irrigation and water management decisions, e.g., the "internet of things" (García et al. 2020; Raj et al. 2021; Abu et al. 2022). Tools focusing on irrigation may refer to water saving practices (Pereira et al. 2009; Jovanovic et al. 2020), to modeling growth and yield (Villalobos et al. 2006; Rahmati et al. 2018) or, most often, to SWB models (Pereira et al. 2020a). However, only few report computer software models (e.g., Rosa et al. 2012a, b; Šimůnek et al. 2016). The use of all those tools to support irrigation management requires precise knowledge of crop water requirements. The various methods need to be known for their accuracy requirements while Tables summarizing the information provided in literature need to be completed with indication of field methods used to derive K_c/K_{cb}.

The objective of this paper, in line with the previous review and addressing particularly Mediterranean and warm temperate fruit and leaf tree and vine crops, consists of reviewing updated single and basal crop coefficient values (K_c and K_{cb}) obtained under near-pristine eustress conditions and use the available K_c and K_{cb} data for tabulating standard, transferable K_c and K_{cb} values. The current review is expected to identify the main results of recent research on standard K_c and K_{cb} values, assessing the methodologies then used and their range of variation. The selected base data and collected values are, therefore, summarized and tabulated to support readers' information on tabulated K_c and K_{cb} values. Section "Materials and methods" focus on requirements for accuracy of the ET methods reported on transferability requirements of standard K_c and K_{cb} values, and on the methodologies used to select and tabulate the standard crop coefficient values. Section "Table and wine grapes" and following consist of presenting and discussing the literature review relative to the derivation of $K_{c\ act}$ and $K_{cb\ act}$ of wine and table grapes, olive, citrus, avocado, loquat, persimmon, and tea, followed by the tabulation of the respective standard K_c and K_{cb} values. Conclusions and recommendations consist of the last Section.

Materials and methods

The FAO56 evapotranspiration method. Crop coefficients and requirements for transferability

Adopting the FAO56 method, crop evapotranspiration, ET_c (mm d^{-1}) is estimated by multiplying the grass reference ET_o (mm d^{-1}), by a crop coefficient, K_c (dimensionless):

$$ET_c = ET_o K_c \tag{1}$$

ET_o is defined as the evapotranspiration of a grass reference crop which is a hypothetical crop with height of 0.12 m, a surface resistance of 70 s m^{-1}, and an albedo of 0.23, closely resembling an extensive surface of green grass of uniform height, actively growing, adequately watered, and well covering the ground (Allen et al. 1998). The daily ET_o is computed with the PM-ET_o equation (Eq. 2), obtained by parameterizing the Penman–Monteith combination equation for that grass crop with fixed and well-defined aerodynamic and surface resistance terms (Allen et al. 1998; Pereira et al. 1999). Daily grass reference evapotranspiration is then obtained with the following equation:

$$ET_o = \frac{0.408\Delta\left(R_n - G\right) + \gamma\frac{900}{T+273}u_2\left(e_s - e_a\right)}{\Delta + \gamma\left(1 + 0.34u_2\right)}, \tag{2}$$

where Δ is the slope of the saturation vapor pressure–temperature curve at mean air temperature (kPa °C^{-1}), (R_n–G) is the available energy at the vegetated surface (MJ m^{-2} d^{-1}), γ is the psychrometric constant (kPa °C^{-1}), T is mean daily air temperature (°C), u_2 is mean daily wind speed (m s^{-1}) at 2 m height and (e_s−e_a) is the vapor pressure deficit (VPD) of the atmosphere (kPa). The PM-ET_o equation considers only vertical fluxes of heat and vapor. Thus, ET_o incorporates most of the weather and related energy effects and then represents the evaporative demand of the atmosphere. Since K_c is the ratio between ET_c and ET_o (Eq. 1), its variations should mainly be attributed to the specific crop characteristics and only for a limited extent to the climate, which enables the transfer of standard K_c values between locations and climates when local and/or regional advection is excluded.

Apart from the FAO-PM-ET_o equation, other alternative equations have been tested to calculate ET_o, either with full or limited weather data sets. Processes with full data sets have the tendency to overlook the conceptual framework (Pereira et al. 2015). For reduced data sets, the Hargreaves–Samani equation (Hargreaves and Samani 1985) and the FAO PM temperature (FAO-PMT) method have been widely used; consolidated methodologies are discussed and described by (Paredes et al. 2020), as well as the use of reanalysis weather data and of geostationary satellite products (Paredes et al. 2021). However, the use of alternative approaches requires the scrutiny of input data and ET_o results since processes are not linear. Therefore, for scientific research studies intending to derive standard transferable crop coefficients, the FAO-PM-ET_o Eq. (2) should be used.

The crop coefficient represents an integration of the effects of three primary characteristics that distinguish any crop from the reference one: crop height, that affects roughness and aerodynamic resistance (r_a); bulk crop–soil surface resistance (r_s), which relates to leaf area, the fraction of ground covered by the vegetation (f_c), leaf age and condition, degree of stomatal control, and soil surface wetness; and albedo of the crop–soil surface influencing the net radiation, that is determined by the fraction of ground covered by vegetation, and soil surface wetness (Allen et al. 1998).

Two K_c approaches are considered (Allen et al. 1998): one consists of a time-averaged single K_c, which includes multi-day effects of evaporation from the soil in addition to plant transpiration, whereas the second refers to the dual K_c, sum of the basal crop coefficient (K_{cb}) and the soil evaporation coefficient (K_e). These coefficients represent, respectively, the ratios of crop transpiration (T_c), or soil evaporation (E_s), to ET_o. Therefore, $K_c = K_{cb} + K_e$ with $K_{cb} = T_c/ET_o$ and $K_e = E_s/ET_o$.

Various authors have developed models or procedures for partitioning ET into T_c and E_s. However, the FAO56 approach (Allen et al. 1998, 2005) has been successfully used and implemented in various SWB models such as SIMDualKc (Rosa et al. 2012a), whose applications to vineyards (Fandiño et al. 2012; Silva et al. 2021; Darouich et al. 2022b), olive (Paço et al. 2014, 2019; Puig-Sirera et al. 2021; Ramos et al. 2023), and citrus (Rosa 2018; Peddinti and Kambhammettu 2019; Darouich et al. 2022a; Ramos et al. 2023) are reported herein.

For transferability purposes, FAO56 adopted the concept of standard K_c and potential ET_c (Allen et al. 1998; Pereira et al. 2015), which refer to well-watered and pristine/eustress cropping conditions and are distinct of actual field conditions, often under-optimal due to insufficient (or non-uniform) irrigation, crop density, salinity, agronomic practices and soil management. The tabulated K_c, therefore, must refer exclusively to the standard K_c. For tree and vine crops, the standard K_c refers to adopting crop-specific eustress practices, i.e., limited stress practices that do not, or minimally, impose reduction of the maximal yield. Under water and salt stress conditions, ET_c gives place to the actual crop ET ($ET_{c\ act}$), with K_c replaced by the actual $K_{c\ act}$ or, using the dual approach, by $K_s\ K_{cb} + K_e$:

$$ET_{c\ act} = K_s\,ET_c = K_s\,K_c\,ET_o = \left(K_s\,K_{cb} + K_e\right)ET_o, \quad (3)$$

where K_s (0–1.0) is the stress coefficient. K_s depends upon the sufficiency of available soil water to maintain the crop ET rate, i.e., $K_s = 1.0$ for pristine conditions for maximal yield. This concept eases a consistent estimation and transferability of measured standard K_c and avoids the need to define multiple K_c values for the same crop depending upon the various water and crop management practices adopted by the growers that cause $K_s < 1.0$ and $K_{c\ act}$ values to vary widely, contrarily to the standard K_c. Plot level use of crop coefficient-based simulations can be backed up by soil and plant water status measurements to detect water stress conditions (e.g., leaf or stem water potential) and to support the use of models.

The estimation of $K_{c\ act}$, assuming any value up to the standard K_c, may be performed using the A&P approach (Allen and Pereira 2009; Pereira et al. 2020b, 2021c). $K_{cb\ act}$ is then computed from the fraction of ground cover and crop height (f_c and h) while K_e is computed from the wetted fraction of exposed soil, $1-f_c$ (FAO56, Allen et al. 1998). The A&P approach shall be used with observed f_c and h and the parameters proposed in Pereira et al. (2020b, 2021c). It is advisable to compare $K_{c\ act} = K_{cb\ act+} + K_e$ with the standard K_c for computation control. Field and remote sensing methods for measuring f_c and h are referred by those authors.

Evapotranspiration relies on the amount of energy available at the surface, resulting from the energy balance of that surface:

$$\lambda ET = \left(R_n - G\right) - H, \quad (4)$$

where λET is latent heat flux, or the energy available to the evaporation process, R_n is net radiation at the crop surface, G is soil heat flux density and H is sensible heat flux, with all terms expressed in MJ m^{-2} day^{-1}. The energy balance imposes physical limits to the evaporation process resulting that the upper limits to K_c are approximately 1.2 in sub-humid regions and 1.2–1.4 in arid regions (Allen et al. 2011). Higher values might result from errors in ET measurement, in weather data for ET_o calculation, in data processing procedure, or may be due to advective energy. Awareness of such upper limits of K_c is extremely important; conditions where measurements were acquired or those from where K_c's are meant to be applied must be considered, namely in terms of advection: If the λET term of the surface energy balance equation (Eq. 4) results in a value higher than R_n–G, the surface is receiving sensible heat downwards, instead of just losing it by convection to the atmosphere. Therefore, a larger amount of energy will be available for the process of evapotranspiration. However, there is an upper boundary to ET_c, imposed by limitations in aerodynamic transfer and equilibrium forces over a vegetated surface (Allen et al. 2011). Then, limits apply and, in general, $K_c \le 1.2$ except in the presence of advection. Advection conditions can limit transferability of crop coefficients, either because they were determined under advection conditions or they are to be applied in such conditions.

Advection can result from the small dimension of the stand under consideration, not providing adequate conditions for the development of a boundary layer in equilibrium with the surface, or by favoring a "clothesline effect", where stand vegetation is more exposed to atmosphere drive than the surrounding vegetation (Allen et al. 2011). Advection can also result from inadequate field measurement conditions, e.g., when lysimeters are not correctly set, causing local and micro-scale advection, or a "clothesline effect"; or when fetch conditions in EC and BREB systems are not observed, or data quality selection criteria against wind direction/fetch are not applied (Hu et al. 2014). Under advection, H decreases to very small values, given the downward advective H flux and, therefore, $\lambda ET \geq (R_n - G)$. Hence, it is expected that under advection conditions, and over small stands of vegetation, ET_c would reach a much larger value (Allen et al. 2011), which is not the case for large stands, where limits for K_c near 1.2 apply.

Advection effects on ET_c of woody crops are rarely reported in literature. However, since trees and vines do not attain full crop development due to pruning and training and are partial cover crops, in the absence of advection, K_c values should not surpass 1.2 (Rallo et al. 2021), but under advective conditions much larger transpiration and larger soil evaporation values may be observed (Kool et al. 2018; Wang et al. 2019); nevertheless, too much large K_c values are reported in literature without signaling the occurrence of advection. For application in small and isolated areas of vegetation, K_c can exceed the limits for grass reference (1.2–1.4), while for large areas, or small areas surrounded by vegetation with similar roughness and soil water status, K_c values must stick to values equal or smaller than those limits (Allen et al. 2011).

The concepts of standard K_c and potential crop ET and related terminology are progressively being accepted by the user communities (Pereira et al. 2015). However, the standard K_c and K_{cb} values for tree and vine crops vary with the fraction of ground cover and height (Allen and Pereira 2009; Jensen and Allen 2016) due to crop age and crop management, particularly crop training. The present review has shown that satisfactorily accurate reported K_c and K_{cb} values for the same crop show dissimilarity among locations, which is due to differences in cultivar and rootstock, plant density, orchard management and pruning, training, as well as soil properties, irrigation method and strategy, soil–crop management practices and (Minacapilli et al. 2009; Cammalleri et al. 2013a; Marsal et al. 2014; Rallo et al. 2021). It is, however, possible to derive local, actual crop coefficients from f_c and h of tree and vine crops (Pereira et al. 2020b, 2021c) when appropriate parameters are used. K_c variability due to weather is less important than causes referred above. Since most papers did not provide weather data on the experiment, the correction of K_c values for climate as proposed in FAO56 was not applied to literature reported K_c.

Accuracy of ET estimation and transferability of derived standard K_c and K_{cb}

Literature reporting field derived crop coefficients has shown diverse objectives and used quite different methodologies with variable accuracy, often aiming to just obtain K_c values for local use, which are not transferable. Results are frequently published without sufficient information relative to the methods and instrumentation used, or about the crop itself, the cropping practices and training, which causes difficulties to transferability. When the published material shown serious limitations to transferability, it was not used. Main limitations refer to:

(1) Adopting other than the standard FAO or ASCE PM-ET_o equation. Because K_c is defined as the ratio ET_c/ET_o, if ET_o equation changes K_c also changes and the resulting $K_{c\ act}$ is not usable to derive a standard K_c.
(2) Using a K_c curve different from the standard segmented FAO K_c curve. Using a curve as a function of time, or a function of LAI, or else, there is no clear definition of the K_c (and K_{cb}) values for the initial, mid-season and end-season stages, respectively, $K_{c\ ini}$, $K_{c\ mid,}$ and $K_{c\ end}$. Then, only approximate estimations of $K_{c\ ini}$, $K_{c\ mid,}$ and $K_{c\ end}$ could be made from the reported graphical data or, often more difficult, from tabulated information.
(3) Using non-standard cultivation conditions. In case of using mulch for controlling E_s, or active ground cover for fighting erosion result management-specific K_c values. When reported K_c values were insufficient to properly recognize the standard K_c values, papers could not be used.
(4) Adopting deficit irrigation practices. Then, deviating from the desirable eustress conditions, the reported $K_{c\ act}$ had only local value.
(5) Reporting insufficient data and information on the experiment. Then, it was not possible to assume that field survey practices were adequate, or that data handling were properly performed. To avoid using poor data, papers were discarded or used with much caution.
(6) Using K_c values transferred from other studies. Without field testing, papers were discarded, except a few review papers.

Field data acquisition processes must respect well-defined requirements. Field data sets used to derive K_c or K_{cb} were obtained using various field techniques. The requirements for data quality acquisition by these methods are extensively described in Allen et al. (2011), reviewed by Pereira et al. (2021a, b) and Rallo et al. (2021), and summarized hereafter.

Techniques that recur to soil water balance methods calculate ET_c as the remaining term as commented (Evett et al. 2012a, 2012b; Pereira et al. 2020a). The main sources of error arise from the quantification of deep percolation and/or capillary rise. Other difficulties may arise from the different patterns of soil water extraction by the roots, namely for heterogeneous stands, as sampling processes may not represent adequately the stand. Techniques must consider: (i) a comprehensive characterization of soil hydraulic properties,

(ii) representativeness of data in spatial and temporal terms, (iii) appropriate sensors calibration, (iv) uniform spatial wetting by irrigation, (v) consideration of deep percolation and capillary rise, (vi) root water extraction patterns, and (vii) sampling criteria. Accuracy of computation procedures depends upon the calibration of parameters and the adequacy of selected algorithms (Pereira et al. 2020a).

Weighing, drainage, and water-table lysimeters (WL, DL, and WTL) are often used for K_c derivation but their accuracy depends upon various issues (Allen et al. 1991; López-Urrea et al. 2006; Evett et al. 2016). Causes of inaccuracy include: (i) differences in cropping conditions inside and outside of the lysimeter relative to vigor and growth of vegetation; (ii) poor setting of the lysimeter, with dissimilar surrounding vegetation causing local advection or clothesline effects; (iii) insufficient fetch to establish the equilibrium boundary layer of air (EBL); (iv) lack of consideration of the area effectively used by the crop for ET, which may often occur with trees and vines; (v) large rim favoring heat transfer into the lysimeter.

The BREB method relies on the surface energy balance equation (Eq. 4) and requires measurements of air temperature and vapor pressure gradients at an appropriate level above the evaporating surface (Hu et al. 2014). The accuracy of the method relies strongly on representativeness of R_n and G measurements and on an adequate fetch for the establishment of the EBL. Main requirements for BREB data quality include: (i) large enough fetch; (ii) adequate positioning of sensors above the canopy to avoid the roughness sublayer; (iii) multiple R_n and G measurement points for heterogeneous or sparse crops. The EC method implies the knowledge of vertical wind speed and fluctuations around the mean of air temperature and humidity in vertical fluxes of sensible and latent heat, sampling statistically turbulent eddies (Cammalleri et al. 2013a). For accuracy, requirements include: (i) large enough fetch and adequate elevation of sensors; (ii) application of the required corrections; (iii) recognition of advection situations and taking of corrective actions, and (iv) correcting data for lack of closure of the energy balance equation, when needed.

The transpiration component in ET_c is generally obtained by sap flow measurement systems that use heat as a tracer to measure the flux in the xylem of plants. These methods generally follow well the transpiration dynamics but require calibration for accurate results (Fernández et al. 2008; Siqueira et al. 2020). Sap flow measurements require: (i) a sensor calibration at each new application, (ii) because measurements are plant-based processes, scaling from plant to stand level is required, then also dealing with measurement representativeness, and (iii) an accurate estimate of conductive xylem area.

Remote sensing is increasingly used to calculate ET_c, namely using surface energy balance models (Pôças et al. 2014, 2020; Karimi and Bastiaanssen 2015; Sánchez et al. 2019), currently largely used for K_c and ET calculation. Vegetation indices derived from satellite information or using UAV, require ground data for validation and are related to actual crop coefficients (Garrido-Rubio et al. 2020; Pôças et al. 2020). Inaccuracies in measuring crop ET and in computing ET_o often result in high K_c values, commonly indicating that the corresponding energy use would largely exceed the energy available at the surface for evaporation (Allen et al. 2011) as referred early.

Methods adopted to select the papers

The review focused on articles published after the FAO56 guidelines (Allen et al. 1998), until March 2023. The search first targeted the articles that quoted FAO56 or that referred crop coefficients. Several search engines were used (e.g., Schooler google, Elsevier, Springer, Wiley, Csiro publishing, Scielo, Scopus) as well as different combination of keywords (crop coefficients, orchards, and names and scientific names of plants). Various languages were used for the search (English, Portuguese, Spanish, French, Italian and German). Because Insufficiencies and inaccuracies referred in the previous sections limit the transferability of reported K_c values, to update the tabulated $K_{c,}$ it was necessary to operate a careful literature selection. Limitations relative to accuracy of data acquisition, the K_c curves or crop conditions obliged a careful review of published material as referred before, to check when the proposed K_c or K_{cb} were limited to local interest and/or represented non-standard experimental conditions, thus contrasting to K_c resulting from near-pristine eustress cropping practices. Thus, studies were selected when:

- Adopted the FAO-PM-ET_o equation (Allen et al. 1998) or the ASCE-ET_o equation (Allen et al. 2005) or other ET_o equations if their ratios to FAO-PM-ET_o could be approximated.
- Presented data referred to two or more experimental seasons, or studies having various treatments, so that it was possible to understand if the results were or not occasional. However, a few cases referring only one season were considered for Neglected and Underutilized Species (NUS) crops.
- Descriptions of experiments are sufficient to consider their accuracy and that crops were at conditions close to non-stress or just eustress.
- Adopted the FAO K_c curve, or a K_c–time curve that allowed to identify K_c or K_{cb} for the mid-season and, preferably, also for the initial and end season.
- Papers describing field studies using BREB or EC systems, which reported upon the upwind fetch conditions and the energy balance closure.

- Studies using SWB methods describing all the terms of the balance, not just focusing the upper soil depth, and providing for an adequate description of sensors used and location, frequency of observations, and the model calibration and validation, were selected.
- Studies using lysimeters were accepted when adequate setting and management were referred, namely avoiding "oasis" and "cloth-line" effects, and correction of the evaporative surface when the tree/vine canopy exceeded the lysimeter surface ("bloom effect").
- Studies using remote sensing were considered when adequate ground observations for model or vegetation index calibration/validation was taken into consideration.
- Studies reporting acceptable K_c values (K_c up to 1.30 and $K_{cb} < K_c$) unless convincing explanations were given.

The assumed criteria made it possible to select a good number of papers, covering numerous species, developed in a variety of countries and regions, and in quite reasonable quality conditions. Users are invited to read the papers relative to the crops of interest and judge by themselves about the adequateness of the reported research.

Selection and tabulation of updated standard K_c and K_{cb} values

Standard values were established considering the ranges of K_c and K_{cb} values collected in the selected literature and the tabulated values since 1998. This work developed in the following steps:

First step: grouping the various studies relative to every crop considering:

(i) The density of plants and spacing (DPS);
(ii) The training and/or trellis systems used (TTS);
(iii) The fraction of ground cover (f_c), or fraction of the intercepted PAR (f_{IPAR}); and
(iv) The crop height (h).

Second step: building a provisional table for every crop. For all the groups of studies/papers, the ranges of $K_c/K_{cb\ ini}$, $K_c/K_{cb\ mid}$ and $K_c/K_{cb\ end}$ were defined and included as columns of K_c/K_{cb} observed values in a provisional table relative to every crop. The ranges of previously tabulated K_c/K_{cb} values in FAO56 (Allen et al. 1998), Allen and Pereira (2009), Jensen and Allen (2016), and Rallo et al. (2021) were also included as columns in that provisional table.

Third step: draft definition of the standard values for $K_c/K_{cb\ ini}$, $K_c/K_{cb\ mid}$ and $K_c/K_{cb\ end}$ for all crops through assessing the various ranges inscribed in each line of the provisional tables relative to sets of DPS, TT, f_c or f_{IPAR}, and h.

Fourth step: Definition of the standard values for $K_{cb\ ini}$, $K_{cb\ mid}$, and $K_{cb\ end}$ for all crops through the computation of the A&P approach (Allen and Pereira 2009; Pereira et al. 2020b) for every set of f_c and h using the parameters M_L, which is a multiplier on f_c describing the effect of canopy density on shading and on maximum relative ET per fraction of ground shaded [1.0–2.0], and F_r, which is is an adjustment factor relative to crop stomatal control [0.0–1.0]. M_L and F_r are available in Pereira et al. (2021c) for most crops, or may be obtained by adjusting the parameter F_r for not previously validated values comparatively with similar crops.

Fifth step: Once defined the K_{cb} values, definition of the standard K_c by summing estimated values of K_e for each stage and the defined standard $K_{cb\ ini}$, $K_{cb\ mid}$ and $K_{cb\ end}$. The estimated values of K_e were obtained from observing the differences (K_c-K_{cb}) in the selected papers and in the previously published Tables quoted above with consideration of changes in K_c due to rain and assuming a reduced soil evaporation due to using drip or micro-sprinkling under the canopies and/or for larger plant density. Young plantations are assigned with larger K_e values. K_e was assumed smaller for the mid-season, particularly for deciduous crops, and was also assumed smaller for the evergreen crops.

Sixth step: consolidating the draft standard K_c and K_{cb} through comparing all values (1) for various plant densities and ground cover fractions of the same crop; (2) for various crops of the same group, for instance within citrus; (3) for various training and trellis systems, e.g., among the multiple cases of grapes; and (4) between K_c and $K_{cb.}$

The Tables presenting the updated standard $K_{cb\ ini}$, $K_{cb\ mid}$, and $K_{cb\ end}$ and standard $K_{c\ ini}$, $K_{c\ mid}$, and $K_{c\ end}$ show their values in the last two columns, while the first ones are those indicating plant density and training or trellis systems, f_c and h as well as the values assumed for M_L and F_r relative to the initial, mid- and end-season stages, which may be useful for further uses of the A&P approach. The ranges of observed and previously tabulated $K_c/K_{cb\ ini}$, $K_c/K_{cb\ mid}$ and $K_c/K_{cb\ end}$ are also included for information to users.

Table and wine grapes

Table and wine grapes are widely grown worldwide, even in less suitable environments, as they are the most popular woody Mediterranean crop. Domesticated after thousands of years, these plants have been cultivated for a long time using specific pruning and training systems that adapt to the climate of the site environment, the soil, the availability of water, the rootstock and the use of fruit (table grapes or wine). Furthermore, these variables also have impact on the timing of full bearing or maturity. Related knowledge is enormous, namely in relation to pruning and training as well as on water and irrigation requirements, including responses to the timing and severity of water deficits. Therefore, it has been possible to collect a variety of articles referring to evapotranspiration and crop water requirements aimed at irrigation scheduling. The collected information from the selected articles refer to the characteristics of the vineyards (Table 1) and to the observed crop coefficients (Table 2).

The former studies for K_c tabulation in FAO56 (Allen et al. 1998) and by Rallo et al. (2021), and reporting for Tables relative to the use of the A&P approach (Allen and Pereira 2009; Pereira et al. 2020a, 2021c) have evidenced that abiotic factors—the fraction of ground cover by the crop vegetation (f_c), which defines the amount of shadowed soil and the fraction ($1-f_c$) from where soil water evaporates, the average crop height (h), the plants spacing or density in terms of plants per unit surface, the crop stress due to water or associate salinity, plant age, and training or trellis system—play a main role in determining crop evapotranspiration and transpiration. This is true, not only for grapes but also to other crops. Biotic impacts from the cultivar and rootstock are also to be considered as both influence the vigor of the crop. In addition, the destination of the grapes determines the dates of harvest and the K_c by the end of the crop season. The determination of the end season K_c results difficult when not appropriately defined, particularly because post-harvest irrigation may occur to provide for producing and store carbohydrates, less dry woody tissues, less incidence of winter injury, and to promote for an even bud break and shoot growth.

Collected values for characterizing the crop (Table 1) include these items, as well as the irrigation method and the irrigation strategy relative to water stress. A few of these factors are referred again in the Table 2, where K_c and K_{cb} are presented, which consist of the three values required to describe the traditional K_c and K_{cb} FAO curves.

Table 1 shows that selected studied vineyards cover a large, worldwide distribution of locations and cultivars for both table and wine grapes. This large coverage contributes to the desired perception of the reviewed case studies, hence providing for higher quality of the review. All reported actual K_c and K_{cb} were derived from field surveys of $ET_{c\ act}$, which used a large panoply of measurement methods with verifiable accuracy. ET_o has been always computed with the FAO-PM-ET_o equation or similar, while $ET_{c\ act}$ has been observed with WL and DL lysimeters, or computed with SWB from soil profiles or DL observations, in some cases using the SIMDualKc model for data handling, BREB and EC measurements of energy balance, or the SR approach and observations to use the A&P approach. In addition, there are various cases relative to obtaining $T_{c\ act}$ from SF measurements.

All vineyards but one were micro-irrigated adopting a full irrigation strategy. Drip was largely the main irrigated method and just two cases used micro-sprinkling. Various types of drippers were used. These conditions prefigure good control of water application depths and low soil evaporation. The sole non-irrigated vineyard is located in the sub-alpine slopes of Alessandria, in Italy, where precipitation is enough to satisfy crop water requirements. It could be assumed that the selected papers report on vineyards that have not been under water stress except for short periods due to deficient irrigation scheduling, thus corresponding to the conditions defined for standard crop coefficients. As per Table 2, most cases refer to bare soil (BS) and only a few to active ground cover (AGC), generally during and immediately after the rainy season, which require a specific solution to identify ET from the crop and from the AGC, and soil evaporation (Rosa et al. 2012a, b).

There is a great variability of spacing and planting densities, that relate with the trellis system used, and a great variety of training and trellis systems, which, generally, are differentiated into the two groups of table grapes and wine grapes. Reported information on pruning was very scarce and, therefore, is not referred herein; however, some studies reported that pruning was performed annually during dormancy, in a few cases also a slight summer pruning, depending upon the vigour of the plants. The diverse training and trellis systems determine crop height and the fraction of ground cover, with f_{IPAR} assumed as an estimate of f_c. Collected data confirms that f_c and h are generally larger for table grapes than for wine grapes. However, there is a very large variability of f_c data for both table and wine vineyards. That variability also relates with age, with young plants (< 5 years) having smaller f_c. But the variability of f_c also refers to crop conditions and age that favor ground shadow, e.g., the cases studied by López-Urrea et al. (2012) and Picón-Toro et al. (2012) that show a correspondence between f_c and $K_{c\ mid}$ or $K_{cb\ mid}$.

The trellis systems for table grapes vineyards are dominantly overhead trellis, "Y" or "T" trellis, cross-arm trellis and high vertical shoot positioning (VSP), thus resulting in $h \geq 2.0$ m. For wine grapes, overhead systems (e.g., pergola) are rare and a variety of trellis systems are used such as VSP, single and double Guyot, single and bilateral cordon, Y-trellis bilateral cordon, Guyot, Lyre trellis, GDC trellis, and QCT (Quadrilateral cordon trained). Detailed descriptions of trellis systems and their relations to cultivars and vineyards mechanization were given by Fidelibus (2014), and an analysis of relationships between trellis systems, shot positioning, and light interception is available in Louarn et al. (2008). Wider analysis referring to trellis systems, canopy architecture, water use, and K_c values is provided by Williams and Fidelibus (2016) and Williams et al. (2022).

Actual K_c and K_{cb} values obtained from field ET observations and the corresponding ET_o values are presented in Table 2 for all reported cultivars and rootstocks together with factors that mainly influenced them: f_c, h, and trellis systems.

Table 1 Characteristics of selected vineyards

Author	Cultivar (rootstock)	Location and main climate	$ET_{c\ act}$ method (ET_o equation)	Irrigation method and strategy	Plants/ha (spacing, m)	Training system	Age (years)	Height (h, m)	f_c or f_{IPAR}
Table grapes (*Vitis vinifera* L.)									
Williams and Ayars (2005)	Thompson Seedless (clone 2A)	Kearney, California, USA Med., warm	WL, Kc f. shadow (CIMIS-PM-ET_o)	Drip & FI	1325 (3.5×2.15)	Cross-arm (0.6 m)	Mature	2.0	0.53
Teixeira et al. (2007)	Superior Seedless (n/r)	Petrolina, Brazil Semiarid	BREB (FAO-PM-ET_o)	Micro-spr. & FI	714 (3.5×4.0)	Overhead horiz. trellis	3–4	1.8	n/r
Netzer et al. (2009)	Superior Seedless (1103 Paulsen)	Southern Israel Semiarid	DL (CIMIS-PM-ET_o)	Drip & FI	1429 (3.5×2.0)	Y-shaped open-gable	2–8	2.0	0.8
Villagra et al. (2011, 2014)	Thompson Seedless (Harmony)	Valparaiso, Chile Med., semiarid	EC (FAO-PM-ET_o)	Drip & n/r	1633 (3.5×1.75)	Overhead trellis	8–9	n/r	0.97
Moratiel and Martínez-Cob (2012)	Red Globe (n/r)	Zaragoza, Spain Med., semiarid	SR, A&P (FAO-PM-ET_o)	Drip & FI	1429 (3.5×2.0)	Y-shaped gable	8–9	2.20	0.90
Er-Raki et al. (2013)	Perlete (n/r)	Costa de Hermosillo, Sonora, Mexico Arid and hot	EC & NDVI (FAO-PM-ET_o)	Drip & FI	2630 (3.8×1.0)	Y-shaped gable	Mature	2.25	0.62
	Superior (n/r)				1460 (3.8×1.8)				0.60
Suvočarev et al. (2013)	Crimson & Autumn Royal (110 Ritcher)	Caspe, Zaragoza, Spain Med., semiarid	SF (FAO-PM-ET_o)	Drip & FI	1143 (3.5×2.5)	Overhead	n/r	n/r	0.85
Vanino et al. (2015)	Italia, Victoria, Red Globe (n/r)	Apulia region, Italy Med, semiarid	RS approach (FAO-PM-ET_o)	Drip & FI	1890 (2.3×2.3)	Overhead “tendone”	n/r	2.0	n/r
Parry et al. (2019)	Thompson Seedless (n/r)	Kearney, CA, USA Med., warm	WL, SR, EC (FAO-PM-ET_o)	Drip & FI	1325 (3.5×2.15)	T trellis	25–26	2.0	0.51
Williams et al. (2022)	Thompson Seedless (n/r)	Kearney (KAREC), Fresno, CA, USA Med., warm	K_c from A&P WL (FAO-PM-ET_o)	Drip & FI	1325 (3.5×2.15)	Single wire at top (2.13 m)	n/r	2.0	0.51
						Cross-arm (0.6 m)	n/r	2.0	0.55
						Cross-arm (1.2 m)	n/r	2.0	0.76
		Napa Valley, CA, USA Med., warm	K_c from A&P (FAO-PM-ET_o)	Drip & FI	2564 (2.1×1.8)	VSP	n/r	2.0	0.44
		Paso Robles, CA, USA Med., warm			1792 (3.1×1.8)	VSP	n/r	2.0	0.27
		Livermore Valley, CA, US Med., warm			2986 (1.8×1.8)	VSP	n/r	2.0	0.52
		Salinas Valley, CA, USA Med., warm			2240 (2.4×1.83	VSP	n/r	2.0	0.36

Table 1 (continued)

Author	Cultivar (rootstock)	Location and main climate	ET$_{c\ act}$ method (ET$_o$ equation)	Irrigation method and strategy	Plants/ha (spacing, m)	Training system	Age (years)	Height (h, m)	f_c or f_{IPAR}
Wine grapes (*Vitis vinifera* L.)									
Teixeira et al. (2007)	Petite Syrah (n/r)	Lagoa Grande, Pernambuco, Brazil Tropical, Semi-arid	BREB (FAO-PM-ET$_o$)	Drip & FI	2381 (3.5×1.2)	Bilateral Cordon	12–13	1.6	n/r
Intrigliolo et al. (2009)	Riesling (101–14)	Geneva, NY, USA Humid	SF (FAO-PM-ET$_o$)	Drip & FI	1738 (2.7×2.1)	VSP	2	n/r	0.3
Campos et al. (2010)	Tempranillo & other (n/r)	Albacete, Spain Med., temp	EC, RS-VI (FAO-PM-ET$_o$	Drip & FI	2222 (3.0×1.5)	VSP	7	n/r	0.30
Carrasco-Benavides et al. (2012)	Merlot (n/r)	Talca Valley, Chile Med., semiarid	EC (FAO-PM-ET$_o$)	Drip & FI	2667 (2.5×1.5)	VSP	8–9	n/r	0.28–0.31
Fandiño et al. (2012)	Albariño (n/r)	Pontevedra, Spain Med. oceanic	SWB-TDR, SIM-DualKc (FAO-PM-ET$_o$)	Drip & FI	2222 (3.0×1.5)	Guyot (VSP)	mature	2.0	0.53
López-Urrea et al. (2012)	Tempranillo (110 Richter)	Albacete, Spain Med., semiarid	WL (FAO-PM-ET$_o$)	Drip & FI	2222 (3.0×1.5)	VSP	8	1.50	0.45
							9		0.33
							10		0.40
Picón-Toro et al. (2012)	Tempranillo (110 Richter)	Badajoz, Spain Med., hot, semiarid	WL (FAO-PM-ET$_o$)	Drip & FI	3333 (2.5×1.2)	Bilateral cordon	5	1.5	0.28
							6		0.48
							7		0.45
							8		0.50
							9		0.60
Poblete-Echeverría and Ortega-Farias (2013)	Merlot (101–14 Mgt)	Talca Valley, Maule, Chile Med., semiarid	SF, EC (FAO-PM-ET$_o$)	Drip & FI	2667 (2.5×1.5)	VSP	8–9	n/r	0.30
Zhao et al. (2015, 2018)	Merlot (n/r)	Shiyanghe, Gansu, China Arid	SWB-grav, EC SF, SW model (FAO-PM-ET$_o$)	Furrow & n/r	3704 (2.7×1.0)	Wire vertical trellis	14–15	n/r	0.30
Montoro et al. (2016)	Tempranillo (110 Richter)	Albacete, Spain Med, semiarid	WL (FAO-PM-ET$_o$)	Drip & FI	2222 (3.0×1.5)	VSP	12	1.50	0.65
							14		0.50
Marras et al. (2016)	Vermentino (n/r)	Sardinia, Italy Med	EC (FAO-PM-ET$_o$)	Drip & FI	5952 (2.1×0.8)	Guyot	15	2.0	0.50
Munitz et al. (2019)	Cabernet Sauvignon (110 Richter)	Central Israel Med, semiarid	DL (FAO-PM-ET$_o$)	Drip & FI	2222 (3.0×1.5)	VSP	5–10	n/r	n/r
Silva et al. (2021)	Loureiro (n/r)	Ponte de Lima, Portugal Med. Atlantic	SWB-FDR, SIM-DualKc (FAO-PM-ET$_o$)	Drip & FI	1666 (3.0×2.0)	Single upward cordon	18–19	2.4	0.40

Table 1 (continued)

Author	Cultivar (rootstock)	Location and main climate	$ET_{c\ act}$ method (ET_o equation)	Irrigation method and strategy	Plants/ha (spacing, m)	Training system	Age (years)	Height (h, m)	f_c or f_{IPAR}
Fandiño (2021)	Albariño (110-Richter)	O Rosal, Pontevedra, Galice, Spain Med. oceanic	SWB-TDR, SIMDualKc (FAO-PM-ET_o)	Drip & FI	1667 (3×2)	Lyra vertical	10–12	2.1	0.25
Darouich et al. (2022b)	Barbera (n/r)	Alessandria, Italy Med. Sub-alpine	SWB-FDR, SIMDualKc (FAO-PM-ET_o)	Rainfed & n/r	3636 (2.75×1.0)	VSP	28–31	1.85	0.37
								1.78	0.28
	Touriga Nacional & other (n/r)	Samora Correia, Portugal Med., sub-humid		Drip & DI summer	3571 (2.8×1.0)	VSP	10–12	1.70	0.36
Williams et al. (2022)	Cabernet Sauvignon (110R)	Napa Valley, CA, USA Med, warm	K_c from A&P (FAO-PM-ET_o)	Drip & FI	2401 (2.74×1.52)	Lyre trellis	n/r	2.0	0.57
						VSP trellis	n/r		0.32
						VSP trellis	n/r		0.52
	Cabernet Sauvignon (5C)	Napa Valley, CA, USA Med, warm		Drip & FI	2155 (3.05×1.52)	Lyre trellis	n/r	2.0	0.49
						GDC trellis	n/r		0.61
						‘Y’ trellis	n/r		0.68
	Cabernet Sauvignon (n/r)	Dunningan Hills (Phillips), Yolo, CA Med, warm		Drip & FI	1493 (3.66×1.83)	Lyre trellis	n/r	2.0	0.40
	Sauvignon blanc (n/r)					QCT (sprawl canopy)	n/r	2.0	0.51
	Chardonnay (n/r)	Kearney (KAREC), Fresno, CA Med, warm	K_c from A&PWL (FAO-PM-ET_o)	Drip & FI	1493 (3.66×1.83)	GDC	n/r	2.0	0.44
	Chardonnay (n/r)					Lyre trellis	n/r		0.41
	Syrah (n/r)					QCT	n/r		0.51
	Syrah (n/r)				1631 (3.35×1.83)	Bilateral cordon	n/r		0.46
	Cabernet Sauvignon (n/r)	Edna Valley, San Luis Obispo, CA, USA Oceanic warm	K_c from A&P (FAO-PM-ET_o)	Drip & FI	1792 (3.05×1.83)	VSP	n/r	2.0	0.32
						QCT	n/r	2.0	0.53
	Chardonnay (n/r)	Temecula Valey, CA Med warm	K_c from A&P (FAO-PM-ET_o)	Drip & FI	1493 (3.66x 0.83)	QCT	n/r	2.0	0.51
	Syrah (n/r)	Fresno, CA Med warm	K_c from A&P (FAO-PM-ET_o)	Drip & FI	1631 (3.35×1.83)	Bilateral cordon	n/r	2.0	0.48
Morgani et al. (2022)	Malbec	Mendoza, Argentina Med warm	K_c from shadow (FAO-PM-ET_o)	Drip & FI	2,666 (2.5×1.5)	VSP	6–7	n/r	n/r
Rojo et al. (2023)	Cabernet Sauvignon (110R)	Pencahue, Maule Central Valley, Chile Med warm	EC combined w/ SR (REB) (ASCE-PM-ET_o)	Drip, FI in wet year	4348 (2.5×1.0)	VSP	8	2.0	0.47
	Cabernet Sauvignon (1103P)				2,666 (2.5×1.5)	High-wire cordon, HWC	8	2.3	0.64

Table 1 (continued)

Author	Cultivar (rootstock)	Location and main climate	$ET_{c\ act}$ method (ET_o equation)	Irrigation method and strategy	Plants/ha (spacing, m)	Training system	Age (years)	Height (h, m)	f_c or f_{IPAR}
Juice grapes (Vitis labrusca L.)									
Conceição et al. (2017a)	BRS Carmem &Isabel Precoce (IAC 572 and 766)	Votuporanga, São Paulo, Brazil Tropical humid	K_c from A&P (FAO-PM-ET_o)	Micro-spr. & n/r	4545 (2 × 1.1)	VSP	3	2.0	0.30

Abbreviations and symbols are defined in list of symbols heading

Tabulated observed $K_{c\ mid}$ and $K_{cb\ mid}$ show to vary greatly among cultivars and for the same cultivar, as well as with the trellis system. Finding the most appropriate standard K_c and K_{cb} values would be nearly impossible without following the conclusions of Williams et al. (2022) that the prime factor influencing K_c values is training and trellis system disregarding if vineyards are of table or wine grapes. It resulted then a good organization of study results and the Table 3 was then built, first a draft working approach as referred in Section"Selection and tabulation of updated standard K_c and K_{cb} values", then simplified as shown herein. Plant density will vary within a given training system and, therefore, their ranges of values in Table 3 shall be considered as indicative to users.

Table 3 shows initial, mid-, and end-season K_c and K_{cb} of table and wine grapes grouped according to the degree of ground cover (DGC), training and trellis system (TTS), and plant density and spacing (PDS). DGC varies from very low when plants are young (< 5 years), to high in case of overhead trellis in table grapes, or to very high in case of well covering Y-trellis, the Geneva Double Curtain double wire system, and the overhead trellis system. The diverse degree of ground cover corresponds to diverse TTS, which are influenced by the pruning intensity, and to various plant density and spacing. The described groups are also characterized by ranges of the fraction of ground cover and height, f_c and h, which may help to decide which group is more appropriate for the case under study. Moreover, f_c and h may be utilized to compute K_{cb} for the three stages with the A&P approach (Allen and Pereira 2009; Pereira et al. 2020a) with help of the proposed parameters M_L and F_r, also tabulated.

The proposed standard K_{cb} and K_c are given in the last two columns of the Table 3. The ranges of K_{cb} and K_c obtained from field measurements and proposed in the selected papers and the ranges reported in previous Tables, namely FAO56, are also tabled as they were used for selecting the values of the proposed standard coefficients. Readers are advised to interpolate the proposed K_{cb} and K_c using the data they have available.

It is evidenced by Table 3 that standard K_{cb} and K_c for vineyards mainly increase with ground cover and plant density, thus depending upon training and trellis systems as they favor or not ground shading, thus the light intercepted by the canopy. Soil evaporation, contrarily, is governed by the TTS that provide for larger or limited solar radiation at the soil surface, thus for larger or reduced energy for soil water evaporation.

Table 2 Field derived crop coefficients of table grapes and wine grapes vineyards

Author	Cultivar (rootstock)	Training system	f_c or f_{IPAR}	Height (m)	Ground cover	Age (years)	K_c /K_{cb} derived from field observations					
							$K_{c\ ini}$	$K_{c\ mid}$	$K_{c\ end}$	$K_{cb\ ini}$	$K_{cb\ mid}$	$K_{cb\ end}$
Table grapes (*Vitis vinifera*)												
Williams and Ayars (2005)	Thompson Seedless (clone 2A)	Cross-arm 0.6 m	0.53	2	n/r	Mature	0.15	1.00	n/r	n/r	n/r	n/r
Teixeira et al. (2007)	Superior Seedless (n/r)	Overhead horiz. Trellis	n/r	1.8	AGC	3–4	0.70	0.95	0.75	0.50	0.80	0.65
Netzer et al. (2009)	Superior Seedless (1103 Paulsen)	Y-shaped	0.80	2.0	n/r	2–8	0.30	1.20	n/r	n/r	n/r	n/r
Villagra et al. (2011, 2014)	Thompson Seedless (Harmony)	Overhead trellis	0.97	n/r	n/r	8–9	0.20	1.10	0.80	n/r	n/r	n/r
Moratiel and Martínez-Cob (2012)	Italia, Victoria, RedGlobe (n/r)	Overhead system	n/r	2.0	BS	n/r	0.40	1.00	n/r	n/r	n/r	n/r
Er-Raki et al. (2013)	Perlete (n/r)	Y-shaped gable	0.62	2.25	BS	Mature	0.20	0.55	0.25	n/r	n/r	n/r
	Superior (n/r)	Y-shaped gable	0.60	2.25	BS		0.10	0.60	0.30	n/r	n/r	n/r
Suvočarev et al. (2013)	Red Globe (n/r)	Y-shaped gable	0.90	2.2	netting BPM	8–9	n/r	0.79	0.98	0.10	1.05	0.80
										0.10	0.65	0.50
Vanino et al. (2015)	Crimson & Autumn Royal seedless (110 Ritcher)	Overhead system	0.85	n/r	BS	n/r	n/r	n/r	n/r	n/r	0.65	n/r
Parry et al. (2019)	Thompson Seedless (n/r)	T trellis	0.51	2.0	BS	25–26	n/r	0.86	n/r	n/r	n/r	n/r
Williams et al. (2022)	Thompson Seedless (n/r)	Single wire top	0.51	2.0	BS	n/r	n/r	0.87	n/r	n/r	0.82	n/r
		Cross-arm 0.6 m	0.55					0.93			0.88	
		Cross-arm 1.2 m	0.76					1.30			1.11	
		VSP	0.44	2.0	BS	n/r	n/r	0.74	n/r	n/r	0.69	n/r
		VSP	0.27	2.0	BS	n/r	n/r	0.46	n/r	n/r	0.41	n/r
		VSP	0.52	2.0	BS	n/r	n/r	0.87	n/r	n/r	0.82	n/r
		VSP	0.36	2.0	BS	n/r	n/r	0.61	n/r	n/r	0.56	n/r
Wine grapes (a)												
T eixeira et al. (2007)	Petite Syrah (n/r)	Vertically BC	n/r	1.6	BS	12–13	0.65	0.80	0.65	0.55	0.70	0.60
Intrigliolo et al. (2009)	Riesling (101–14)	VSP	0.30	n/r	BS	2	n/r	0.55	n/r	n/r	0.50	n/r
Campos et al. (2010)	Tempranillo & other (n/r)	VSP	0.30	n/r	BS	7	0.30	0.50	n/r	0.15	0.45	n/r
Carrasco-Benavides et al. (2012)	Merlot (n/r)	VSP	0.28–0.31	n/r	BS	8–9	0.41	0.55	n/r	n/r	n/r	n/r
Fandiño et al. (2012)	Albariño (n/r)	Guyot (VSP)	0.53	2.0	AGC	mature	n/r	n/r	n/r	0.09	0.60	0.46
										0.60	0.98	0.91
López-Urrea et al. (2012)	Tempranillo (110 Richter)	VSP	0.45	1.50	BS	8	0.37	0.75	n/r	0.22	0.69	n/r
			0.33			9	0.35	0.51		0.18	0.46	
			0.40			10	0.32	0.72		0.22	0.67	

Table 2 (continued)

Author	Cultivar (rootstock)	Training system	f_c or f_{IPAR}	Height (m)	Ground cover	Age (years)	K_c /K_{cb} derived from field observations					
							$K_{c\ ini}$	$K_{c\ mid}$	$K_{c\ end}$	$K_{cb\ ini}$	$K_{cb\ mid}$	$K_{cb\ end}$
Picón-Toro et al. (2012)	Tempranillo (110 Richter)	BC	0.28	1.5	BS	5	0.20	0.95	0.35	0.15	0.60	n/r
			0.48			6	0.20	0.90	0.20	0.15	0.85	n/r
			0.45			7	0.20	1.20	0.20	0.15	0.90	n/r
			0.50			8	0.15	1.00	0.20	0.10	0.95	n/r
			0.60			9	0.30	1.10	0.20	0.15	1.05	n/r
Poblete-Echeverría and Ortega-Farias (2013)	Merlot (101–14 Mgt)	VSP	0.30	n/r	n/r	8–9	0.37	0.62	0.56	0.24	0.53	0.43
Zhao et al. (2015, 2018)	Merlot (n/r)	Wire vertical trellis	0.30	n/r	n/r	14–15	n/r	n/r	n/r	0.15	0.53	*0.10
Montoro et al. (2016)	Tempranillo (110 Richter)	VSP	0.65	1.50	BS	12–14	n/r	n/r	n/r	n/r	1.00	n/r
			0.50								0.75	
Marras et al. (2016)	Vermentino (n/r)	Guyot	0.50	2.0	n/r	15	n/r	0.80	0.50	n/r	n/r	n/r
Munitz et al. (2019)	Cabernet Sauvignon (110 Richter)	VSP	n/r	n/r	n/r	5–10	0.20	0.75	0.30	0.16	0.62	0.25
Silva et al. (2021)	Loureiro (n/r)	Single upward cordon	0.40	2.4	AGC	18–19	n/r	0.61	0.57	0.27	0.42	0.41
Fandiño (2021)	Albariño (110-Richter)	Lyra vertical	0.25	2.1	AGC	10–12	1.17	0.74	0.58	0.33	0.64	0.48
Darouich et al. (2022b)	Barbera (n/r)	VSP	0.37	1.85	Tilled	28–31		n/r	n/r	0.20	0.47	0.34
			0.28	1.78	Mowed AGC					0.35	0.47	0.40
	Touriga & other (n/r)	VSP	0.36	1.70	AGC, spring	10–12	n/r	n/r	n/r	0.17	0.47	0.39
Williams et al. (2022)	Cabernet Sauvignon (110R)	Lyre	0.57	2	BS	n/r	n/r	0.96	n/r	n/r	0.91	n/r
		VSP	0.32					0.54			0.49	
		VSP	0.52					0.89			0.84	
	Cabernet Sauvignon (5C)	Lyre	0.49	2	BS	n/r	n/r	0.83	n/r	n/r	0.78	n/r
		GDC	0.61					1.03			0.98	
		‘Y’ trellis	0.68					1.16			1.11	
	Cabernet Sauvignon (n/r)	Lyre	0.40	2	BS	n/r	n/r	0.68	n/r	n/r	0.63	n/r
	Sauvignon blanc (n/r)	QCT	0.51	2	BS	n/r	n/r	0.87	n/r	n/r	0.82	n/r
	Chardonnay (n/r)	GDC	0.44	2	BS	n/r	n/r	0.74	n/r	n/r	0.69	n/r
		Lyre trellis	0.41					0.71			0.66	
	Syrah (n/r)	BC	0.46	2	BS	n/r	n/r	0.78	n/r	n/r	0.73	n/r
		QCT	0.51					0.86			0.81	
	Cabernet Sauvignon (n/r)	VSP	0.32	2	BS	n/r	n/r	0.54	n/r	n/r	0.49	n/r
		QCT	0.53					0.90			0.85	
	Chardonnay (n/r)	QCT	0.51	2	BS	n/r	n/r	0.86	n/r	n/r	0.81	n/r
	Syrah (n/r)	BC	0.48	2	BS	n/r	n/r	0.80	n/r	n/r	0.75	n/r

Table 2 (continued)

Author	Cultivar (rootstock)	Training system	f_c or f_{IPAR}	Height (m)	Ground cover	Age (years)	K_c /K_{cb} derived from field observations					
							$K_{c\ ini}$	$K_{c\ mid}$	$K_{c\ end}$	$K_{cb\ ini}$	$K_{cb\ mid}$	$K_{cb\ end}$
Morgani et al. (2022)	Malbec (own rooted)	VSP	n/r	n/r	n/r	n/r	0.10	0.72	n/r	n/r	n/r	n/r
Rojo et al. (2023)	Cabernet Sauvignon (110R)	VSP	0.47	2	BS	8	0.30	0.50	0.35	n/r	n/r	n/r
	Cabernet Sauvignon (1103P)	HWC	0.64	2.3	BS	8	0.30	0.65	0.45	n/r	n/r	n/r
Juice grapes (Vitis labrusca L.)												
Conceição et al. (2017a)	BRS Carmem	VSP	0.30	2.0	AGC and netting	3	0.60	0.74	n/r	n/r	n/r	n/r
	Isabel Precoce (IAC 572 and 766)						0.63	0.81				

Abbreviations and symbols are defined in list of symbols heading

Olive orchards

Olive trees are, after centuries, main references of the Mediterranean landscapes, either isolated or in small groups, or in orchards. Due to their physiological characteristics, olives are resistant to dryness and droughts and other abiotic stresses (Fernández 2014) but then decreasing growth and yield. Climate change is affecting olives water requirements and, then, the landscape (Tanasijevic et al. 2014). Traditional orchards are rainfed, have wide tree spacing, and are vase-trained. They continue to be used but are declining and being replaced by irrigated orchards with increasing plant density, such as the modern super high density hedgerow system. Plant density increased from 225–250 trees ha^{-1} to almost 2000 trees ha^{-1}. Unlike vineyards, f_c and h show a relatively little variability, however with exceptions.

The selected orchards (Table 4) are mainly located in the Mediterranean region, with only one from a Chilean location with Mediterranean climate, the Talca Valley. Cultivars are often changing from traditional ones (e.g., 'Picual', 'Cobrançosa') to cultivars adapted to high density systems like 'Arbequina'. Training systems and plant density affect tree maturity, with intensive orchards trained in vase, reaching full bearing by 7–8 years, while high-density systems, trained as hedges, reach full bearing 4–5 years after planting. In these latter systems, the mechanical harvesters limit plant height and therefore pruning is mandatory at least once a year.

All reported ET_o computations refer to the FAO-PM-ET_o. Field ET studies were performed mostly using EC systems and SWB with various sensors and the model SIMDualKc; SF systems were used for measuring transpiration. Drip irrigation was used in most cases but always adopting controlled or regulated deficit irrigation (Table 4). The eustress concept used for vineyards does not apply to olives due to their resistance and resilience to droughts and water stress, which calls to adopt limited water use and costs by currently adopting deficit irrigation, mainly during the pit hardening stage.

The crop coefficients show some variability, both K_c and K_{cb} (Table 5). The K_c curves present a mid-season value lower than the $K_{c\ ini}$ and $K_{c\ end}$ which is the consequence of the Mediterranean rainfall regime, with rain by the initial stage, by the early spring, and by the final stage, at mid-autumn, with a dry summer mid-season. The K_{cb} curves are different because transpiration is much higher in mid-summer under irrigation than during the initial and end stages. The Med climate does not change much inter-annually, but global change is making the dry summer season longer. Without irrigation both K_c and K_{cb} curves tend to flat down due to impacts of water stress. Soil evaporation is important during the non-growing period, mostly the winter, when precipitation occurs; it is negligible during the mid-season

Table 3 Initial, mid-, and end-season standard single and basal crop coefficients for vineyards as related with the training trellis system, fraction of ground cover and height for table and wine grapes with indication of ranges of observed K_c and K_{cb}, and of former tabulations of their standard values

Degree of ground cover, training, and plant density	f_c	h	Crop stage	M_L	F_r	Ranges of observed values		Ranges of previously tabulated values		Proposed values	
						K_{cb}	K_c	K_{cb}	K_c	K_{cb}	K_c
Table grapes (*Vitis vinifera*)											
Low (Young, < 5 years), diverse trellis and trainings	< 0.40	< 1.5	Ini	1.1	1.00	0.50	0.70	0.20	0.30	0.20	0.35
			Mid	1.3	1.00	0.80	0.95	0.55–0.60	0.60–0.65	0.55	0.65
			End	1.3	1.00	0.65	0.75	0.45–0.50	0.50–0.60	0.45	0.55
Medium (T-trellis, Y-trellis, and VSP) (1200–1700 pl/ha)	0.40–0.60	1.5–2.2	Ini	1.5	0.90	–	–	0.15	0.30	0.25	0.35
			Mid	1.5	0.95	0.82–0.88	0.86–0.93	0.75–0.90	0.85–0.95	0.85	0.95
			End	1.5	0.70	–	–	0.40–0.70	0.45–0.75	0.60	0.70
High (Y-trellis and overhead system) (1200–1700 pl/ha)	0.60–0.95	2.0–2.5	Ini	1.5	0.90	0.10–0.50	0.20–0.70	0.20	0.30	0.35	0.45
			Mid	1.5	0.95	0.65–1.11	0.79–1.30	0.65–1.05	0.70–1.10	1.05	1.10
			End	1.5	0.70	0.50–0.80	0.75–0.98	0.50–0.80	0.55–0.85	0.75	0.80
Wine grapes (*Vitis vinifera*)											
Very low (Young < 5 years, diverse trellis, and trainings), 2000–3300pl/ha	< 0.15	< 1.5	Ini	1.1	1.00	–	0.60–0.63	–	–	0.10	0.30
			Mid	1.1	1.00	0.50	0.55–0.81	–	–	0.20	0.35
			End	1.1	1.00	–	–	–	–	0.15	0.30
Low (diverse trellis and trainings), 2000–3300 pl/ha	0.15–0.35	1.5–2.0	Ini	1.5	0.95	0.03–0.35	0.20–0.63	0.25	0.30	0.20	0.35
			Mid	1.5	0.90	0.41–0.60	0.46–0.95	0.40–0.45	0.45–0.50	0.45	0.60
			End	1.5	0.70	0.05–0.43	0.35–0.56	0.30–0.35	0.40–0.45	0.25	0.40
Medium (VSP, single & double Guyot, single & bilateral cordon, GDC, Lyre, Y-trellis) 2000–3300 pl/ha	0.35–0.50	1.5–2.0	Ini	1.5	0.85	0.10–0.27	0.15–0.37	0.15–0.20	0.30–	0.25	0.40
			Mid	1.5	0.90	0.42–0.95	0.50–1.20	0.45–0.70	0.50–0.75	0.70	0.80
			End	1.5	0.75	0.34–0.41	0.20–0.57	0.35–0.50	0.40–0.55	0.45	0.55
High (VSP, GDC, Lyre, Y-trellis, T-trellis, Pergola, QCT) 2000–4300 pl/ha	0.50–0.65	1.5–2.5	Ini	1.5	0.90	0.09–0.55	0.20–0.65	–	–	0.30	0.40
			Mid	1.5	0.90	0.60–1.05	0.65–1.10	0.45–0.65	0.50–0.70	0.85	0.95
			End	1.5	0.70	0.25–0.91	0.20–0.65	0.35–0.50	0.40–0.55	0.55	0.65
Very high (Y-trellis, GDC, and overhead system) 2000–4300 pl/ha	> 0.60	1.8–2.5	Ini	1.7	0.95	–	–	0.20	0.30	0.35	0.45
			Mid	1.5	0.90	0.98–1.11	1.03–1.16	0.70	0.75	0.95	1.05
			End	1.5	0.60	–	–	0.55	0.60	0.60	0.70

Abbreviations and symbols are defined in list of symbols heading

Table 4 Characteristics of the selected olive orchards (*Olea europea* L.)

Author	System cultivar		Location and main climate	$ET_{c\ act}$ method (ET_o equation)	Irrigation method and strategy	Trees/ha (Spacing, m)	Training system	Age (years)	Height (m)	f_c or f_{IPAR}
Villalobos et al. (2000)	Traditional Picual		Cordoba, Spain Med. arid	EC and PM eq (FAO-PM-ET_o)	Drip and FI	278 (6×6)	n/r	mature	4.0	A: 0.4 B: 0.3
Cammalleri et al. (2013b)	Traditional Nocellare del Belice		Castelvetrano, Sicily, Italy Med	EC, SF, Scintil (FAO-PM-ET_o)	Drip and DI	250 (8×5)	n/r	mature	3.7	0.35
Fernández et al. (2006)	Traditional Manzanilla de Seville		Seville, Spain Med	SF, SWB (FAO-PM-ET_o)	Drip and RDI SDI, PRD	286 (7×5)	Spheric open top	35	n/r	0.34
Er-Raki et al. (2010)	Traditional n/r		Marrakech, Morocco Med. dry	EC, SWB, (FAO-PM-ET_o)	Basin and RDI	225 (n/r)	n/r	240	6.0	0.60
Torres-Ruiz et al. (2012)	Traditional Manzanilla de Seville		Seville, Spain Med	SWB, Orgaz software (FAO-PM-ET_o)	Drip and n/r	286 (7×5)	Vase	> 40	n/r	0.34
Villalobos et al. 2013	Traditional Arbequina		Cordoba Med	SF (FAO-PM-ET_o)	Drip and FI	408 (7×3.5)	Free form	11	3.5	0.49
Conceição et al. (2017b)	Traditional Arbequina		Ferreira do Alentejo, Portugal Med	SWB-neutron, SF, A&P, DI (FAO-PM-ET_o)	Drip and DI	300 (7×4.8)	Vase	mature	3.2–3.5	0.22
Puig-Sirera et al. (2021)	Traditional Nocellare del Belice		Castelvetrano, Sicily, Italy Med	SF, SIMDualKc (FAO-PM)	Drip and DI	250 (8×5)	Vase	10	3.5	0.35
Siakou et al. (2021)	Traditional	Koroneiki	Nicosia, Cyprus Med	SWB, Dielect (FAO-PM-ET_o)	Spaghetti drip and DI	278 (6×6)	Vase	17	2.5	0.38
Ramos et al. (2023)	Traditional	Arbequina	Aljustrel, Portugal Med	SWB-TDR SIMDualKc (FAO-PM-ET_o)	Drip and DI	319 (n/r)	Vase	11–12	4.1	0.26
	Traditional	Cobrançosa				297 (n/r)		12–13	3.0	0.23
	Traditional	Picual				297(n/r)		11–12	3.9	0.27
Testi et al. (2004)	Intensive, young Arbequina		Cordoba, Spain Med. dry	EC (FAO-PM-ET_o)	Drip and DI	408 (7×3.5)	n/r	1–3	1.4–2.9	0.05–0.25
Martínez-Cob and Faci (2010)	Intensive Arbequina		Zaragoza, Spain Med	EC, SWB (FAO-PM-ET_o)	Drip and DI	556 (6×3)	Hedgeprune	7	3.5	0.33
López-Olivari et al. (2016)	Superintensive Arbequina		Talca Valley, Maule, Chile Med	SWB-TDR, SF, EC (FAO-PM-ET_o)	Drip and RDI	1333 (5×1.5)	n/r	6	3.2	0.29–0.31
Paço et al. (2014)	Super high-density Arbequina		Viana do Alentejo, Portugal Med	METRIC, EC, SF, SIMDualKc (FAO-PM-ET_o)	Drip and RDI	1975 (3.75×1.35)	Hedgerow	4–6	3.5	0.35
Paço et al. (2019)	Super high-density Arbequina		Viana do Alentejo, Portugal Med	SWB-TDR, EC, SF, SIMDualKc (FAO-PM-ET_o)	Drip and RDI	1975 (3.75×1.35)	Hedgerow	5–7	3–4	0.38

Abbreviations and symbols are defined in list of symbols heading

if rain is very low and irrigation is under canopy as for drip and micro-sprinkling; intermediate conditions occur by the initial and final periods depending upon the distribution of rainfall. AGC and mulch are rarely practiced but natural AGC occurs during spring, with AGC converting into residual mulch during the summer.

The proposed standard K_{cb} values in Table 6 were defined in agreement with the observed ranges, often slightly larger than these. But the K_c values are smaller than the observed ranges and the ranges previously tabulated because when irrigation is under the canopies and practiced with good quality equipment and efficiently there are no reasons for high soil evaporation or operational losses. This is particularly true in the hedgerow olive orchards since differences between ranges observed for K_{cb} and K_c are high, likely indicating non negligible soil evaporation losses. As for vineyards, the plant densities referred in Table 6 are guidelines for users.

Citrus orchards

Various tree species are included among the citrus trees: clementine, grapefruit, lemon, lime, mandarin, and orange. Studies relative to orange are by far the most common, followed by clementine and mandarin. Studies were carried mostly in the Mediterranean region but those for lime (*Citrus latifolia* Tan.) were developed in Brazil, where this crop is very popular; those for orange, following its wide dissemination, in addition to the Med basin, come from North and South America, South Africa and Iran (Table 7). This wide origin of the selected studies proposes various perspectives that favor the analysis aimed at finding the appropriate standard K_c and K_{cb} for all the crops. Moreover, cultivars referred for each crop are also diverse.

As for the grapes and olives, the appropriateness and accuracy of computation of ET_o and crop evapotranspiration were analyzed (Table 7). In most cases, the FAO-PM ET_o was adopted with only 2 cases of using the Penman equation and the class A pan were observed. A diverse panoply of field ET measurement was reported. The most common approach was SWB based on diverse soil water sensors, followed by the sap-flow measurement of transpiration and the EC measurement of ET, often combined. Weighing lysimeters and the surface renewal method were also used. Drip and micro-sprinkler irrigating under canopy were generally adopted. Full irrigation, sometimes in excess, was the main strategy. Information reported in literature was however insufficient to understand if, likely, eustress was considered. In general, it could be considered that conditions existed to favor water saving and high yields.

A variety of plant densities and spacing are reported but it was not possible to relate them to training, with many papers not reporting about training. The most common is vase but some hedgerow, yet with relatively low plant spacing, were also referred. Generally, plant heights varied from about 2.5 to 4.0 m but much larger and uncommon heights near 6 m were reported for orange in Florida. Tree height was lower for mandarin (<2.8 m) and clementine (<4.1 m). The fraction f_c followed a similar trend, smaller for mandarin, lime, lemon and clementine, largest for orange (up to 0.90). Differences in architecture and sizes, as well as physiological but not referred herein, justify that K_c and K_{cb} were not given in a single group of citrus.

Generally, results in Table 8 show well the dependence of $K_{c\ mid}$ and $K_{cb\ mid}$ on crop age, height, and f_c as it is the case of studies by Castel (2000) for clementines, Alves et al. (2007) for lime trees, Maestre-Valero et al. (2017) for mandarin, and Consoli et al. (2006) for orange. Since citrus are evergreen trees, they also show a K_c curve where higher values are for $K_{c\ ini}$ and $K_{c\ end}$ for climates like Mediterranean, with very small precipitation in summer and the rainfall season initiating by the fall and ending by the spring. In other climates, this may not happen. Because citrus are evergreen and for some species or cultivars show differences in crop stages, some growers and advisers adopt a constant K_c, which lead to flat down the period between spring and winter, i.e., when irrigation is required. Several citrus studies report K_c/K_{cb} values on a monthly time scale, so the growth stages of the plants were defined according to the tree's annual cycle (3 vegetative growth peaks corresponding to spring, summer and autumn). Therefore, the initial stage corresponds to flower initiation (December–January in the Northern Hemisphere, June–July in the Southern Hemisphere), the mid-season stage is a very long period corresponding to fruit growth extending from March to November (Northern Hemisphere) or from September to May (Southern Hemisphere). The end-season occurs after maturation and harvesting, i.e., in November (Northern Hemisphere) or May (Southern Hemisphere). However, these stages depend on the species and cultivar. It is, therefore, advisable to define well the initial, crop development, flowering and fruiting mid-season, and maturation and harvesting. Then the K_c and K_{cb} curves are expected to be as referred above, however distinct among species and, less, cultivars (Table 8).

The definition of the standard K_c and K_{cb} (Table 9) followed the same methodology used and shown for grapes and olives. Initially, all citrus trees were considered together but, due to differences among the various species, three groups were considered. Thus, clementine, lime and mandarin trees consist of the first group of species, which is characterized by the smaller tree height, fraction of ground cover and K_c/

Table 5 Field derived crop coefficients of olive orchards (*Olea europea* L.)

Author	System and cultivar	Training system	f_c or f_{IPAR}	Height (m)	Ground cover	Age (years)	K_c/K_{cb} derived from field observations					
							$K_{c\ ini}$	$K_{c\ mid}$	$K_{c\ end}$	$K_{cb\ ini}$	$K_{cb\ mid}$	$K_{cb\ end}$
Villalobos et al. (2000)	Traditional Picual	n/r	0.40	4.0	BS w/AGC in spring	Mature	0.95	0.60	0.95	0.25	0.45	0.25
			0.30				0.90	0.55	0.90	0.20	0.35	0.20
Cammalleri et al. (2013a, b)	Traditional Nocellare del Belice	n/r	0.35	3.7	AGC	Mature	0.40	0.35	0.50	n/r	0.30	0.35
Fernández et al. (2006)	Traditional Manzanilla de Seville	Vase	0.35	n/r	BS	35	0.76	0.63	0.77	n/r	n/r	n/r
Er-Raki et al. (2010)	Traditional n/r	n/r	0.60	6.0	BS = 75% AGC = 25%	240	0.65	0.45	0.65	n/r	n/r	n/r
Torres-Ruiz et al. (2012)	Traditional Manzanilla de Seville	Vase	0.34		BS	> 40	0.76	0.63	0.77	n/r	n/r	n/r
Villalobos et al. 2013	Traditional Arbequina	Free form	0.49	3.5	n/r	11	n/r	n/r	n/r	0.35	0.35	0.45
Conceição et al. (2017b)	Traditional Arbequina	Vase	0.22	3.2–3.5	BS and AGC	Mature	n/r	n/r	n/r	0.22	0.52	0.10
Puig-Sirera et al. (2021)	Traditional Nocellare del Belice	Vase	0.35	3.5	n/r	10	0.92	0.55	0.96	0.30	0.42	0.37
Siakou et al. (2021)	Traditional Koroneiki	Vase	0.38	2.5	n/r	17	0.70	0.37	0.84	n/r	n/r	n/r
Ramos et al. (2023)	Trad., Arbequina	Vase	0.26	4.1	BS w/AGC in spring	11–12	0.95	0.44	0.93	0.32	0.35	0.33
	Trad., Cobrançosa		0.23	3.0		12–13	0.91	0.44	0.93	0.32	0.35	0.33
	Trad., Picual		0.27	3.9		11–12	0.89	0.44	0.87	0.33	0.36	0.34
Testi et al. (2004)	Intensive, young Arbequina	n/r	0.05	1.4	BS	1	0.20	0.20	0.35	n/r	n/r	n/r
			0.13	2.0		2	0.30	0.30	0.40			
			0.25	2.9		3	0.40	0.40	n/r			
Martínez-Cob and Faci (2010)	Intensive Arbequina	Hedge-prune	0.33	3.5	BS	7	0.65	0.48	0.90	n/r	n/r	n/r
López-Olivari et al. (2016)	Superintensive Arbequina	Triangular hedgerow	0.29	3.2	n/r	Mature	n/r	0.50	n/r	n/r	0.31	n/r
			0.31	3.2				0.48			0.32	
Paço et al. (2014)	Super-high-density Arbequina	Hedgerow	0.35	3.5	BS w/AGC in spring	4–6	0.82	0.60	0.95	0.36	0.41	0.34
Paço et al. (2019)	Super-high-density Arbequina	Hedgerow	0.38	3–4	BS w/AGC in spring	5–7	0.87	0.71	0.84	0.30	0.48	0.30

Abbreviations and symbols are defined in list of symbols heading

Table 6 Initial, mid, and end-season standard single and basal crop coefficients for olive orchards as related with the training trellis system, fraction of ground cover and height for table and wine grapes with indication of ranges of observed K_c and K_{cb}, and of former tabulations of their standard values

Degree of ground cover, training and plant density	f_c	h	Crop stages	M_L	F_r	Ranges of observed values		Ranges of previously tabulated values		Proposed values	
						K_{cb}	K_c	K_{cb}	K_c	K_{cb}	K_c
Young (< 7 years traditional, < 4 years intensive)	0.15–0.30	1.5–2.0	Ini	1.0	1.00	0.20	0.20–0.90	0.20–0.30	0.30–0.40	0.20	0.40
			Mid	1.0	1.00	0.35	0.20–0.55	0.20–0.35	0.25–0.40	0.30	0.35
			End	1.0	1.00	0.20	0.35–0.90	0.15–0.30	0.25–0.60	0.20	0.40
Traditional, low, non-irrigated, vase (100–200 pl/ha)	0.15–0.30	2.5–3.5	Ini	1.5	0.60	–	–	–	–	0.25	0.45
			Mid	1.7	0.60	–	–	–	–	0.30	0.45
			End	1.5	0.60	–	–	–	–	0.30	0.45
Traditional, non-irrigated, medium (200–300 pl/ha)	0.20–0.40	3.0–4.5	Ini	1.5	0.60	–	–	–	–	0.30	0.50
			Mid	1.5	0.60	–	–	–	–	0.35	0.50
			End	1.5	0.60	–	–	–	–	0.35	0.50
Intensive, hedge prune (300–800 pl/ha)	0.30–0.40	3.0–3.5	Ini	1.5	0.60	0.22–0.30	0.40–0.95	0.50–0.55	0.60–0.65	0.40	0.50
			Mid	1.7	0.65	0.30–0.52	0.35–0.63	0.40–0.65	0.45–0.70	0.50	0.60
			End	1.7	0.60	0.10–0.37	0.50–0.95	0.35–0.65	0.55–0.75	0.45	0.60
Super-Intensive, low-density, hedgerow (800–1500 pl/ha)	0.35–0.45	3.0–3.5	Ini	1.7	0.60	–	–	–	–	0.45	0.55
			Mid	1.9	0.65	0.31–0.32	0.48–0.50	0.35–0.40	0.40–0.45	0.60	0.65
			End	1.9	0.60	–	–	0.30–0.35	0.70–0.75	0.55	0.65
Super-intensive high-density, hedgerow (1500–2000 pl/ha)	0.45–0.55	3.0–4.0	Ini	1.7	0.60	0.30–0.36	0.82–0.87	–	–	0.50	0.60
			Mid	1.9	0.65	0.41–0.48	0.60–0.71	0.45–0.50	0.50–0.55	0.65	0.70
			End	1.9	0.60	0.30–0.34	0.84–0.95	0.40–0.45	0.75–0.80	0.60	0.70

Abbreviations and symbols are defined in list of symbols heading

Table 7 Characteristics of the selected studies on citrus orchards

Author	Cultivar (rootstock)	Location and main climate	Field method for $ET_{c\ act}$ (ET_o eq.)	Irrigation method and strategy	Trees/ha (spacing, m)	Training system	Age (years)	Height (m)	f_c or f_{IPAR}
Clementine (*Citrus clementina* Hort.)									
Castel (2000)	Clementina de Nules (Citrange carrizo)	Valencia, Spain Med. Semi-arid	WL (FAO-PM-ET_o)	Drip and FI	433 (6×3.85)	n/r	6–14	1.7–2.3	0.09–0.38
Rana et al. (2005)	n/r	Apulia, Italy Med. sub-humid	SF, EC (FAO-PM-ET_o)	Drip and FI	400 (5×5)	n/r	10	4.08	0.70
Darouich et al. (2022a)	Common (*Citrus aurantium*)	Akkar plain, SW Syria Med.sub-humid	SWB-neutron, SIMDualKc (FAO-PM-ET_o)	Drip, Bubbler, Micro-spr Basin and FI	400 (5×5)	Vase	10–14	2.5–3.0	0.46–0.50
				Drip and FI			18–20	3.8–4.0	0.75–0.77
Abou Ali et al. (2023)	Esbal (*Citrus macrophylla*)	S. Massa, Morocco Med. Semi-arid	EC, SWB-TDR (FAO-PM-ET_o)	Drip and FI	1000 (n/r)	n/r	12–13	n/r	0.70
Ramos et al. (2023)	Oronules (n/r)	Aljustrel, Portugal Med., dry	SWB-TDR SIMDualKc (FAO-PM-ET_o)	Drip and FI	675 (n/r)	Vase	5–6	2.7	0.28
Lemon (*Citrus limon* L.)									
Rosa (2018)	Burm. f. cv Eureka (*Citrus*×*aurantium*, vig)	Torres Vedras, Portugal Med., subhumid	SWB-FDR, SIMDualKc (FAO-PM-ET_o)	Drip and FI	500 (5×4)	n/r	21	3.5	0.75
Lime (*Citrus latifolia* Tan.)									
Alves et al. (2007)	Tahiti (Swingle citrumelo)	Piracicaba, São Paulo, Brazil subtropical humid	WL, K_e model (FAO-PM-ET_o)	Drip and FI	357 (7×4)	n/r	2 3 4	n/r	0.13 0.25 0.37
Barboza Júnior et al. (2008)	Tahiti (Swingle citrumelo)	Piracicaba, Brazil subtropical humid	WL (FAO-PM-ET_o)	Drip and FI	357 (7×4)	n/r	7	4.0	0.70
Mandarine (Citrus reticulata Blanco)									
Maestre-Valero et al. (2017)	Hernandina (Citrange carrizo)	Valencia, Spain Med. Semi-arid	EC (FAO-PM-ET_o)	Drip FI	556 (6×3)	n/r	Mature	2.8	0.66
Segovia-Card ozo et al. (2022)	Tardivo di Ciaculli (n/r)	Palermo, Italy Med., dry	SF, SWB-FDR (FAO-PM-ET_o)	Micro-spr, SSDrip and FI	400 (5×5)	n/r	30	2.5	0.40
Ippolito et al. (2023)	Tardivo di Ciaculli (n/r)	Palermo, Italy Med., dry	EC, SWB-FDR, Kc-VI (FAO-PM-ET_o)	Drip Mild DI	400 (5×5)	n/r	Mature	2.5	0.50
Ramos et al. (2023)	Setubalense (n/r)	Aljustrel, Portugal Med., dry	SWB-TDR SIMDualKc (FAO-PM-ET_o)	Drip and FI	529	Vase	5–6	2.8	0.29

Table 7 (continued)

Author	Cultivar (rootstock)	Location and main climate	Field method for $ET_{c\ act}$ (ET_o eq.)	Irrigation method and strategy	Trees/ha (spacing, m)	Training system	Age (years)	Height (m)	f_c or f_{IPAR}
Orange (*Citrus sinensis* L.)									
Consoli et al. (2006)	Navel (n/r)	Lindsay, CA, USA Med., sub-humid	Surf. renewal (ASCE-PM-ET_o)	Micro-spr n/r	335 (6.1 × 4.9)	n/r	2	1.0	0.10
					335 (6.1 × 4.9)		4	2.3	0.20
					299 (6.1 × 5.5)		15	4.5	0.47
					283 (6.1 × 5.8)		34–36	4.5	0.70
Morgan et al. (2006)	Hamlin (Carrizo citrange)	Florida, USA Subtropical humid	SWB-capacit (Penman-ET_o)	Micro-spr FI	529 (6.1 × 3.1)	Hedgerow	14	5.9	0.59
Snyder and O'Connell (2007)	Navel (Troyer citrange)	Lindsay, CA, USA Med. Sub-humid	Surf. renewal (ASCE-PM-ET_o)	Micro-spr FI	283 (6.1 × 5.8)	Like hedgerow	33–37	4.5	0.70
García-Petillo and Castel (2007)	Valencia (*Poncirus trifoliata*)	South Uruguay Temperate humid	SWB-neutron (ClassA panET_o)	Drip FI	417 (6 × 4)	n/r	16–19	3.0	0.30–0.50
Jia et al. (2007)	Parson Brown (n/r)	Central Florida Subtropical humid	EC (ASCE-PM-ET_o)	Micro-spr n/r	340 (7.7 × 3.8)	n/r	15	5–6	n/r
	Hamlin (Swingle citrumelo)	North Florida Subtropical humid	EC (ASCE-PM-ET_o)	Micro-spr n/r	498 (6.7 × 3.0)	n/r	16	4.5–5.5	n/r
Er-Raki et al. (2009)	n/r	Marrakech, Moroc Semi-arid	EC (FAO-PM-ET_o)	Drip and FI	667 (5 × 3)	n/r	13	3.15	0.70
				Basin and FI	204 (7 × 7)		15	3.30	0.30
Consoli and Papa (2013)	Tarocco Ippolito (n/r)	Sicily, Italy Med. semi-arid	EC, SF, PMeq (FAO-PM-ET_o)	Drip and FI	455 (5.5 × 4.0)	n/r	mature	3.75	n/r
Villalobos et al. (2013)	Lane late (n/r)	Seville, Spain Med. semi-arid	SF (FAO-PM-ET_o)	Drip and FI	477 (7 × 3)	n/r	11	n/r	0.42
		Valencia, Spain Med. Semi-arid	SF (FAO-PM-ET_o)	Drip and FI	417 (6 × 4)	n/r	10	2.3	0.33
Consoli and Vanella (2014)	Tarocco Ippolito (n/r)	Sicily, Italy Med. semi-arid	EC, RS-VI, SWB-TDR (FAO-PM-ET_o)	Drip FI	455 (5.5 × 4.0)	n/r	20	3.7	0.50

Table 7 (continued)

Author	Cultivar (rootstock)	Location and main climate	Field method for $ET_{c\ act}$ (ET_o eq.)	Irrigation method and strategy	Trees/ha (spacing, m)	Training system	Age (years)	Height (m)	f_c or f_{IPAR}
Taylor et al. (2014)	'Delta' Valencia ('Swingle' citrumelo)	Groblersdal, Limpopo, RSA Summer rainfall	SF, OPEC, SR, SWB-capacit (FAO-PM ET_o)	Drip FI	661 (2.75 × 5.5)	n/r	11–12	5 to 3.5 after harvest	0.60
	'Bahaininha' Navel (Carrizo' citrange)	Groblersdal, Limpopo, RSA Summer rainfall	SF, SWB-TDR (FAO-PM ET_o)	Drip FI	833 (2 × 6)	n/r	6–7	2.5	n/r
	'Rustenburg' Navel ('Troyer' citrange)	Citrusdal, Western Cape, RSA Winter rainfall	SF, EC, SWB-capacit (FAO-PM ET_o)	Drip FI	666 (2.5 × 6)	n/r	15	3.3	0.88
	'Midknight' Valencia ('Swingle' Citrumelo)	Malelane, Mpumalanga, RSA Summer rainfall	SF, OPEC, SWB-capacit (FAO-PM ET_o)	Drip FI	571 (2.5 × 7)	n/r	16–18	4	0.54
Taylor et al. (2015)	Delta Valencia (Swingle citrumelo)	Limpopo, S. Africa Summer rainfall	SF, A&P app (FAO-PM-ET_o)	Drip FI	661 (5.5 × 2.75)	n/r	11	4.1	0.60
	Bahianinha Navel (Carrizo citrange)	Limpopo, S. Africa Summer rainfall	SF, A&P app (FAO-PM-ET_o)	Drip FI	833 (6 × 2)	Near hedgerow	6	2.3	0.63
Taylor et al. (2015, 2017)	Rustenburg Navel (Troyer citrange)	Western Cape, RSA Winter rainfall	SF, A&P app (FAO-PM-ET_o)	Drip FI	800 (5 × 2.5)	n/r	14	3.3	0.88
Peddinti and Kambhammettu (2019)	n/r	Vidabha, central India Tropical	EC, SF, SWB-ML, SIMDualKc (FAO-PM-ET_o)	Flood, Drip DI	400 (5 × 5)	n/r	8	2.5–3.0	0.70
Saitta et al. (2020)	Tarocco Sciara, (Carrizo citrange)	Lentini, Sicily, Italy Med	SF, EC (FAO-PM ET_o	Drip FI	417 (4 × 6)	n/r	8–9	3.5	n/r
Jamshidi et al. (2020)	Washington Navel (n/r)	Fars, South Iran Semi-arid	SWB-neutron, ML (HS-ET_o)	Drip FI	400 (5 × 5)	n/r	12	2.8	0.75–0.80
Jafari et al. (2021)	Tarocco Ippolito (n/r)	Fars, Southern Iran Semi-arid	SWB-neutron, ML (FAO-PM-ET_o)	Drip FI	333 (6 × 5)	n/r	25	3.0	0.85
Ramos et al. (2023)	Fukumoto (n/r)	Aljustrel, Portugal Med., dry	SWB-TDR SIMDualKc (FAO-PM-ET_o)	Drip and FI	404 (n/r)	Vase	5–6	2.4	0.29

Abbreviations and symbols are defined in list of symbols heading

Table 8 Field-derived crop coefficients of citrus orchards

Author	Cultivar (rootstock)	Training system	f_c or f_{IPAR}	Height (m)	Ground cover	Age (years)	K_c/K_{cb} derived from field observations						
							Conditions	$K_{c\ ini}$	$K_{c\ mid}$	$K_{c\ end}$	$K_{cb\ ini}$	$K_{cb\ mid}$	$K_{cb\ end}$
Clementine (*Citrus clementina* Hort.)													
Castel (2000)	Clementina de Nules (Citrange carrizo)	n/r	0.09	1.7 to 2.3	AGC	6		0.33	0.30	0.38	n/r	n/r	n/r
			0.15			7		0.53	0.40	0.45			
			0.18			8		0.35	0.50	0.55			
			0.21			9		0.38	0.45	0.66			
			0.25			10		0.42	0.45	0.60			
			0.27			11		0.65	0.50	0.62			
			0.28			12		0.75	0.50	0.60			
			0.30			13		0.60	0.45	0.60			
			0.38			14		0.55	0.55	0.64			
Rana et al. (2005)	n/r	n/r	0.70	4.08	AGC 15–30%	10		0.80	0.70	0.80	n/r	n/r	n/r
Darouich et al. (2022a)	Common (*C. aurantium*)	Vase	0.46–0.50	2.5–3.0	partly AGC	10–14	Drip	1.14	0.76	1.15	0.54	0.54	0.54
							Bubbler	1.14	1.06	1.15			
							Mini-spr	1.14	1.12	1.15			
							Basin	1.14	1.12	1.15			
			0.75–0.77	3.8–4.0		18–20	Drip	0.92	0.78	0.91	0.64	0.64	0.64
Abou Ali et al. (2023)	Esbal (*C. macrophylla*)	n/r	0.70	n/r	n/r	12–13		0.64	0.58	n/r	n/r	n/r	n/r
Ramos et al. (2023)	Oronules (n/r)	Vase	0.28	2.7	AGC fall-spr	5–6		0.95	0.50	0.93	0.40	0.40	0.40
Lemon (*Citrus limon* L.)													
Rosa (2018)	Burm. f. cv eureka (*C.* × *aurantium*, vig)	n/r	0.75	3.5	AGC	21		n/r	n/r	n/r	0.40	0.67	0.67
Lime (*Citrus latifolia* Tan.)													
Alves et al. (2007)	Tahiti (Swingle citrumelo)	n/r	0.13	n/r	BS	2		n/r	0.73	0.67	n/r	0.54	n/r
			0.25			3		0.48	0.84	0.94	n/r	0.61	0.38
			0.37			4		0.65	1.09	n/r	0.40	0.91	n/r
Barboza Júnior et al. (2008)	Tahiti (Swingle citrumelo)	n/r	0.70	4.0	BS	7	$K_{c\ avg} = 0.98$	n/r	1.08	n/r	n/r	n/r	n/r
Mandarine (*Citrus reticulata* Blanco)													
Maestre-Valero et al. (2017)	Hernandina (Citrange carrizo)	n/r	0.66	2.8	BS	Mature	Season 1	n/r	0.65	1.15	n/r	0.50	0.55
							Season 2	1.07	0.96	0.82	0.60	0.55	0.60
							Season 3	1.14	0.61	n/r	0.65	0.55	n/r

Table 8 (continued)

Author	Cultivar (rootstock)	Training system	f_c or f_{IPAR}	Height (m)	Ground cover	Age (years)	K_c/K_{cb} derived from field observations						
							Conditions	$K_{c\ ini}$	$K_{c\ mid}$	$K_{c\ end}$	$K_{cb\ ini}$	$K_{cb\ mid}$	$K_{cb\ end}$
Segovia-Cardozo et al. (2022)	Tardivo di Ciaculli (n/r)	n/r	0.40	2.5	AGC Aut-Spr	30		0.95	0.43	0.95	n/r	0.39	0.90
Ippolito et al. (2023)	Tardivo di Ciaculli (n/r)	n/r	0.50	2.5	AGC	Mature		n/r	0.55	0.75	n/r	n/r	n/r
Ramos et al. (2023)	Setubalense (n/r)	Vase	0.29	2.8	AGC Aut-Spr	5–6		0.94	0.50	0.93	0.40	0.40	0.40
Orange (*Citrus sinensis* L.)													
Consoli et al. (2006)	Navel (n/r)	n/r	0.10	1.0	BS	2		n/r	0.45	n/r	n/r	n/r	n/r
			0.20	2.3		4		n/r	0.57	n/r	n/r	n/r	n/r
			0.47	4.5		15		n/r	0.77	n/r	n/r	n/r	n/r
			0.70	4.5		34–36		n/r	0.93	n/r	n/r	n/r	n/r
Morgan et al. (2006)	Hamlin (Carrizo citrange)	Hedgerow	0.59	5.9	BS	14		0.70	1.05	0.70	n/r	n/r	n/r
Snyder and O'Connell (2007)	Navel (Troyer citrange)	Hedgerow like	0.70	4.5	BS	33–37		1.15	0.96	1.15	n/r	n/r	n/r
García-Petillo and Castel (2007)	Valencia (*Poncirus trifoliata*)	n/r	0.3–0.5	3.0	BS	16–19		0.87	0.71	0.83	n/r	n/r	n/r
Jia et al. (2007)	Parson Brown (n/r)	Hedgerow	n/r	5–6	BS	15		0.73	0.93	1.07	n/r	n/r	n/r
	Hamlin (Swingle citrumelo)	Hedgerow	n/r	4.5–5.5	AGC	16		0.67	0.77	0.65	n/r	n/r	n/r
Er-Raki et al. (2009)	n/r	n/r	0.70	3.15	BS	13		0.45	0.60	0.50	0.35	0.55	0.45
			0.30	3.30		15		0.58	0.55	0.60	0.30	0.50	0.40
Consoli and Papa (2013)	Tarocco Ippolito (n/r)	n/r	n/r	3.75	AGC, 15%	Mature		0.80	0.70	0.75	n/r	n/r	n/r
								0.85	0.75	0.80			
Villalobos et al. (2013)	Lane Late (n/r)	n/r	0.42	n/r	n/r	11		n/r	n/r	n/r	n/r	0.35	0.58
			0.33	2.3		10		n/r	n/r	n/r	n/r	0.30	0.35
Consoli and Vanella (2014)	Tarocco Ippolito (n/r)	n/r	0.50	3.7	n/r	20		n/r	0.71	n/r	n/r	n/r	n/r

Table 8 (continued)

Author	Cultivar (rootstock)	Training system	f_c or f_{IPAR}	Height (m)	Ground cover	Age (years)	K_c/K_{cb} derived from field observations						
							Conditions	$K_{c\ ini}$	$K_{c\ mid}$	$K_{c\ end}$	$K_{cb\ ini}$	$K_{cb\ mid}$	$K_{cb\ end}$
Taylor et al. (2014)	'Delta' Valencia (Swingle citrumelo)	n/r	n/r	0.48	0.42	11–13		n/r	n/r	n/r	n/r	0.48	0.42
	'Bahaininha' Navel (Carrizo' citrange)	n/r	n/r	0.37	0.35	8–10		n/r	n/r	n/r	n/r	0.37	0.35
	'Rustenburg' Navel ('Troyer' citrange)	n/r	n/r	0.57	0.93	n/r		n/r	n/r	n/r	n/r	0.57	0.93
	Midknight Valencia (Swingle Citrumelo)	n/r	n/r	0.46	0.61	n/r		n/r	n/r	n/r	n/r	0.46	0.61
Taylor et al. (2015)	Delta Valencia (Swingle citrumelo)		0.60	4.1	BS	11		n/r	n/r	n/r	0.40	0.41	0.42
	Bahianinha Navel (Carrizo citrange)	Incomplete hedgerow	0.63	2.3	BS	6		n/r	n/r	n/r	0.34	0.37	0.38
Taylor et al. (2015, 2017)	Rustenburg Navel (Troyer citrange)		0.88	3.3	BS	14		n/r	n/r	n/r	0.50	0.35	0.80
Peddinti and Kambhammettu (2019)	n/r	n/r	0.70	2.5–3.0	BS	8		0.80	0.65	0.80	0.60	0.45	0.55
Saitta et al. (2020)	Tarocco Sciara, (Carrizo citrange)	n/r	n/r	3.5	n/r	8–9		n/r	0.60	n/r	n/r	n/r	n/r
Jamshidi et al. (2020)	Washington Navel (n/r)	n/r	0.75–0.80	2.8	BS	12		0.71	0.89	0.82	0.60	0.74	0.71
Jafari et al. (2021)	Tarocco Ippolito (n/r)	n/r	0.85	3.0	BS	25		0.68	0.87	0.81	0.59	0.72	0.72
Ramos et al. (2023)	Fukumoto (n/r)	Vase	0.29	2.4	AGC Aut-Spr	5–6		0.97	0.50	0.92	0.41	0.41	0.41

Abbreviations and symbols are defined in list of symbols heading

K_{cb} for each degree of ground cover, training, and plant density. Orange, grapefruit, and tangelo, in contrast, have trees with higher h, f_c and K_c/K_{cb} values. Lemon trees are in an intermediate position. Nevertheless, the generally required interpolation may be difficult.

Warm temperate plantations: avocado, loquat, persimmon, and tea crops

These crops are not grouped but listed in the same Table. They have great differences: on the one hand, they are evergreen but persimmon that is deciduous; on the other hand, all are trees explored for fruits but tea, which is a shrub explored for the leaves. Thus, tabulated subjects are discussed in isolation or comparatively.

Selected studies on avocado orchards are from Florida, South Africa and Chile, which are among the main producers (Table 10). Only recently, they start to be grown in southern Europe, which may be a consequence of global warming as suggested in a review by Cárceles Rodríguez et al. (2023). Differently, loquat and persimmon have long been cultivated in southern Europe and the selected studies are from the north and east of the Mediterranean region. The selected tea studies are from two main production areas, southern China, and mountainous India, but tea has a quite large distribution, which is also related to the qualities of tea produced.

The FAO-PM-ET_o was adopted for most studies on the various crops (Table 10). Field ET measurements with a SWB approach, followed by EC systems, were the main methods used for avocado ET estimation. For persimmon, EC systems were the main methods to measure ET. Differently, for loquat a test of K_c fitting was employed.

The planting density reported for avocado (Table 10) ranged 148–370 pl ha^{-1} and the training systems reported were hedge pruned or, more often, hedgerow. However, these systems are very different of those used for olive trees since crop heights are quite high, of up to 7.9 m. These hedge systems aim to improve harvesting efficiency, which occurs throughout the year, using Harvest Assist platforms. A large range of heights results in a wide range of f_c values, from 0.40 to 0.80. Persimmon and loquat have training in vase while tea is trained at a low hedgerow, with $h < 0.90$ m, to favor hand harvesting of leaves.

Crop coefficients of avocado are reported with two types of K_c curves (Table 11): where the summer mid-season is dry in opposition to the initial stage and the final stage, the K_c curve has $K_{c\ mid}$ smaller than $K_{c\ ini}$ and $K_{c\ end}$ because mid-season soil evaporation is about negligible; if there is rain in the mid-summer, it is likely that soil evaporation is high by then resulting a $K_{c\ mid}$ higher than $K_{c\ ini}$ and $K_{c\ end}$. The difference among these K_c may be small, then resulting a uniform season K_c. K_{cb} is reported to follow a typical segmented crop coefficient curve with $K_{c\ mid}$ higher than $K_{c\ ini}$ and $K_{c\ end}$ assuming that transpiration is larger during the mid-season stage; however, differences among these K_{cb} values may be small as it often happens to citrus trees. However, for the New Zealand case (Kaneko et al. 2022), with observations in three different locations, $K_{cb\ end} > K_{cb\ mid}$ is reported but without explanations.

There is limited information about loquat (Table 11) but it is likely, as reported by Hueso and Cuevas (2010), that $K_{c\ mid}$ and $K_{cb\ mid}$ be larger than initial and end-season values. On the one hand, flowering occurs by the end of winter and fruit maturation is also anticipated to the spring, thus the crop mid-season is likely when rainfall occurs, resulting that transpiration adds to non-negligeable soil evaporation due to rains occurring by then, thus with K_c resulting from the sum of $K_{cb\ mid}$ with a non-negligible K_e value. On the other hand, leaves are tough and leathery in texture, and densely velvety-hairy below that favor stomatal control during the late season.

Despite data are limited, reports show that Persimmon has K_c and K_{cb} curves with the mid-season values larger than the initial and end season values, as it is common for deciduous trees.

Reported tea results for K_c and K_{cb} (Table 11) show flat K_c and K_{cb} curves since the climate where plantations develop is generally humid, with only short dry spells, which does not favor ET values very different of those of the grass reference, therefore close or equal to 1.0.

The proposed initial, mid-season, and end-season standard single and basal crop coefficients for avocado, loquat, persimmon, and tea plantations (Table 12) are generally in agreement with the ranges of values observed and compatible with those previously tabulated for avocado and tea. However, hedgerow was not yet considered previously for avocado while presently it is likely the most popular where harvesting mechanization is in use; nevertheless, training in vase is continued. K_c for loquat and for persimmon were never tabulated. Proposed values for these crops agree with previous discussions. As previously pointed out the tabulated values of the ranges of plant densities are indicative.

Conclusions and recommendations

The review of crop coefficients for table and vine grape vineyards, olive, citrus, avocado, loquat, persimmon, and tea plantations permitted a good collection of well-performed

Table 9 Initial, mid-, and end-season standard single and basal crop coefficients for citrus orchards as related with the training system, fraction of ground cover and height, with indication of ranges of observed K_c and K_{cb}, and of former tabulations of their standard values

Degree of ground cover, training and plant density	f_c	h (m)	Crop stages	M_L	F_r	Ranges of observed values		Ranges of previously tabulated values		Proposed values	
						K_{cb}	K_c	K_{cb}	K_c	K_{cb}	K_c
Clementine (*Citrus clementina*), **Mandarin** (*C. reticulata*), **Lime** (*C. aurantifolia*)											
Young (< 5 years), vase	0.10–0.20	< 1.5	Ini	1.8	1.00	–	0.33–0.53	–	–	0.35	0.50
			Mid	1.8	1.00	0.54	0.30–0.73	0.35–0.40	0.40–0.45	0.35	0.50
			End	1.8	1.00	–	0.38–0.67	0.35–0.40	0.60–0.65	0.35	0.55
Low, vase (< 400 pl/ha)	0.20–0.35	1.5–2.5	Ini	1.8	0.65	0.40	0.38–0.95	0.45	0.50–0.55	0.40	0.55
			Mid	1.8	0.75	0.40–0.61	0.45–0.84	0.35–0.45	0.40–0.50	0.50	0.60
			End	1.8	0.75	0.38–0.40	0.60–0.94	0.35–0.50	0.50–0.65	0.50	0.60
Medium, vase (400–550 pl/ha)	0.35–0.60	2.5–3.0	Ini	1.8	0.65	0.40–0.54	0.55–1.14	0.60–0.70	0.65–0.80	0.60	0.70
			Mid	1.8	0.70	0.39–0.91	0.43–1.12	0.50–0.70	0.55–0.75	0.65	0.75
			End	1.8	0.70	0.54–0.90	0.64–1.15	0.50–0.70	0.65–0.75	0.65	0.75
High, vase (> 550 pl/ha)	> 0.60	3.0–4.0	Ini	2.0	0.65	0.60–0.65	0.92–1.14	0.65–0.85	0.70–0.95	0.70	0.80
			Mid	2.0	0.70	0.50–0.64	0.46–1.08	0.55–0.95	0.60–1.00	0.75	0.85
			End	2.0	0.70	0.55–0.64	0.82–1.15	0.55–0.95	0.70–1.05	0.75	0.85
Lemon (*C. limon*)											
Young (< 5 years), vase	0.10–0.20	< 1.5	Ini	1.5	1.00	–	–	–	–	0.35	0.50
			Mid	1.6	1.00	–	–	–	–	0.35	0.40
			End	1.6	1.00	–	–	–	–	0.35	0.55
Low density, vase (< 200 pl/ha)	0.20–0.50	1.5–2.5	Ini	1.5	0.651	–	–	0.45–0.70	0.50–0.80	0.40	0.55
			Mid	1.7	0.75	–	–	0.40–0.70	0.45–0.75	0.55	0.60
			End	1.7	0.75	–	–	0.45–0.70	0.50–0.75	0.55	0.65
Medium density, vase (200–400 pl/ha)	0.50–0.70	2.5–3.0	Ini	2.0	0.65	–	–	0.60–0.85	0.65–0.95	0.65	0.75
			Mid	2.0	0.70	–	–	0.55–0.85	0.60–0.90	0.70	0.75
			End	2.0	0.70	–	–	0.60–0.85	0.65–0.90	0.70	0.80
High density, vase (> 400pl/ha)	> 0.70	3.0–4.0	Ini	2.0	0.60	0.40	–	–	–	0.70	0.75
			Mid	2.0	0.65	0.67	–	–	–	0.75	0.80
			End	2.0	0.65	0.67	–	–	–	0.75	0.80
Orange (*C. sinensis*), **Grapefruit** (*C. paradisi*), **Tangelo** (*C. tangelo*)											
Young (< 5 years), vase	0.10–0.20	< 2.0	Ini	1.5	1.00	–	–	–	–	0.35	0.50
			Mid	1.6	1.00	–	0.45–0.57	0.35–0.40	0.40–0.45	0.35	0.45
			End	1.6	1.00	–	–	0.35–0.40	0.60–0.65	0.35	0.50
Low, vase (< 400 pl/ha)	0.20–0.40	2.0–3.0	Ini	1.6	0.60	0.30–0.41	0.58–0.97	0.45–0.70	0.50–0.80	0.40	0.55
			Mid	1.6	0.80	0.30–0.50	0.50–0.85	0.40–0.70	0.45–0.75	0.50	0.60
			End	1.6	0.75	0.35–0.41	0.60–0.92	0.45–0.70	0.50–0.75	0.45	0.60

Table 9 (continued)

Degree of ground cover, training and plant density	f_c	h (m)	Crop stages	M_L	F_r	Ranges of observed values		Ranges of previously tabulated values		Proposed values	
						K_{cb}	K_c	K_{cb}	K_c	K_{cb}	K_c
Medium, vase (400–600 pl/ha)	0.40–0.70	3.0–4.0	Ini	1.5	0.60	0.35–0.60	0.45–0.87	0.60–0.85	0.65–0.95	0.60	0.70
			Mid	1.5	0.65	0.35–0.55	0.60–0.93	0.55–0.95	0.55–1.00	0.65	0.70
			End	1.5	0.60	0.42–0.58	0.50–0.83	0.50–0.95	0.65–0.1.05	0.60	0.70
High, vase (600–950 pl/ha)	> 0.70	> 4.0	Ini	2.0	0.50	0.35–0.60	0.68–0.71	–	–	0.65	0.70
			Mid	2.0	0.60	0.64–0.74	0.87–0.89	–	–	0.75	0.80
			End	2.0	0.50	0.37–0.72	0.81–0.82	–	–	0.70	0.75
Hedgerow (industry) (> 1250 pl/ha)	> 0.60	> 4.0	Ini	2.0	0.60	0.34	0.67–1.15	–	–	0.65	0.80
			Mid	2.0	0.65	0.37	0.77–1.05	–	–	0.70	0.85
			End	2.0	0.65	0.38	0.65–1.15	–	–	0.70	0.85

Abbreviations and symbols are defined in list of symbols heading

field studies and data handling that elucidated about water use practices and requirements for those crops. The selected papers allow to conclude that good knowledge exist about the referred crops and their exploitation, the evapotranspiration and water use process, while water management practices require to be improved in such a manner that water use be controlled, limited, while yields are increased. However, further studies on crops having limited information available are welcome, e.g., lemon and loquat.

The control and optimization of water use, including water saving, require appropriate choice and use of irrigation equipment and adequate irrigation scheduling targeting the standard K_c when irrigation equipment allows a good control of quantities applied and water available is enough to satisfy that target application. Numerous papers refer to regulated or controlled deficit irrigation; however, that deficit must be referred to the potential ET_c, product of the standard K_c by the grass reference ET_o. The application of those deficit irrigation practices also imply that farmers, managers and farmer advisers improve their knowledge on these subjects, on using models that may help decision-making, as well as on the use of weather data and information. Estimating K_{cb} and K_c from the fraction of ground cover or shading and plant height (A&P approach) provides for quite realistic estimates of crop coefficients for trees and vines as demonstrated by Pereira et al. (2020a, b) and as used with the California remote sensing SIMS framework (Melton et al. 2012; Pereira et al. 2021a, b, c), with parameterization described by the latter. Similar approaches on the use of standard K_c and K_{cb}, or the A&P approach, apply to studies on irrigation planning as well as on consumptive use assessment at project or watershed level.

When searching for water saving and scheduling irrigations for any kind of controlled deficit irrigation, users may either use the standard K_c or K_{cb} decreased by a saving fraction or may schedule irrigations following the actual ET conditions of the orchard. In the latter case, users may estimate the $K_{c\ act}$ using the A&P approach as referred in the Introduction. Then $K_{cb\ act}$ may be computed from the observed actual fraction of ground cover and crop height and K_e may be estimated from the observed actual wetted fraction of exposed soil, $1-f_c$. The resulting actual values for K_c or K_{cb} shall then be compared with the standard K_c or K_{cb} for computation quality control. It is important to make the best use of related information and effectively achieve high water and financial productivity aiming the sustainability of production and the progressive adaptation to climate change challenges.

Users are advised to read and analyze the quoted papers in addition to the information provided and tabulated in the current review paper. Above all, it is required to develop awareness on water scarcity and water saving, the latter mainly based on the knowledge of standard crop coefficients

Table 10 Characteristics of selected avocado, loquat, persimmon, and tea plantations

Author	Cultivar (rootstock)	Location and main climate	Field method for $ET_{c\ act}$ (ET_o equation)	Irrigation method and strategy	Trees/ha (spacing, m)	Training system	Age (years)	Height (m)	f_c or f_{IPAR}
Avocado (*Persea americana* Mill.)									
Gardiazabal et al. (2003)	Hass (Mexicola)	Valparaíso, Chile Temperate	SWB tens (FAO-PM-ET_o)	Micro spr Controled DI	278 (6×6)	n/r	8–10	n/r	n/r
Kiggundu et al. (2012)	Simmonds (Waldin)	Homestead, FL, USA Subtrop. humid	SWB, tens (FAO-PM-ET_o)	Micro spr FI	370 (6×4.5)	Hedge pruned	3	2	n/r
Mbabazi et al. (2015)	Simmonds & Beta	Homestead, FL, USA Subtrop. humid	SWB, IS-APP (FAO-PM-ET_o)	Micro spr FI	n/r	Hedgerow	Mature	n/r	n/r
Holzapfel et al. (2017)	Hass (Mexicola)	Peumo Valley, Cachapoal, Chile Sub-humid Med	Test K_c, SWB-neutron (ClassA pan-ET_o)	Microjet FI	357 (7×4)	n/r	7–9	6–7	0.70
Mazhawu et al. (2018)	Hass (Dusa)	Pietermaritzburg, RSA Subtrop. humid	EC (FAO-PM-ET_o)	Micro-spr FI	357 (7×4)	n/r	4	3.8	0.40–0.50
Taylor et al. (2021)	Harvest (Dusa)	Howick, South Africa Subtrop. hot, humid	EC, SF (FAO-PM-ET_o)	Micro-spr FI	357 (7×4)	Hedgerow	1–3	1.7	0.17
	Hass						4–6	3.8	0.43
	Hass						11–13	7.4	0.80
	Hass (Dusa, R0.06)	Tzaneen, S. Africa Subtrop. hot, humid			312 (8×4)	Hedgerow	5–7	4.0	0.60
Kaneko et al. 2022	Hass (‘Zutano’ seedling rootstock)	Bay of Plenty, Whangarei,Far North N. Zealand Temperate	SF, SWB-reflec (FAO-PM-ETo)	Micro-spr FI	148 (9×7.5)	Vase	10	6.7	0.82
					204 (7×7)		10	6.8	0.92
					312 (8×4)		6	5.3	0.77
Loquat (*Eriobotrya japonica* Lindl.)									
Hueso and Cuevas (2010)	Algerie (Provence)	El Ejido, Almería, Spain Semi-arid, Subtrop	Test Kc (ClassA pan-ET_o)	Drip FI	400 (5×5)	Vase	Mature	n/r	n/r
Persimmon (*Diospyros kaki L.f.*)									
Kanety et al. (2014)	Triumph (n/r)	Hefer plain, Israel Med., subhumid	SF (FAO-PM-ET_o)	Drip and FI	417 (6×4)	n/r	9–11	n/r	n/r
Intrigliolo et al. (2018)	Rojo Brillante (*Diospyros lotus*)	Valencia, Spain Med., subhumid	SF, SWB-capac (FAO-PM-ET_o)	Drip and FI	455 (5.5×4)	Vase	Mature Young	2.9	0.33
Ballester et al. (2022)	Rojo Brillante (*Diospyros lotus*)	Valencia, Spain Med., subhumid	SF (FAO-PM-ET_o)	Drip and FI	455 (5.5×4)	Vase	9	2.9	0.33
					800 (5×2.5)	Vase	5	2.7	0.15
					571 (5×3.5)	Vase	6	2.7	0.16

Table 10 (continued)

Author	Cultivar (rootstock)	Location and main climate	Field method for $ET_{c\ act}$ (ET_o equation)	Irrigation method and strategy	Trees/ha (spacing, m)	Training system	Age (years)	Height (m)	f_c or f_{IPAR}
Tea (*Camellia sinensis* L.)									
Sikka et al. (2009)	B-6	Udhagamandalam Tamil Nadu, India Tropical	WL (FAO-PM-ET_o)	Rainfed	13,333 (n/r)	n/r	2	n/r	n/r
Borkar et al. (2010)	n/r	Uttarakhand, India Temperate trop	SWB-FDR (FAO-PM-ET_o)	Drip FI	n/r	n/r	Mature (n/r)	n/r	n/r
Zheng et al. (2021)	Baiye1	Shaoxing, China Subtrop. monsoon	DL, SWB-TDR (FAO-PM-ET_o)	Rainfed	20,200 (1.5 × 0.33)	n/r	4–5	0.77	n/r
	Longjing43						4–5	0.88	
Yan et al. (2022)	Anji White	Jiangsu, China Subtrop. monsoon	BREB, SWB-TDR (FAO-PM-ET_o)	Rainfed	16,025 (1.2 × 0.52)	n/r	3–5	n/r	n/r

Abbreviations and symbols are defined in list of symbols heading

Table 11 Field-derived crop coefficients of avocado, loquat, persimmon, and tea plantations

Author	Cultivar (rootstock)	Training system	f_c or f_{IPAR}	Height (m)	Ground cover	Age (years)	K_c/K_{cb} derived from field observations					
							$K_{c\ ini}$	$K_{c\ mid}$	$K_{c\ end}$	$K_{cb\ ini}$	$K_{cb\ mid}$	$K_{cb\ end}$
Avocado (*Persea americana* Mill.)												
Gardiazabal et al. (2003)	Hass (Mexicola)	n/r	n/r	n/r	n/r	8–10	0.72	0.72	0.72	n/r	n/r	n/r
Kiggundu et al. (2012)	Simmonds (cv. Waldin)	Hedge prune	n/r	2	n/r	3	0.50	0.71	0.50	n/r	n/r	n/r
Mbabazi et al. (2015)	Simmonds & Beta	Hedgerow	n/r	n/r	n/r	Mature	0.60	1.00	0.70	n/r	n/r	n/r
Holzapfel et al. (2017)	Hass (Mexicola)	n/r	0.70	6–7	n/r	7–9	1.00	1.00	1.00	n/r	n/r	n/r
Mazhawu et al. (2018)	Hass (Dusa)	n/r	0.40–0.50	3.8	AGC	4	0.60	1.15	0.60	n/r	n/r	n/r
Taylor et al. (2021)	Harvest (Dusa)	Hedgerow	0.17	1.7	AGC	1–3	1.00	1.05	n/r	n/r	n/r	n/r
	Hass	Hedgerow	0.43	3.8	AGC	4–6	0.85	1.20	n/r	0.25	0.50	0.30
	Hass	Hedgerow	0.80	7.4	AGC	11–13	0.75	1.05	n/r	0.70	1.00	0.60
	Hass (Dusa & R0.06)	Hedgerow	0.60	4.0	AGC	5–7	n/r	n/r	n/r	0.35	0.55	0.30
Kaneko et al. 2022	Hass (‘Zutano’)	n/r	≥ 0.77	≥ 5.3	AGC mowed	Fruit load high				0.60	0.78	1.25
						Low					0.65	
Loquat (*Eriobotrya japonica* Lindl.)												
Hueso and Cuevas (2010)	Algerie (Provence)	Vase	n/r	n/r	n/r	Mature	0.50	0.75	0.70	n/r	n/r	n/r
Persimmon (*Diospyros kaki* L.f.)												
Kanety et al. (2014)	Triumph (*n/r*)	n/r	n/r	n/r	BS	9–11		0.95			0.62	
Intrigliolo et al. (2018)	Rojo Brillante (*Diospyros lotus*)	Vase	0.33	2.9	BS	Mature	0.27	0.87	0.50			
						Interm	0.19	0.60	0.35			
						Young	0.05	0.17	0.10			
Ballester et al. (2022)	Rojo Brillante (*Diospyros lotus*)	Vase	0.33	2.9	BS	9				0.10	0.53	0.15
			0.15	2.7		5				n/r	0.40	0.20
			0.16	2.7		6				0.15	0.48	n/r
Tea (*Camellia sinensis* L.)												
Sikka et al. (2009)	B-6	n/r	n/r	n/r	n/r	2	0.55	1.25	0.40	n/r	n/r	n/r
Borkar et al. (2010)	n/r	n/r	n/r	n/r	n/r	Mature	0.73	0.95	n/r	n/r	n/r	n/r
Zheng et al. (2021)	Baiye1	n/r	n/r	0.77	n/r	4	0.68	0.76	0.44	n/r	n/r	n/r
						5	0.56	0.84	0.68			
	Longjing43	n/r	n/r	0.88	n/r	4	0.73	0.88	0.63	n/r	n/r	n/r
						5	0.76	1.01	0.81			
Yan et al. (2022)	Anji White	n/r	n/r	n/r	Bare soil	3	0.95	0.95	0.95	n/r	n/r	n/r
						4	1.00	1.00	1.00			
						5	1.00	1.00	1.00			

Abbreviations and symbols are defined in list of symbols heading

Table 12 Initial, mid-, and end-season standard single and basal crop coefficients of avocado, loquat, persimmon, and tea plantations as related with the training system, fraction of ground cover and with indication of ranges of observed K_c and K_{cb}, and of former tabulations of standard values

Degree of ground cover, training, and plant density	f_c	*h* (m)	Crop stages	M_L	F_r	Ranges of observed values		Ranges of previously tabulated values		Proposed values	
						K_{cb}	K_c	K_{cb}	K_c	K_{cb}	K_c
Avocado (*Persea americana* Mill.)											
Young (< 3 years), vase	< 0.20	< 2.0	Ini	1.5	1.00	0.50	–	–	–	0.30	0.50
			Mid	1.7	1.00	0.30	–	–	–	0.35	0.50
			End	1.7	1.00	0.50	–	0.25	0.40	0.35	0.50
Low density, vase (< 300 pl/ha)	0.20–0.35	2.0–3.0	Ini	1.5	0.80	–	–	0.60	0.65	0.45	0.60
			Mid	2.0	0.80	–	–	0.50	0.60	0.55	0.65
			End	2.0	0.75	–	–	–	–	0.50	0.65
Medium to high, vase (300–400 pl/ha)	0.35–0.60	3.0–4.0	Ini	1.5	0.65	0.25–0.35	0.60–0.85	0.30–0.50	0.50–0.60	0.65	0.80
			Mid	2.0	0.70	0.50–0.55	1.15–1.20	0.80–0.85	0.85–0.90	0.75	0.85
			End	2.0	0.70	0.30	0.60	0.70–0.80	0.75–0.80	0.70	0.85
Very high, vase (> 400 pl/ha)	> 0.60	> 4.0	Ini	1.5	0.60	0.70	0.75–1.00	0.30	0.50	0.80	0.90
			Mid	2.0	0.80	1.00	1.00–1.05	0.95	1.00	0.90	1.00
			End	2.0	0.60	0.60	1.00	0.85	0.90	0.80	0.90
Hedgerow, medium density (300–400 pl/ha)	0.35–0.60	3.5–4.0	Ini	1.5	0.80	–	0.50	–	–	0.70	0.80
			Mid	2.0	0.80	–	0.71	–	–	0.75	0.85
			End	2.0	0.75	–	0.50	–	–	0.70	0.80
Hedgerow, high density (> 400 pl/ha)	0.60–0.85	> 4.0	Ini	1.5	0.75	–	0.60	–	–	0.85	0.90
			Mid	2.0	0.80	–	1.00	–	–	0.95	1.00
			End	2.0	0.75	–	0.70	–	–	0.85	0.90
Loquat (*Eriobotrya japonica* Lindl.)											
Young (4 < years), vase	< 0.25	< 2.5	Ini	1.1	1.00	–	–	–	–	0.30	0.50
			Mid	1.3	1.00	–	–	–	–	0.35	0.55
			End	1.3	1.00	–	–	–	–	0.35	0.55
Low to medium, vase (450–600 pl/ha)	0.25–0.50	2.5–3.5	Ini	1.5	0.60	–	0.50	–	–	0.40	0.55
			Mid	2.0	0.75	–	0.75	–	–	0.65	0.75
			End	2.0	0.70	–	0.70	–	–	0.60	0.70
High, vase (> 600 pl/ha)	> 0.50	> 3.5	Ini	1.4	0.50	–	–	–	–	0.50	0.60
			Mid	2.0	0.70	–	–	–	–	0.75	0.85
			End	2.0	0.60	–	–	–	–	0.65	0.75
Persimmon (*Diospyros kaki L.f.*)											
Young (< 5 years)	< 0.15	< 2.0	Ini	1.5	1.00	-	0.05	–	–	0.15	0.35
			Mid	1.6	1.00	-	0.17	–	–	0.25	0.40
			End	1.3	1.00	-	0.10	–	–	0.10	0.25

Table 12 (continued)

Degree of ground cover, training, and plant density	f_c	h (m)	Crop stages	M_L	F_r	Ranges of observed values K_{cb}	Ranges of observed values K_c	Ranges of previously tabulated values K_{cb}	Ranges of previously tabulated values K_c	Proposed values K_{cb}	Proposed values K_c
Low to medium (300–500 pl/ha)	0.15–0.40	2.0–2.5	Ini	1.5	0.65	0.10–0.15	0.19–0.27	–	–	0.15	0.30
			Mid	2.0	0.85	0.40–0.53	0.60–0.87	–	–	0.55	0.65
			End	2.0	0.50	0.15–0.20	0.35–0.50	–	–	0.20	0.35
High (500–800 pl/ha)	0.40–0.60	2.5–3.0	Ini	1.5	0.65	–	–	–	–	0.20	0.35
			Mid	2.0	0.80	0.62	0.95	–	–	0.80	0.90
			End	2.0	0.50	–	–	–	–	0.45	0.50
Tea (*Camellia sinensis* L.)											
Young (<2 years), low hedgerow (7000–13500 pl/ha)	<0.50	<0.70	Ini	1.2	1.00	0.85	0.55	–	–	0.60	0.80
			Mid	2.0	1.00	0.85	1.31	–	–	0.70	0.90
			End	2.0	1.00	0.85	0.36	–	–	0.70	0.90
Mature, hedgerow (7000–13500 pl/ha)	0.50–0.90	>0.70	Ini	2.0	1.00	0.95–1.05	–	0.90	0.95	0.95	1.05
			Mid	2.0	1.00	0.95–1.05	0.78–1.00	0.95	1.00	0.95	1.05
			End	2.0	1.00	0.95–1.05	–	0.90	1.00	0.95	1.05

Abbreviations and symbols are defined in list of symbols heading

and related transfer for different locations and diverse climate conditions.

Acknowledgements The support of the FCT—Fundação para a Ciência e a Tecnologia, I.P., under the project UIDB/04129/2020 of LEAF-Linking Landscape, Environment, Agriculture and Food, Research Unit, and to P. Paredes (DL 57/2016/CP1382/CT0022) are acknowledged, as well as the FAO LoA FAO-ISA-RP- 355071. R. López-Urrea and F. Montoya thank the support from the Education, Culture and Sports Council (JCCM, Spain) (Award numbers SBPLY/21/180501/000070 and SBPLY/21/180501/000152) and the Agencia Estatal de Investigación with FEDER (grant numbers PID2021–123305OB-C31, and PID2020–113498RB-C21), and Next-GenerationEU (TED2021–130405B-I00) co-financing. R. López-Urrea also thanks all the support from his former workplace (Instituto Técnico Agronómico Provincial, ITAP) while this study was being carried out.

Author contributions LSP, PP, FM, RLU designed and contributed to the search and selection of the reviewed articles; LSP wrote the main manuscript text, with the contribution of PP, FM, RLU, and MS, and CMO revised the horticultural issues and tabulation. All authors revised the text and agreed on the submitted version of the manuscript.

Funding Open access funding provided by FCT|FCCN (b-on). This article is funding by Fundação para a Ciência e a Tecnologia, UIDB/04129/2020, UIDB/04129/2020, UIDB/04129/2020, Ministerio de Educación, Cultura y Deporte, SBPLY/21/180501/000070, SBPLY/21/180501/000070.

Declarations

Conflict of interest The authors declare no competing interests.

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