Irrigation Science
https://doi.org/10.1007/s00271-024-00964-0

REVIEW

Single and basal crop coefficients for temperate climate fruit trees, vines and shrubs with consideration of fraction of ground cover, height, and training system

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Received: 13 May 2024 / Accepted: 26 July 2024
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Abstract

The objective of the present review article was to update the standard single (K_c) and basal (K_{cb}) crop coefficients published in the FAO Irrigation and Drainage Paper No. 56 (FAO56), focusing on temperate climate fruit trees (pome, stone and nut fruit trees), vines and shrubs (kiwi, hop and blue- and blackberries). Standard conditions refer to crops grown in medium to large fields, having enough fetch for non-impeding accurate use of flux measuring equipment to represent non-limiting conditions of crop evapotranspiration, ET_c. Moreover, the crop needs to be managed without soil water deficit, free of pests and diseases, and must be able to reach full production under the given environmental conditions. For this purpose, more than 150 articles published over the last 25 years were reviewed. Of these, we selected 76 that refer to case studies that reporting on appropriate yield conditions, describe adequate ET_c measurement and adopt the FAO reference evapotranspiration or another method closely related to it. The selection of papers to be analysed followed the same methods as the companion papers on Mediterranean woody fruit crops (Pereira et al. 2023), and on tropical and subtropical ones (Paredes et al. 2024). The literature review focused on articles that are in line with the FAO56 methodology; that is, where the grass reference evapotranspiration (ET_o) was computed with the FAO Penman–Monteith ET_o, the ASCE Penman–Monteith ET_o equations, or other equations whose results relate well to the former. In addition, where the crop evapotranspiration (ET_c) and/or crop transpiration (T_c) were determined with sufficient accuracy from field observations in crops grown under standard, well-watered conditions, i.e., under pristine (i.e., non-stress cropping conditions) or eustress (i.e., "good stress") conditions. Information collected from the selected studies included cultivar and rootstock, plant density and spacing, training system, fraction of ground cover or intercepted PAR radiation, crop height and age. Additional data were gathered on irrigation system and strategy for full or deficit irrigation. The K_c and K_{cb} values reported were recomputed and grouped according to the degree of ground cover, training system and plant density. Thus, the proposed tabulated standard K_c and K_{cb} values for initial, mid- and end-season are based on the values obtained from field observations reported in the selected papers, and on the ranges of K_c/K_{cb} values previously tabulated, mainly in FAO56. The currently tabulated values are updated, with the aim being their use in orchard management. They should consist of the upper limit of K_c/K_{cb} application, and take into account the general awareness of water scarcity and water conservation, thus helping improve the accuracy in estimating crop water requirements and optimizing irrigation scheduling.

Introduction

The global harvested area of irrigated fruit trees and vines has increased in recent years (FAO 2021). Accurate knowledge of their water needs is crucial for estimating irrigation requirements, planning and managing crop water use, determining the availability and demand of water resources at the basin level, and supporting hydrologic studies. Given that irrigated agriculture is the primary water user, far outweighing the demand for other purposes (e.g., for industrial and domestic use), the accuracy of evapotranspiration

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Published online: 16 September 2024

estimations is essential, especially in cases of water scarcity, and because sustainable irrigation requires crop demand not to be exceeded in order to curb the tendency for water overuse (Pereira et al. 2009; López-Urrea and Chávez 2019). Moreover, related challenges are increasingly difficult to deal with due to the need to feed an ever-growing world population (expected to reach 10 billion people in 2050), under conditions of decreased water supply reliability, droughts, climate change and uncertainties linked to poorly engaged water resource governance. Therefore, a more efficient and sustainable use of natural resources is mandatory, with water being among the most important factors in crop productivity (Renard and Tilman 2019).

Crop evapotranspiration (ET_c) is generally estimated using weather data and physical, physiological and aerodynamic parameters related to the crop that govern the evapotranspiration process. The FAO56 approach is often used, which calculates ET_c by multiplying the precisely defined FAO-PM grass reference evapotranspiration (ET_o) by a crop coefficient (K_c), i.e., $ET_c = K_c\ ET_o$ (Allen et al. 1998; Pereira et al. 2021a). Reference ET represents the actual evaporative demand of the atmosphere and K_c integrates the physical and physiological differences between the crops and the grass reference surface in terms of ET (Pereira et al. 1999). The K_c–ET_o approach is easy to apply but its implementation calls for the highest level of computation and measurement accuracy, especially when obtaining crop coefficients for a specific crop based on ground observations (Allen et al. 2011a, b).

Another approach considered in FAO56 is the dual crop coefficient method, which consists of $K_c = K_{cb} + K_e$, the sum of the basal crop coefficient (K_{cb}) and an evaporation coefficient (K_e), the first representing crop transpiration (T_c) and the second referring to soil evaporation (E_s). This approach allows us to perceive how the wetting events are used, respectively, for crop growth and yielding or for evaporation from the top soil. It is computationally more intensive than the single K_c approach and needs to be performed on a daily basis, thus necessitating the use of computers. The use of this approach is recommended when improved estimates for K_c are needed, e.g., for daily schedule irrigations for individual fields, mainly for incomplete cover crops as orchards, or for increased accuracy in hydrologic studies (Allen et al. 1998).

FAO56 (Allen et al. 1998) established the concept of standard K_c and K_{cb}, which refer to pristine and/or eustressed cropping conditions, with the intention being to ensure their transferability. Thus, there is a need to avoid ET measurements over small expanses of crop vegetation because effects of local advection may lead to overestimating ET_c. Measurements are typically biased since the internal boundary layer above the vegetation may not be in equilibrium with the surface and may not have developed up to the height of any meteorological or flux instrumentation (Allen et al. 2011a). For further information on the advection effects on crop coefficients, the reader is referred to the companion paper by Pereira et al (2023). The tabulated crop coefficients (K_c and K_{cb}), which represent the upper limits of the actual crop coefficients, must refer exclusively to standard K_c and K_{cb} values. In practice, however, many fruit tree orchards and vineyards are managed under sub-optimal conditions due to water or salt stress, non-uniform irrigation, irregular plant density, inadequate soil management, cultural practices (e.g. pruning, thinning, fertilizing), and other factors. Under these circumstances, the observations refer to actual crop ET ($ET_{c\ act}$) and not standard ET_c, with $ET_{c\ act} \leq ET_c$, being equal to ET_c only when the crop is well-watered and managed in a pristine or eustress condition (Pereira et al. 2023). The resulting actual ET_c then consists of the product of ET_o by $K_{c\ act,}$ which represents K_c affected by a stress coefficient (K_s), which describes the effect of water and/or salt stress on crop ET. When using the dual crop coefficient method, only crop transpiration is affected, thus only K_{cb} is modified, i.e., $K_{c\ act} = K_{cb}\ K_s + K_e$, where the last term is the coefficient of soil evaporation not affected by stress (Allen et al. 1998).

Considering the scarcity of water resources, many studies have focused on applied deficit irrigation strategies for fruit trees and vines, or to assume fruit quality targets (Intrigliolo and Castel 2011; Romero et al. 2013; Martínez-Moreno et al. 2023). Alternatively, eustress can be adopted, consisting of mild and controlled water stress that should favour yield quality with minimal reduction of yield quantities. Thus, to improve water use and irrigation management for fruit trees and vines, it is essential to expand accurate knowledge on crop water requirements and the impacts of their deficits, and to define eustress issues. However, to date, only a few studies have provided tabulated standard K_c and K_{cb} values for fruit trees and vines over the growing season. The FAO56 (Allen et al. 1998) is likely the first and main reference for K_c/K_{cb} values for vegetables, field, and woody crops. More recently, Jensen and Allen (2016) and Rallo et al. (2021) reported K_c and K_{cb} values for fruit tree crops taking the earlier research into account.

Allen and Pereira (2009) developed a method for predicting crop coefficients from the fraction of ground cover/shaded by the canopy and plant height, commonly referred to as the A&P approach. In this approach K_{cb} values along the plant season are a function of a density coefficient (K_d) and a K_{cb} at maximum plant growth near full ground cover ($K_{cb\ full}$). K_d describes the increase in K_{cb} with increasing vegetation density thus as a function of the fraction of ground covered by the crop (f_c), mean plant height (h) and a multiplier for f_c relative to canopy density and shading (M_L). M_L reflects the density and thickness of the canopy and sets an upper limit on the relative magnitude of transpiration per unit of ground area as represented by f_c. $K_{cb\ full}$ is computed as a function of h and adjusted for both stomatal control of transpiration (F_r) and to the climatic conditions prevailing across each crop development stage. The F_r parameter applies a downward adjustment ($F_r \leq 1.0$) to $K_{cb\ full}$ and consequently to K_{cb}, if the vegetation has stronger stomatal control of transpiration than is typical for agricultural crops (Allen and Pereira 2009; Pereira et al. 2021b).

The A&P approach performs particularly well for fruit trees and vines (Pereira et al. 2020). Using ground and remote sensing data, the A&P approach was validated and parameterized for a large number of crops, namely for tree and vine crops, for non-stressed conditions, and so approximate to standard. The resulting calibrated parameters of the A&P approach from these studies were therefore tabulated to support further applications (Pereira et al. 2020, 2021b). Moreover, the computed K_{cb} and K_c values were also included in those tables. The A&P approach has been further applied to support irrigation management, e.g., in the Satellite Irrigation Management Support used in California (Melton et al. 2020) and citrus orchards in Syria (Darouich et al. 2023), as well as to derive crop coefficients for various tree crops in Portugal (Paço et al. 2012), South Africa (Mashabatu et al. 2023; Ntshidi et al. 2023) and in Italy (Vinci et al. 2023).

The main aim of this review article was to update and tabulate standard single (K_c) and basal (K_{cb}) crop coefficients for temperate climate pome, stone and nut fruit trees, and vines and shrubs managed under non-stress or eustress conditions. The current review is expected to determine the most significant results of recent research on standard K_c and K_{cb} values and their range of variation, assessing the methodologies used for determination of crop ET and crop coefficients. The tables also include ancillary data aiming to support models used to supplement K_c/K_{cb}, namely plant density and training system, fraction of ground cover and plants height, as well as the parameters of the A&P approach corresponding to the tabulated K_{cb}, which facilitate further use of this approach in field and irrigation management.

Materials and methods

Accuracy requirements in determining crop evapotranspiration

With the aim of providing accurate updated standard K_c and K_{cb} values, it was necessary for the crop ET data reported in the literature to be free of biases and errors that would compromise their accuracy. In this sense, the studies by Allen et al. (2011a, b), and later by Pereira et al. (2021a), described the main methods for measuring actual ET_c or indirectly deriving ET_c estimates, emphasizing the accuracy requirements in measurements and the main pitfalls to avoid.

A variety of measurement systems and different approaches are used to determine crop ET or T in the field, such as lysimeters (Lys), eddy covariance (EC), the Bowen ratio energy balance (BREB), soil water balance (SWB), sap flow (SF), remote sensing from vegetation indices (RSVI) and energy balance (RSEB). When used correctly, the accuracy of the described measurement systems can be very high. However, understanding the underlying physics of turbulence and transfer of heat, water and energy that govern measurement is crucial to avoid subtle biases and errors that will compromise the accuracy of the data (Allen et al. 2011a, b). For the purpose of producing representative and reliable data, the deployment of equilibrium air-boundary layer systems, such as EC and BREB, must obey fetch requirements and minimum equipment heights. BREB methods must incorporate representative measurements of net radiation and soil heat flux density, as well as of the vertical gradients of temperature and relative humidity, which typically require multiple locations for sensors when used in spatially non-uniform systems. Measurements of EC require physically based "corrections" to obtain the so-called energy balance closure,where the sum of latent, sensible and soil heat fluxes equals net radiation (Twine et al. 2000; Rambikur and Chávez 2014). When ET measurement systems are occasionally used by people who have insufficient training or experience significant measurement bias may occur.

Lysimeters and SWB potentially provide reliable measurements but only if fundamental criteria for representativeness of vegetation and environmental conditions are met (Evett et al. 2006; 2012). SF sensors rely on empirical correction factors derived from the physiology and anatomy of species under observation, and on the accuracy of the scaling techniques used to go from branch or tree to a group of plants and larger area estimates of the transpiration component, to which evaporation from soil must be added (e.g. Testi and Villalobos 2009).

In order to achieve high data integrity, readers are referred to studies by Allen et al. (2011a, b) and Pereira et al. (2021a) where a detailed description of the necessary and desired information in support of each ET measurement and estimation method is provided. Furthermore, different problems and requirements related to each of them are discussed, as analysed in the companion papers.

Requirements for transferability of standard single and basal crop coefficients and criteria used to select the source articles

For transferability purposes, FAO56 adopted the concept of standard K_c/K_{cb} and potential ET_c (Allen et al. 1998), which refer to well-watered and pristine or eustress cropping conditions. These are often different from actual field conditions, frequently under-optimal due to insufficient (or non-uniform) irrigation, crop density, salinity, agronomic practices and soil management. As discussed in the introduction, the tabulated K_c must refer exclusively to standard K_c. For tree and vine crops, the standard K_c often refers to adopting crop-specific eustress practices, i.e., limited stress practices that result in no or minimal (non-significant) yield reduction relative to the maximum obtainable yield (Pereira et al. 2023; Paredes et al. 2024).

Several hundred papers have been published over the past 25 years reporting the determination of ET_c and updated K_c/K_{cb} values for a wide variety of fruit trees and vines. Although the information these papers provide was sufficient to achieve the proposed respective objectives, making the reported K_c/K_{cb} values transferable to different environments is not enough. Moreover, many of these articles lacked information on the techniques and instrumentation used, meteorological conditions, and the crops and the cultivation practices considered, meaning their transferability is significantly limited and are thus not usable in the present review. The numerous issues limiting the transferability of K_c/K_{cb} data were recently reviewed by Pereira et al. (2021a, c, 2023) and were taken as selection criteria, as detailed in this section. These limitations prompted us to conduct a meticulous review of published articles to check when reported K_c/K_{cb} values are only of local (site-specific) interest (use) and/or represent non-standard experimental conditions, contrasting with K_c/K_{cb} data obtained under eustress and pristine cropping conditions, thus being transferrable to other locations and production environments.

The review focused on papers published after the FAO56 guidelines (Allen et al. 1998), until May 2024. As for the companion papers, the databases used for the search were Scopus, WoS, Google Scholar, Elsevier, Springer, Wiley, CSIRO and Scielo, the engines of journals where papers on K_c are published, as well as using different keywords, specifically crop coefficient, evapotranspiration, water use, water requirements, irrigation and species names (common and scientific). The languages used were English, French, Italian, Persian, Portuguese and Spanish.

Following the methodology described in the companion papers by Pereira et al. (2023) and Paredes et al. (2024), the source articles were selected from among all papers, aiming to meet the following research requirements:

i) use of the standard FAO-PM-ET_o equation, the grass ASCE-PM-ET_o equation, or other ET equations having recognized ratios between the results of that ET_o equation and the FAO-PM-ETo equation;

ii) reported results based on two or more cropping seasons, or studies having different treatments, allowing for the analysis of the consistency of data between experimental seasons, which may depend on various factors, such as weather conditions and crop management practices;

iii) studies conducted in experimental plots with an adequate size to allow local advection effects to be minimized;

iv) plots adopting appropriate crop management practices to favour the control of biotic and abiotic stresses;

v) use of the FAO K_c curve with identification of the four crop growth stages, or presentation of K_c results in such a way as to facilitate the identification of K_c/K_{cb} values for the mid-season and, when possible, for the initial and end-season;

vi) reporting on field experiments using EC and BREB systems including fetch length in predominant wind directions, thresholds for data filtering, discussion on the closure error and method of closure;

vii) studies based on the SWB approach should sufficiently describe the terms of the balance, use adequate number of sensors and their positioning in field and with depth, allowing the soil water fluxes to be correctly monitored, and providing reasonably good results of the calibration and validation of the model when used;

viii) relative to lysimeter measurements, that describe the equipment, its location and consider the environmental factors to which they are highly sensitive (e.g. ‘‘oasis’’ and ‘‘cloth-line’’ effects) as well as fetch;

ix) reference studies on remote sensing with vegetation indices or energy balance based on adequate ground observations aimed at their calibration/validation;

x) reporting acceptable crop coefficient values ($K_{c\ mid} \leq 1.30$, $K_{c\ mid} > K_{c\ end}$, and $K_{cb} < K_c$) unless convincing explanations were given (see Allen et al. 2011a).

Studies reporting values of $K_{cb} > K_c$ and those evidencing stressed crops were removed. For this reason, papers should show that crops were grown under well-watered conditions and managed in near-pristine or eustress conditions. Therefore, to avoid misunderstandings, these concepts were first defined.

The chosen criteria allowed for the selection of 76 papers of reasonable to excellent quality, covering numerous species, and carried out in a wide range of regions and environments around the world. Readers are referred to the original articles to make their own assessment on their suitability for the use of the tabulated information.

Tabulation of updated standard single and basal crop coefficients

The ranges of observed K_c and K_{cb} values gathered from the chosen papers and the values tabulated since 1998 were taken into consideration when standard values of K_c/K_{cb} were produced. A detailed description of the steps followed to build the new tables of standard K_c and K_{cb} values can be found in the companion paper by Pereira et al (2023). An overview of these steps is as follows:

1) from the studies, information was obtained related to: plant density (spacing), training system, fraction of ground cover (f_c) or fraction of intercepted radiation (f_{IPAR}) which is assumed as an estimate of f_c, and crop height (h);
2) a provisional table was built for each crop including the range of observed K_c/K_{cb} values, as well as those previously tabulated (Allen et al. 1998; Allen and Pereira 2009; Jensen and Allen 2016; Rallo et al. 2021);
3) a draft of tentative K_c/K_{cb} values for initial, mid- and end-season was defined for each crop, establishing different categories based mainly on the f_c and h ranges, and the training system;
4) for each crop and range of f_c and h, K_{cb} values were computed applying the A&P approach (Allen and Pereira 2009), discussed in the introduction, using the parameters h, M_L and F_r available from Pereira et al. (2021c), or adjusting these parameters for crops not yet studied by comparison with values relative to crops with similar characteristics;
5) defining the standard K_c values by summing the estimated values of K_e for each stage with the defined standard values of $K_{cb\ ini}$, $K_{cb\ mid}$ and $K_{cb\ end}$. The estimated values of K_e were obtained by observing the differences (K_c-K_{cb}) in the selected papers and in the previously published tables, considering changes in K_c due to rainfall, and assuming a reduced soil evaporation due to using drip or micro-sprinkling under the canopies, and/or for a large plant density and use of mulches. Young plantations are assigned with larger K_e values. K_e were assumed to be smaller for the mid-season.
6) Consolidation of the draft standard K_c and K_{cb} by comparing all K_c/K_{cb} values for: (i) various plant densities and ground cover fractions of the same crop; (ii) the various crops of the same group; and (iii) between K_c and K_{cb}.

The tabulated information for each crop consists of the cultivar and rootstock, the location and climate, the method for determining the actual ET_c and the reference ET_o, the irrigation method and the strategy relative to water stress if used, the plant spacing and density, the training or trellis system, the tree or vine age and height, and the fraction of ground cover or intercepted radiation. Another table is used to present the K_c and K_{cb} values derived from field determinations of crop ET or T, as well as the relevant data for analysis of the K_c and K_{cb} values. Other factors affecting crop water requirements, such as pruning, fruit thinning and fruit load, were not considered due to a lack of information in the selected papers. The tabulated style adopted is in line with that adopted for Mediterranean and tropical and subtropical woody fruit plants (Pereira et al. 2023; Paredes et al. 2024).

Tabulated standard K_c and K_{cb} values

This article focuses on temperate climate fruit trees, vines and shrubs. The best-known temperate tree fruits belong to the Rosaceae family and include pome fruits such as apple and pear, and stone fruits, such as apricot, cherry, peach and plum. The annual cycle of deciduous fruit trees in temperate climates is characterized by a dormant phase and a growing and fruiting phase. The annual cycle extends from the initial budbreak and fruit setting (initial stage), active growth (mid-season) and growth cessation (end-season). During the dormant period, trees need to be exposed to a certain number of chilling hours to synchronize budbreak and flowering, favouring potential production. However, the extent of chilling requirements varies with species and cultivar. With special techniques designed to overcome dormancy, some tree crops from temperate zones can grow at lower latitudes in much warmer climate conditions, i.e. tropical and subtropical regions (Pio et al. 2019). However, under climate change conditions, the required chilling period may not be achieved and a warmer winter shifts flowering forward, which can provoke frost damage by the beginning of spring (Salama et al. 2021).

The most common soil management in orchards consists of natural grass sward in alleys (with multiple cuts) and herbicide application to control weeds along the rows. During the summer, in temperate climate regions, as well as in Mediterranean countries, the inter-row natural grasses dry out turning into organic mulch. The use of inter-row planted grasses has rarely been reported.

Pome fruit trees

With an area of around 4.8 million hectares, the apple (*Malus domestica* Borkh.) is one of the most important deciduous fruit trees in the world. The main producer is China, followed by the USA. Pear (*Pyrus communis* L) production is also significant, with around 1.4 million hectares harvested. The main producers are China, Argentina, USA, and Italy (FAOSTAT 2023). These fruit tree species have the most technologically advanced production system, typically in high-density orchards, with dwarf rootstocks and trellis training systems, which enable high productivity and profitability. European pome orchards are predominantly pedestrian, i.e., all work is done from the ground, eliminating the need for ladders.

Table 1 shows the main characteristics of apple and pear orchards obtained from the 20 selected papers. The selected pome fruit studies were carried out in a wide range of locations around the world (in 9 countries, including Spain, South Africa, Portugal and Australia). This

Table 1 Characteristics of the selected pome fruit orchards

Author	Cultivar (rootstock)	Location & main *climate*	$ET_{c\ act}$ method (ET_o equation)	Irrig. Method & strategy	Plants/ha (Spacing m)	Training system	Age (years)	Height (m)	f_c or f_{IPAR} [a]
Apple (*Malus domestica* Borkh)									
Girona et al. (2011)	Golden Smoothee (M9, dwarf)	Lerida, Spain *Med*	WL (FAO-PM-ET_o)	Drip & FI	1563 (4 × 1.6)	Mod central leader	3 4 5 6 7	3.00 3.30 3.65 3.61 3.61	0.29 0.34 0.40 0.41 0.46
Marsal et al. (2013)	Golden Smoothee (M9, dwarf)	Lerida, Spain *Med*	WL (FAO-PM-ET_o)	Drip & FI	1563 (4 × 1.6)	Mod central leader	3–11	3.00–4.40	0.35–0.66
Marsal et al. (2014b)	Golden Smoothee (M9, dwarf)	Lerida, Spain *Med*	WL (FAO-PM-ET_o)	Drip & FI	1563 (4 × 1.6)	Mod central leader	8 11	3.00 4.10	0.65 0.65
Odi-Lara et al. (2016)	Pink Lady (M7, semi vig)	Talca Valley, Chile *Med*	EC (FAO-PM-ET_o)	Drip & FI	1667 (4.0 × 1.5)	Solaxe system	2 4	3.50–4.00	0.30 0.40
Volschenk (2017)	Golden Delicious (M793, vig)	Koue Bokkeveld, Western Cape, SA, *Med*	SWC-neutron (FAO-PM-ET_o)	Micro-spr & FI	1481 (4.5 × 1.5)	n/r	13	> 3.50	n/r
Gush et al. (2019)	Pink Lady (M793, vig)	Ceres, West. Cape, South Africa *Med*	SF, EC, S-W model (FAO-PM-ET_o)	Micro-spr & n/r	2000 (4.0 × 1.25)	n/r	12	5.10	n/r
Zanotelli et al. (2019)	Fuji (M9, dwarf)	South Tyrol, Italy *Humid, cold winter*	EC (ASCE-PM-ET_o)	Sprinkler, drip & FI	3333 (3.0 × 1.0)	Spindle bush	13–15	3.50–4.00	0.70
Mobe et al. (2020)	Golden Delicious	Koue Bokkeveld, Western Cape, South Africa *Med*	SF (FAO-PM-ET_o)	Micro-spr & FI	1667 (4.0 × 1.5)	n/r	22	4.50	0.64
	Cripps Pink						9	2.80	0.64
	G Delicious Reinders®						3	2.00	< 0.20
	Rosy Glow				2268 (3.5 × 1.25)		4	3.00	< 0.20
	G Delicious Reinders®	Western Cape, RSA *Med*			1250 (4.0 × 2.0)		5	3.00	0.26–0.37
	Cripps Pink						6	4.00	0.26–0.37
Jia and Wang (2021)	Red Fuji (n/r)	Yulin, Shaanxi, China *Cold win, hot sum*	SF (FAO-PM-ET_o)	n/r & FI	500 (5.0 × 4.0)	n/r	7 8	2.82	n/r
Hardie et al. (2022)	Galaxi (M26, semi dwarf)	Huon Valley, Tasmania *Humid, temperate*	SF (FAO-PM-ET_o)	Drip & SDI	2100 (4.0 × 1.2)	Central leader	10	n/r	n/r
Sousa et al. (2022)	Gala (M9, dwarf)	Alcobaça, Portugal *Med. Subhumid*	SWB-FDR, model CSS. Pome (FAO-PM-ET_o)	Drip & FI	Various	Central leader	Mature	n/r	> 0.50

Table 1 (continued)

Author	Cultivar (rootstock)	Location & main *climate*	$ET_{c\ act}$ method (ET_o equation)	Irrig. Method & strategy	Plants/ha (Spacing m)	Training system	Age (years)	Height (m)	f_c or f_{IPAR} [a]
Pear (*Pyrus communis* L.)									
Naor et al. (2000)	Spadona (Quince, low vig)	Upper Galilee, Israel *Dry sum, Temp win*	SWB-tensiom (ClassA pan ET_o)	Drip & SDI and RDI	988 (4.5 × 2.25)	n/r	15	n/r	n/r
Girona et al. (2004)	Conference (MA Quince, low vig)	Lerida, Spain *Dry, hot*	WL (FAO-PM-ET_o)	Drip & FI	1562 (4.0 × 1.6)	Palmette	4	n/r	0.35
Girona et al. (2011)	Conference (MA quince, low vig)	Lerida, Spain *Dry, hot*	WL (FAO-PM-ET_o)	Drip & FI	1562 (4.0 × 1.6)	Mod central leader	4 5 6 7 8	2.10 2.20 2.64 2.90 2.95	0.35 0.38 0.44 0.45 0.45
Eid and Abou Grah (2012)	Le-Conte (*P. communis,* vig)	Kalyubia, Egypt *Dry, hot*	SWB gravim (FAO-PM-ET_o)	Surface & FI	400 (5.0 × 5.0)	Vase	23	n/r	n/r
Goodwin et al. (2012, 2014)	Williams' Bon Chrétien (*P. calleryana* D6, high vig)	Shepparton, Victoria, Australia *Dry sum, warm win*	SF (FAO-PM-ET_o)	Microjets & FI	1111 (4.5 × 2.0)	Central leader	n/r	n/r	0.61
		Ardmona, Victoria, Australia *Dry sum, warm win*	SF (FAO-PM-ET_o)	Drip & FI	2222 (4.5 × 1.0)	2-leader on Open trellis	5	n/r	0.59
Marsal et al. (2014a)	Conference (MA quince, low vig)	Lerida, Spain *Dry, hot*	WL (FAO-PM-ET_o)	Drip & FI	1562 (4.0 × 1.6)	Mod central leader	4 5 6 7 10	2.10 2.20 2.60 2.90 3.60	0.34 0.35 0.39 0.43 0.42
Marsal et al. (2014b)	Conference (MA quince, low vig)	Lerida, Spain *Dry, hot*	WL (FAO-PM-ET_o)	Drip & FI	1562 (4.0 × 1.6)	Mod central leader	11 12	3.30 3.60	0.60 0.60
Rosa (2018)	Rocha (BA29, semi vig)	Torres Vedras, Portugal *Med*	SWB-FDR, SIMDualKc (FAO-PM-ET_o)	Drip & FI	1250 (4.0 × 2.0)	Central leader	Mature	3.70	0.60
Sousa et al. (2022)	Rocha (n/r)	Alcobaça & Cadaval, Portugal *Med. Subhumid*	SWB-FDR, model CSS. Pome (FAO-PM-ET_o)	Drip & FI	Various	Central leader, Palmette & other	Mature	n/r	>0.50 [b]

[a] f_c or f_{IPAR}: the fraction of ground cover or intercepted radiation; [b] for orchards older than 3 years

broad coverage contributes to the desired perception that the number of studies reviewed is suitable, hence safeguarding the high quality of the review. All reported K_c and K_{cb} values for pome fruit trees (Table 2) were obtained from determinations of crop ET using weighing lysimeters (WL), eddy covariance (EC) systems, or T using sap flow (SF) sensors, or computed with a soil water balance (SWB), as well as using the Shuttleworth-Wallace (S-W) model in an apple tree study in the Western Cape, South Africa (Gush et al. 2019). In all studies, ET_o was calculated using the FAO-PM ET_o equation or similar, except in one study in Upper Galilee, Israel, which used the Class A pan ET_o (Naor et al. 2000).

In most of the selected studies, drip irrigation was used, with full irrigation strategies being adopted. Micro-sprinkler or sprinkler systems were used in only 5 cases. It may be assumed that the selected information on pome fruit trees was obtained under well-watered conditions, near-pristine or eustress conditions, or under mild controlled water stress during selected periods of the growing season, thus corresponding to the conditions defined for standard K_c and K_{cb} values in the revised version of FAO56 (Pereira et al. 2024).

Table 2 Field derived single (K_c) and basal (K_{cb}) crop coefficients of the selected pome fruit orchards

Author	Cultivar (rootstock)	Training system	f_c or f_{IPAR} [a]	Height (m)	Ground cover	Age (years)	K_c /K_{cb} derived from field observations					
							$K_{c\ ini}$	$K_{c\ mid}$	$K_{c\ end}$	$K_{cb\ ini}$	$K_{cb\ mid}$	$K_{cb\ end}$
Apple (*Malus domestica* Borkh)												
Girona et al. (2011)	Golden Smoothee (M9, dwarf)	Mod central leader	0.29	3.00	BS	3	–	0.50	–	n/r	n/r	n/r
			0.34	3.30		4	0.15	0.70	0.40			
			0.40	3.65		5	0.20	0.80	–			
			0.41	3.61		6	0.20	0.90	0.35			
			0.46	3.61		7	0.25	1.05	–			
Marsal et al. (2013)	Golden Smoothee (M9, dwarf)	Mod central leader	0.35	3.00	BS	3	0.25	0.42	n/r	n/r	n/r	n/r
			0.39	3.30		4	0.15	0.55				
			0.45	3.65		5	0.15	0.75				
			0.50	3.61		6	0.20	0.90				
			0.60	3.61		7	0.30	1.05				
			0.63	3.00		8	0.25	0.80				
			0.66	4.40		9	0.15	0.80				
			0.63	4.10		11	0.20	1.00				
Marsal et al. (2014b)	Golden Smoothee (M9, dwarf)	Mod centra l Leader	0.65	3.00	BS	8	n/r	n/r	n/r	0.50	0.90	0.70
			0.65	4.10		11				0.25	1.00	0.70
Odi-Lara et al. (2016)	Pink Lady (M7, semi vig)	Solaxe system	0.30	3.50	AGC Aut-Spr	2	n/r	0.60	n/r	n/r	0.55	-
			0.40	4.00		4		0.77			0.70	0.40
Volschenk (2017)	Golden Delicious (M793, vig)	n/r	n/r	> 3.50	AGC Aut-Spr	13	0.15	0.80	0.40	n/r	n/r	n/r
Gush et al. (2019)	Pink Lady (M793, vig)	n/r	n/r	5.10	n/r	12	0.40	0.76	0.17	0.20	0.60	0.10
Zanotelli et al. (2019)	Fuji (M9, dwarf)	Spindle bush	0.70	4.00	n/r	13	0.50	1.10	0.50	n/r	n/r	n/r
						14	0.50	1.05	0.50			
						15	0.25	1.10	0.50			
Mobe et al. (2020)	G. Delicious Reinders®	n/r	< 0.20	2.00	n/r	3	n/r	n/r	n/r	0.20	0.20	n/r
	Rosy Glow		< 0.20	3.00	n/r	4	n/r	n/r	n/r	0.15	0.20	0.15
	G. Delicious Reinders®		0.26—0.37	3.00	n/r	5	n/r	n/r	n/r	0.30	0.45	0.25
	Cripps Pink		0.26—0.37	4.00	n/r	6	n/r	n/r	n/r	0.40	0.60	n/r
	Golden Delicious		0.64	4.50	n/r	22	n/r	n/r	n/r	0.65	0.70	0.50
	Cripps Pink		0.64	2.80	n/r	9	n/r	n/r	n/r	0.45	0.55	0.25
Jia and Wang (2021)	Red Fuji (n/r)	n/r	n/r	2.80	n/r	7–8	0.43 0.40	0.68 0.82	n/r	n/r	n/r	n/r
Hardie et al. (2022)	Galaxi (M26, semi dwarf)	C. leader	n/r	n/r	AGC Aut-Spr	10	n/r	n/r	n/r	0.10	0.75	n/r
Sousa et al. (2022)	Gala (M9)	C. leader	> 0.50	n/r	AGC Aut-Spr	Mature	n/r	0.85	n/r	n/r	0.57	n/r

Table 2 (continued)

Author	Cultivar (rootstock)	Training system	f_c or f_{IPAR}[a]	Height (m)	Ground cover	Age (years)	K_c /K_{cb} derived from field observations					
							$K_{c\ ini}$	$K_{c\ mid}$	$K_{c\ end}$	$K_{cb\ ini}$	$K_{cb\ mid}$	$K_{cb\ end}$
Pear (*Pyrus communis* L.)												
Naor et al. (2000)	Spadona (Quince, low vig)	n/r	n/r	n/r	n/r	15	n/r	1.00	n/r	n/r	n/r	n/r
Girona et al. (2004)	Conference (MA quince low vig)	Palmette	0.35	n/r	n/r	4	0.22	0.85	0.40	n/r	n/r	n/r
Girona et al. (2011)	Conference (MA quince low vig)	Mod central-leader	0.35	2.10	BS	4	0.40	0.80	0.20	n/r	n/r	n/r
			0.38	2.20		5	0.15	1.10	0.40			
			0.44	2.64		6	0.20	1.00	0.40			
			0.45	2.90		7	0.20	1.00	0.40			
			0.45	2.95		8	0.40	1.00	0.50			
Eid and Abou Grah (2012)	Le-Conte (*P. communis,* vig)	Vase	n/r	n/r	BS	23	0.61	0.86	0.48	n/r	n/r	n/r
					AGC		0.65	0.91	0.50			n/r
					Organ M		0.58	0.79	0.46			n/r
					Bplast M		0.51	0.72	0.43			n/r
Goodwin et al. (2012, 2014)	Williams' Bon Chrétien (*P. calleryana* D6, high vig)	C. leader	0.61	n/r	n/r	n/r	n/r	n/r	n/r	n/r	0.55	n/r
		2-leader on Open trellis	0.59	n/r	n/r	5	n/r	n/r	n/r	n/r	0.60	n/r
Marsal et al. (2014a)	Conference (MA quince, low vig)	Mod central leader	0.34	2.10	BS	4	0.20	0.90	n/r	n/r	n/r	n/r
			0.35	2.20		5	0.15	1.10				
			0.39	2.60		6	0.20	1.05				
			0.43	2.90		7	0.20	1.00				
			0.42	3.60		10	0.25	0.70				
Marsal et al. (2014b)	Conference (MA quince, low vig)	Mod central leader	0.60	3.30	BS	11	n/r	n/r	n/r	0.40	0.90	0.30
			0.60	3.60		12				0.35	0.90	–
Rosa (2018)	Rocha (BA29, semi vig)	C. leader	0.60	3.70	AGC Aut-Spr	Mature	n/r	n/r	n/r	0.60	0.95	n/r
										0.80	1.00	
Sousa et al. (2022)	Rocha (n/r)	C. leader, Palmette & other	> 0.50	n/r	AGC Aut-Spr	Mature	n/r	0.81	n/r	n/r	0.67	n/r

[a] f_c or f_{IPAR} the fraction of ground cover or intercepted radiation

Abbreviations and symbols in the body of all the tables are defined in Appendix 1.

There was a great variability in plant density and spacing, ranging from 400 to 3333 plants/ha (Table 1) as well as in the f_c and h data collected, which is related to age, pruning, training system, and crop management conditions. The canopy training system in most of the orchards was central leader or modified central leader, although there are also some cases of palmette and one case of 2-leader on open trellis. In general, there is a lack of information on pruning, and so it is not included in the tables. However, some studies reported one pruning per year during the wintertime, being severe in the study by Volschenk (2017).

Table 2 shows the actual K_c and K_{cb} values derived from field observations of crop ET or T for all the cultivars and rootstocks of the selected studies. They present great variability (e.g., for apple trees $K_{c\ mid}$ ranged from 0.42 to 1.10 when the trees were 3 and 13 years old, respectively), mainly due to differences in f_c and h, which are directly related to the training system and tree age. In general, determining the end season values was difficult as it is often not well defined. However, after harvesting, during the late growth stage, the trees may be irrigated to support the storage of carbohydrates for the following season, and so it is essential to determine K_c values correctly at this end stage.

Table 3 shows the derived standard initial, mid- and end-season single and basal crop coefficients for apple and pear tree orchards according to the degree of ground cover (DGC), plant density and training system. DGC varies from very low values for young orchards to very high values for full bearing orchards with high plant density. In the case of apple trees, different DGCs correspond to diverse plant densities, trained as central leader. However, for pear trees, different DGCs are related to diverse training systems, which are impacted by the severity of pruning, and to different plant density and spacing. The groups described are also differentiated by ranges of canopy cover and tree height, f_c and h, which may assist in determining the group most suitable for selecting the K_c/K_{cb} values for the given case. In addition, to these values of f_c and h, tabulated values are also provided for M_L, which is a multiplier for 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 for F_r, which is an adjustment factor relative to crop stomatal control [0.0–1.0]. These parameters can be used to compute the values of $K_{cb\ ini}$, $K_{cb\ mid}$ and $K_{cb\ end}$ using the A&P method (Allen and Pereira 2009; Pereira et al. 2021c).

The proposed K_c and K_{cb} values for initial, mid- and end-season presented in Table 3 are based on the ranges of values obtained from field observations reported in the selected papers, and on the ranges of K_c/K_{cb} values previously tabulated in FAO56 (Allen et al. 1998), and in the articles published by Allen and Pereira (2009) and Rallo et al. (2021). Evidently, the crop coefficients increase as the canopy cover increases due to the direct relationship of the latter to the basal K_{cb} representing plant transpiration, while the evaporative component (represented by K_e) is mainly determined by the fraction of ground exposed to solar radiation, the frequency and depth of rainfall or irrigation events, and the energy available at soil surface for water evaporation, which is conditioned by the training system and the radiation intercepted by the canopy, and thus by the f_c values.

Stone fruit trees

Stone fruits include apricots (*Prunus armeniaca* L.), peaches and nectarines (*Prunus persica* L. Batsch), cherries (*Prunus avium* L.), and plums (*Prunus Salicina* Lindl. (Japanese plum) and *P. domestica* (European plum)), which are currently harvested around the world across an area of around 5.1 million hectares producing 43.2 million tons (FAOSTAT 2023). Apricots are mainly grown in Turkey, Uzbekistan, and Iran; the principal producers of peaches and nectarines are China, Spain, Italy, and Turkey; cherries are grown primarily in Turkey, USA and Chile; and the larger producers of plums include China, Romania, Chile and Serbia. Peaches and nectarines account for 57% of the production of stone fruits and tend to have the highest water demand. In contrast to pome fruit trees, the selection of rootstocks for stone fruit trees depends primarily on soil characteristics and soil pests and diseases.

As for pome fruit trees, the stone fruit trees also require sufficient winter chill to break endodormancy in spring and avoid production problems. Although these fruit trees are characteristic of temperate climates, they are increasingly grown in warmer latitudes, which, also due to global warming, may result in their not receiving the necessary chilling hours. Problems are also associated with late frosts since higher temperatures bring forward blooming and flowering.

Table 4 shows the main characteristics of apricot, cherry, peach, nectarine and plum orchards as collected from the selected papers. The selected studies were conducted in 8 countries representing a variety of locations worldwide, but primarily in Spain, South Africa and USA, including different environmental and crop management conditions. This large coverage contributes to the high quality of the present study. The main methods used for measuring actual ET_c and/or plant transpiration were the SWB using gravimetry and different type of sensors for monitoring the soil water content, WL and SF systems. Also used were drainage lysimeters (DL), EC systems and SWB supported by models such as SIMDualKc and HYDRUS-2D.

Table 3 Initial, mid- and end-season standard K_c and K_{cb} values for pome fruit trees as related to plant density and training, degree/fraction of ground cover and height for apples and pears. The ranges of observed and previously tabulated standard K_c and K_{cb} values are also shown

Degree of ground cover, plant density and training	f_c [a]	h [b]	Crop stage	M_L [c]	F_r [d]	Observed values ranges		Previously tabulated values ranges		Proposed values	
						K_{cb}	K_c	K_{cb}	K_c	K_{cb}	K_c
Apple (*Malus domestica* Borkh)											
Young (< 4 years), central leader	< 0.25	< 3.0	Ini	1.5	1.00	0.20	0.25	0.25	0.40	**0.20**	**0.30**
			Mid	1.4	1.00	0.20–0.55	0.42	0.35–0.65	0.40–0.70	**0.45**	**0.55**
			End	1.3	1.00	–	–	0.25–0.50	0.35–0.55	**0.25**	**0.35**
Low, full bearing, central leader (< 1500 pl/ha)	0.25–0.40	3.0–4.0	Ini	1.6	1.00	0.15–0.40	0.15	0.25	0.40	**0.25**	**0.35**
			Mid	1.4	0.95	0.20–0.70	0.55–0.77	0.45–0.70	0.50–0.75	**0.55**	**0.65**
			End	1.3	0.68	0.15–0.40	0.40	0.30–0.50	0.40–0.60	**0.30**	**0.40**
Medium, full bearing, central leader (1500–3000 pl/ha)	0.40–0.50	3.0–4.0	Ini	1.7	0.90	–	0.15–0.25	0.30–0.50	0.50–0.60	**0.35**	**0.45**
			Mid	1.6	0.85	0.70	0.75–1.05	0.65–1.00	0.70–1.05	**0.75**	**0.85**
			End	1.3	0.60	0.40	0.35–0.40	0.45–0.70	0.55–0.75	**0.35**	**0.45**
High, full bearing, central leader (1500–3000 pl/ha)	0.50–0.70	3.0–4.5	Ini	1.5	0.95	0.10–0.65	0.15–0.50	0.30–0.50	0.50–0.60	**0.40**	**0.50**
			Mid	1.8	0.82	0.55–1.0	0.68–1.10	0.85–1.10	0.90–1.15	**0.90**	**0.95**
			End	1.7	0.50	0.25–0.70	0.50	0.45–0.75	0.50–0.80	**0.50**	**0.60**
Very high, full bearing, central leader (> 3000 pl/ha)	> 0.70	> 3.0	Ini	1.7	0.85	–	–	–	–	**0.45**	**0.55**
			Mid	2.0	0.85	–	–	0.95–1.05	1.0–1.10	**0.95**	**1.00**
			End	2.0	0.45	–	–	0.60–0.65	0.65–0.70	**0.50**	**0.60**
Pear (*Pyrus communis* L.)											
Young (< 5 years), all training systems	< 0.35	< 2.5	Ini	1.6	1.00	–	0.20	0.25	0.40	**0.25**	**0.35**
			Mid	1.3	1.00	–	0.90	0.35–0.65	0.40–0.70	**0.50**	**0.60**
			End	1.1	1.00	–	–	0.20–0.50	0.30–0.55	**0.35**	**0.45**
Low, full bearing, vase (< 1000 pl/ha)	0.35–0.40	2.0–2.5	Ini	1.5	0.95	–	0.15–0.40	–	–	**0.30**	**0.40**
			Mid	1.7	0.90	–	0.80–1.10	0.50–0.55	0.55–0.60	**0.70**	**0.75**
			End	1.5	0.65	–	0.20–0.40	0.35–0.40	0.45–0.50	**0.40**	**0.50**
Medium, full bearing, central leader, (1000–1600 pl/ha)	0.35–0.60	2.5–4.0	Ini	1.5	0.95	0.35–0.80	0.20–0.65	0.30–0.50	0.50–0.60	**0.40**	**0.50**
			Mid	2.0	0.87	0.60–1.0	0.70–1.05	0.80–1.00	0.85–1.05	**0.90**	**0.95**
			End	1.5	0.65	0.30	0.40–0.50	0.60–0.70	0.65–0.75	**0.50**	**0.60**
High, full bearing, central leader, other trellis syst. (> 1500 pl/ha)	> 0.60	> 3.5	Ini	1.8	0.95	–	–	0.30	0.50	**0.55**	**0.65**
			Mid	2.0	0.87	0.55	–	0.95–1.10	1.00–1.15	**1.00**	**1.05**
			End	1.5	0.55	–	–	0.70–0.75	0.75–0.80	**0.60**	**0.70**

Bold values indicate the most relevant information from the review article, i.e., the proposed (updated) K_c and K_{cb} values

[a] f_c: the fraction of ground cover

[b] h: crop height

[c] M_L: a multiplier for f_c describing the effect of canopy density on shading and on maximum relative ET per fraction of ground shaded [1.0–2.0]

[d] F_r: an adjustment factor relative to crop stomatal control [0.0–1.0]

Table 4 Characteristics of the selected stone fruit orchards

Author	Cultivar (rootstock) & Ripening timing	Location & main *climate*	$ET_{c\ act}$ method (ET_o equation)	Irrigation method & strategy	Plants/ha (Spacing m)	Training system	Age (years)	Height (m)	f_c or f_{IPAR} ^{a}
Apricot (*Prunus armeniaca* L.)									
Abrisqueta et al. (2001)	Bulida (Real Fino seedling, vig) & Early	Murcia, Spain *Med. Semi-arid*	SWB-neutron (ClassA pan ET_o)	Drip & FI, DI	156 (8.0 × 8.0)	n/r	9–11	n/r	0.87
Kaya et al. (2013)	Salak (seedling, vig) & Mid-season	Igdir plain, Turkey *Dry, hot*	SWB-gravim (FAO-PM-ET_o)	Drip & SDI	156 (8.0 × 8.0)	n/r	8	n/r	n/r
Villalobos et al. (2013)	Bulida (Real Fino seedling, vig) & Early	Murcia, Spain *Med. Semi-arid*	SF (FAO-PM-ET_o)	Drip & n/r	208 (8.0 × 6.0)	n/r	10	3.90	0.65
El-Naggar et al. (2018)	Canino (seedling, vig) & Mid-season	Kalubeia, Egypt *Dry, hot*	SWB-gravim (FAO-PM-ET_o)	n/r & SDI	400 (5.0 × 5.0)	n/r	18	n/r	n/r
Cherry (*Prunus avium* L.)									
Candogan and Yazgan (2010)	Z-900 dwarf(Gisela-5) & Mid-season	Canakkale, Turkey *Hot and dry sum*	SWC-gravim (FAO-PM-ET_o)	Micro-spr & FI	800 (5.0 × 2.5)	n/r	2–3	2.30–2.60	n/r
Juhász et al. (2013)	Rita (GiSelA 6) semi-dwarf	Soroksár, Hungary *Cold win, rainy sum*	SF, SWB (FAO-PM-ET_o)	Drip & FI	1250 (4.0 × 2.0)	Hungarian Spindle	4–5 and 7	5.00	0.43
	Rita (Korponay), semi-vig & Early								0.52
Tong et al. (2016)	n/r	Beijing, China *Cold win, rainy sum*	DL, SWB-TDR, SF (FAO-PM-ET_o)	Drip & n/r	833 (4.0 × 3.0)	n/r	11, 12, 13	n/r	n/r
Peach and nectarine (*Prunus persica* L.; Batsch)									
Johnson et al. (2000)	O'Henry (vig) & Late	Kearney, San Joaquin Valley, CA, USA *Med. type-Dry*	WL (CIMIS-Penman ET_o)	Drip & FI	1134 (4.9 × 1.8)	Perpendicular V system	3–7	3.00–4.50	0.37–0.70
Johnson et al. (2002)	Crimson Lady (n/r) & Early						1–2	2.60–3.80	0.31–0.63
Ayars et al. (2003)	O'Henry (vig) & Late						4–6	4.50	0.65–0.70
du Sautoy et al. (2003)	Transvalia (n/r) & Early	Pretoria, S. Africa *Humid, temp*	WL, SWB-neutr (FAO-PM-ET_o)	Micro-spr & FI	1667 (4.5 × 1.0)	Hedgerow	1–2	1.80–2.80	n/r
Paço et al. (2012)	Silver King (GF 677) & n/r	Southern Portugal *Med*	EC, SF, SIMDualKc (FAO-PM-ET_o)	Drip & FI	1000 (5.0 × 2.0)	n/r	2–3	3.00	0.29
Abrisqueta et al. (2013)	Flordastar (GF677, vig) & Early	Murcia, Spain *Med. Dry*	DL (FAO-PM-ET_o)	Drip & FI	400 (5.0 × 5.0)	Vase	6–9	n/r	0.44–0.80
Villalobos et al. (2013)	Baby Gold 6 (n/r) & Mid-Season	Cordoba, Spain *Med*	SF (FAO-PM-ET_o)	Drip & FI	615 (5.0 × 3.25)	Vase	15	n/r	0.54

Table 4 (continued)

Author	Cultivar (root-stock) & Ripening timing	Location & main *climate*	$ET_{c\ act}$ method (ET_o equation)	Irrigation method & strategy	Plants/ha (Spacing m)	Training system	Age (years)	Height (m)	f_c or f_{IPAR} [a]
Gush et al. (2014)	Alpine' nectarines (Sapo 778)	Wolseley, S. Africa *Med type*	SF, EC, SWB-TDR (FAO-PM-ETo)	micro-spray & FI	1667 (4 × 1.5)	n/r	6–7	2.50	0.70
	Alpine' nectarines (n/r)	Rustenburg, S. Africa *Semi-arid*	SF, SWB-waterm (FAO-PM ET_o)	Drip FI	1000 (5 × 2)	n/r	15	3.30	0.88
	'Transvalia' peaches (n/r)	Rustenburg, S. Africa *Semi-arid*	SF, SWC-waterm (FAO-PM ET_o)	Drip FI	1000 (5 × 2)	n/r	16–18	4.00	0.54
Marsal et al. (2014b)	O'Henry (Nemaguard), vig & Late	San Joaquin Valley, CA, USA, *Med.type*	WL (FAO-PM-ET_o)	Drip & FI	1134 (4.9 × 1.8)	KAC V system	4–5	4.10–5.00	0.75–0.80
Zambrano-Vaca et al. (2020)	Tropic Beauty (Flordaguard) (very vig & Early	Citra, FL, USA *Humid, sub-tropical*	SWB tensiom (FAO-PM-ET_o)	Micro-spr & FI	358 (4.6 × 6.1)	Vase	4–5	n/r	n/r
Mashabatu et al. (2023)	Alpine nectarines (Sapo 778)	Wolseley, West Cape, S. Africa, *Med.* type	SF, EC, SWB-TDR (FAO-PM-ETo)	Micro-spr & FI	1667 (4 × 1.5)	n/r	8–10	3.20	0.70
	'Transvalia' peaches (n/r)	Rustenburg, S. Africa humid sub-tropical	SF, SWC-waterm (FAO-PM-ETo)	Drip FI	1000 (5 × 2)	n/r	n/r	n/r	n/r
Plum (*Prunus salicina* Lindl. (Japanese plum) and *P. domestica* (European plum)									
Samperio et al. (2014)	Angeleno (n/r) & Late	Badajoz, Spain *Med., hot dry*	SWB, neutron (FAO-PM-ET_o)	Drip & FI	416 (6.0 × 4.0)	Vase	5–7	2.50–4.60	0.70–0.90
	Red Beaut (n/r) & Early	Badajoz, Spain *Med. Hot dry*		Drip & FI	416 (6.0 × 4.0)	Vase	6	2.80–5.30	0.65
Jovanović et al. (2023)	African Delight (Mariana)	Robertson, W Cape, S Africa, *Med.type*	HYDRUS-2D, SWB-capacit., A&P approach (FAO-PM-ET_o)	Drip & FI	1667 (4.0 × 1.5)	Palmette	Mature	3.00 3.00	0.78 0.80
	Fortune (n/r)	Wellington, W Cape, S Africa *Med.type*		Micro-spr & FI	2857 (3.5 × 1.0)	Palmette trellis	Mature	2.80 3.50	0.81 0.89

[a] f_c or f_{IPAR}: the fraction of ground cover or intercepted radiation

Most studies used the FAO-PM ET_o equation to compute ET_o, except for one study on apricots conducted in south-eastern Spain, which used Class A pan ET_o (Abrisqueta et al. 2001), and studies on peaches conducted at Kearney Agricultural Research and Extension Center in Parlier, California, which used the CIMIS-Penman ET_o equation (Ayars et al. 2003; Johnson et al. 2000, 2002).

In most of the selected studies, drip irrigation systems were used under well-watered conditions; micro-sprinkler systems were used in a few cases. It might be considered that the selected information gathered on stone fruit trees watering referred to near-pristine conditions or to mild water stress during specific stages of the growing season, thus likely matching the previously mentioned eustress criteria for standard K_c and K_{cb} values.

The common training system for stone fruits is the vase, but new training systems have also been developed, that allow for higher tree densities and facilitate cropping practices such as harvesting. An example is the Kearney Agricultural Center Perpendicular "V" (KAC-V), a hybrid of the traditional open vase system and the Tatura system without the trellis (Marsal et al. 2014b). Although the studies on apricot trees did not report the canopy training system adopted in the orchard, the tree spacing reported in the research papers corresponds to a vase-training system. Another training system used was the palmette. The information reported on pruning was very scant and is thus not discussed here. However, some studies reported that pruning was performed annually during dormancy and, in some cases, a light summer pruning was also performed depending on the vigour of the plants. The f_c and h data collected show great variability for the different species of stone fruits, which is linked to age, pruning and training system, and crop management conditions.

As recorded in Table 5, almost all the studies were carried out in bare soil conditions; exceptions are the apricot study by El-Naggar et al. (2018), where the effect of different types of mulching (i.e. rice straw, white and black plastic) on the crop coefficients was analysed, and a plum tree study by Jovanović et al. (2023), where the impact of using active ground cover (AGC) on K_{cb} was studied. The actual K_c and K_{cb} values are shown in the last six columns of Table 5, which were derived from field observations of actual ET_c or T_c for all the cultivars and rootstocks of the selected studies. They show significant variability, mainly due to differences in f_c and h, which are directly related to the training system, pruning and tree age.

Table 6 shows the initial, mid- and end-season standard K_c and K_{cb} values for the different species of stone fruit trees depending on the degree of ground cover, plant density and training system. DGC values range from very low, for young tree orchards, to high or very high for mature orchards with high plant density. Apricot and plum trees are grouped together and have the vase training system in common. In cherries, two different training systems are used (vase and central leader), while in peaches, vase and trellis systems are used depending on plant densities and rootstock vigour. The categories described are further characterized by the ranges of f_c and h, which may aid in selecting the group most suited for the case under consideration. Furthermore, M_L and F_r parameters are also tabulated, with the aim being to enable the computation of K_{cb} values when applying the A&P approach (Pereira et al. 2021c).

The suggested K_c and K_{cb} values for the FAO-typical crop growth stages (i.e. initial, mid- and end-season) are shown in the last two columns of Table 6. These values are based on the ranges derived from field observations in the selected papers and the previously tabulated ranges (Allen et al. 1998; Allen and Pereira 2009; Rallo et al. 2021). For cherries, there is a general lack of information on the K_c/K_{cb} values observed in the different categories established. However, for peaches, the observations of crop coefficients are much more abundant and robust. Clearly, K_c/K_{cb} values increase as f_c increases because of its direct relationship to the transpiration component of crop ET represented by the K_{cb}, while the evaporative component, represented by K_e, is mainly determined by the frequency and depth of irrigation events and rainfall, the soil evaporation area, and the energy available there for evaporation, which is determined by the training system and the canopy-intercepted radiation, i.e., the f_c values.

Nut trees

The increasing per capita share of vegetarian and vegan foods and the growing nutritional awareness of various consumer groups are driving the global nut market. In recent years, production of almost all nut species across the world has expanded. The selected studies on nut trees include almond (*Prunus dulcis* (Miller) D.A. Webb), hazelnut (*Corylus avellana* L.), pecan (*Carya illinoinensis* (Wangenh.) C. Koch), pistachio *(Pistacia vera* L.), and walnut (*Juglans regia* L.). The latest reports point to a global area of 5.3 million hectares under nut tree cultivation, excluding pecans. With around 43% of the area and 42% of the production, almonds are by far the most important crop (FAOSTAT 2023). Pecan trees are native to North America; Mexico and the United States of America (USA) lead world production. South Africa, China and Brazil continue to gradually increase their production. The global harvested area of almond trees has expanded significantly for various reasons, including the mechanization of harvesting; a significant increase in global demand, which has led to a gradual increase in the prices paid to growers, the introduction of new self-fertile cultivars with late or extra-late flowering, which reduce the risk of production losses due to spring frosts; and worldwire awareness of the health benefits of nuts (Mirás-Avalos et al. 2023). Because almond trees have low chilling requirements, vegetative development and flowering begin much earlier in the season than in other deciduous tree species; therefore, to minimize cold damage, plant breeders are striving to develop cultivars that flower later. Rootstocks are available for most tree nut species except hazelnuts.

Studies on almond nuts predominate (Table 7), although there is ample information on the other species. The studies were mainly conducted in semi-arid areas in 11 countries with a temperate Mediterranean climate, including Spain, Australia, the USA, Portugal, France, Serbia, Chile, Turkey and South Africa. This extensive geographic distribution of the selected studies

Table 5 Field derived single (K_c) and basal (K_{cb}) crop coefficients for stone fruit trees

Author	Cultivar (rootstock) & Ripening timing	Training system	f_c or f_{IPAR} [a]	Height (m)	Ground cover	Age	K_c /K_{cb} derived from field observations					
							$K_{c\ ini}$	$K_{c\ mid}$	$K_{c\ end}$	$K_{cb\ ini}$	$K_{cb\ mid}$	$K_{cb\ end}$
Apricot (*Prunus armeniaca L.*)												
Abrisqueta et al. (2001)	Bulida (Real Fino) vig. Early	n/r	0.87	n/r	BS	9–11	0.43	0.74	0.43	n/r	n/r	n/r
Kaya et al. (2013)	Salak (seedling, vig) & Mid-season	n/r	n/r	n/r	BS	8	n/r	0.95[j]	n/r	n/r	n/r	n/r
Villalobos et al. (2013)	Bulida (Real Fino seedling, vig) Early	n/r	0.65	3.90	BS	10	n/r	n/r	n/r	0.10	0.70	0.15
El-Naggar et al. (2018)	Canino (seedling, vig) & Medium	n/r	n/r	n/r	BS	18	0.46	0.90	0.51	n/r	n/r	n/r
					Organic M		0.35	0.77	0.42			
					Wplast M		0.30	0.75	0.38			
					Bplast M		0.30	0.68	0.36			
Cherry (*Prunus avium* L.)												
Candogan and Yazgan (2010)	Z-900 (Gisela-5) dwarf & mid-season	n/r	n/r	2.30–2.60	n/r	2–3	0.79	0.98	0.69	n/r	n/r	n/r
Juhász et al. (2013)	Rita (GiSela 6) & semi-dwarf	Hungarian Spindle	0.43	5.00	AGC	4–5 and 7	n/r	n/r	n/r	n/r	0.90	0.61
	Rita (Korponay) semi- vig & Early		0.52				n/r	n/r	n/r	n/r	0.69	0.54
Tong et al. (2016)	n/r	n/r	n/r	n/r	BS	11	0.65	1.25	0.70	0.50	1.20	0.65
						12	0.70	1.30	0.65	0.60	1.20	0.60
						13	0.70	1.30	0.70	0.60	1.25	0.65
Peach and nectarine (*Prunus persica* L.; Batsch)												
Johnson et al. (2000)	O'Henry (vig) & Late	Perpendic V system	0.37	3.00–4.50	BS	3	0.15	0.65	0.40	n/r	n/r	n/r
			0.70			4	0.30	1.00	0.75			
			0.67			5	0.20	1.05	0.80			
			0.65			6	0.25	1.20	0.70			
			0.65			7	0.20	1.10	0.60			
Johnson et al. (2002)	Crimson Lady (n/r) & Early	V system	0.31	2.60	BS	1	0.10	0.50	0.75	n/r	n/r	n/r
			0.63	3.80		2	0.40	1.00	1.40			
Ayars et al. (2003)	O'Henry (vig) & Late	Perpendic. V system	0.70	4.50	BS	4	0.25	1.05	0.75	n/r	n/r	n/r
			0.67			5	0.25	1.15	0.80			
			0.65			6	0.25	1.20	0.85			
du Sautoy et al. (2003)	Transvalia (n/r) & Early	Hedgerow	n/r	1.80	BS	1	0.25	0.85	0.15	0.15	0.60	0.10
				2.80		2	0.20	0.95	0.50	0.15	0.70	0.20
Paço et al. (2012)	Silver King (GF 677) & n/r	Central leader	0.29	3.00	BS	2–3	n/r	0.60	0.30	n/r	n/r	n/r
Abrisqueta et al. (2013)	Flordastar (GF677) vig & Early	Vase	0.44	n/r	BS	6	0.15	0.85	0.15	0.10	0.80	0.10
			0.78			7	0.15	1.10	0.20	0.10	0.90	0.15
			0.80			8	0.15	1.10	0.25	0.10	1.05	0.10
			0.79			9	0.20	1.00	0.20	0.15	0.95	0.15

Table 5 (continued)

Author	Cultivar (rootstock) & Ripening timing	Training system	f_c or f_{IPAR} [a]	Height (m)	Ground cover	Age	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. (2013)	Baby Gold 6 (n/r), Mid-Season	Vase	0.54	n/r	BS	15	n/r	n/r	n/r	0.25	1.10	0.20
Gush et al. (2014)	Alpine' nectarines (Sapo 778)	n/r	0.70	2.50	AGC aut-spr	6–7	n/r	0.63	0.58	n/r	0.45	0.28
	Alpine' nectarines (n/r)	n/r	0.88	3.30	AGC aut-spr	15	n/r	n/r	n/r	n/r	0.17	0.10
	Transvalia peaches (n/r)	n/r	0.54	4.00	AGC aut-spr	16–18	n/r	n/r	n/r	n/r	0.22	0.15
Marsal et al. (2014b)	O'Henry (Nemaguard) vig & Late	V system	0.75 0.80	4.10 5.00	BS	4 5	n/r	n/r	n/r	0.27 0.27	1.15 1.10	n/r
Zambrano-Vaca et al. (2020)	TropicBeauty (Flordaguard) very vig & Early	Vase	n/r	n/r	BS	4–5	0.15–0.25	0.55–0.70	0.20–0.30	n/r	n/r	n/r
Mashabatu et al. (2023)	Alpine nectarines (Sapo 778)	n/r	0.70	3.20	AGC aut-spr	8–10	n/r	n/r	n/r	0.14	0.42	0.29
	Transvalia peaches (n/r)	n/r	n/r	n/r	AGC aut-spr	n/r	n/r	n/r	n/r	0.10	0.30	0.20
Plum (*Prunus Salicina* L. (Japanese plum) and *P. domestica* (European plum))												
Samperio et al. (2014)	Angeleno & Late	Vase	0.70–0.90	2.5–4.6	AGC aut-spr	5 6 7	0.55 n/r 0.63	1.15 1.05 1.15	0.90 0.75 n/r	n/r	n/r	n/r
	Red Beauty & Early		0.65	2.8–5.3	AGC aut-spr	6	n/r	0.95	0.57	n/r	n/r	n/r
Jovanović et al. (2023)	African Delight (Mariana)	Palmette	0.78 0.80	3.00 3.00	AGC	Mature	n/r	n/r	n/r	0.98 0.97	1.11 1.12	n/r
	Fortune (n/r)	Palmette trellis	0.81 0.89	2.80 3.50	AGC	Mature	n/r	n/r	n/r	1.01 1.01	1.15 1.18	n/r

*[a] f_c or f_{IPAR} the fraction of ground cover or intercepted radiation

Table 6 Initial, mid- and end-season standard K_c and K_{cb} values for stone fruit trees as related to plant density and training, degree/fraction of ground cover and height. The ranges of observed and previously tabulated standard K_c and K_{cb} values are also shown

Degree of ground cover, plant density and training	f_c [a]	h [b]	Crop stage	M_L [c]	F_r [d]	Observed values ranges		Previously tabulated values ranges		Proposed values	
						K_{cb}	K_c	K_{cb}	K_c	K_{cb}	K_c
Apricot (*Prunus armeniaca* L.) and **plum** (*Prunus salicina* Lindl. (Japanese plum))											
Young, vase (< 5 years)	< 0.40	< 2.5	Ini	1.5	1.00	–	–	0.20	0.40	**0.20**	**0.35**
			Mid	1.3	1.00	–	–	0.50–0.55	0.55–0.60	**0.50**	**0.60**
			End	1.0	1.00	–	–	0.30–0.40	0.40–0.45	**0.25**	**0.40**
Low, vase (< 200 pl/ha)	0.40–0.65	2.5–3.0	Ini	1.7	0.90	–	–	0.25	0.45	**0.30**	**0.45**
			Mid	1.5	0.80	–	–	0.55–0.95	0.60–1.00	**0.70**	**0.80**
			End	1.1	0.60	–	–	0.35–0.65	0.45–0.70	**0.35**	**0.45**
Medium, vase (200–400 pl/ha)	0.65–0.70	3.0–4.5	Ini	1.5	0.95	0.10	0.30–0.46	0.30–0.45	0.50–0.55	**0.40**	**0.50**
			Mid	1.7	0.80	0.70	0.68–0.95	0.85–1.10	0.90–1.15	**0.85**	**0.95**
			End	1.2	0.55	0.15	0.36–0.57	0.60–0.75	0.65–0.80	**0.45**	**0.55**
High, vase (> 400 pl/ha)	0.70–0.80	3.0–5.5	Ini	1.8	0.95	–	–	0.30	0.50	**0.45**	**0.55**
			Mid	2.0	0.87	–	–	1.00–1.10	1.05–1.15	**1.00**	**1.05**
			End	2.0	0.50	–	–	0.65–0.75	0.70–0.80	**0.55**	**0.60**
Very high, vase (> 400 pl/ha)	> 0.80	3.0–5.5	Ini	1.7	0.95	0.97–1.01	0.43–0.63	0.30	0.50	**0.50**	**0.60**
			Mid	2.0	0.95	1.11–1.18	0.74–1.15	1.15	1.20	**1.10**	**1.15**
			End	2.0	0.55	–	0.43–0.90	0.80	0.85	**0.60**	**0.65**
Cherries (*Prunus avium* L.)											
Young (< 5 years)	< 0.30	< 3.0	Ini	1.7	1.00	–	0.79	0.25	0.40	**0.25**	**0.40**
			Mid	1.6	1.00	–	0.98	0.50–0.65	0.55–0.70	**0.50**	**0.60**
			End	1.3	1.00	–	0.69	0.30–0.50	0.40–0.55	**0.35**	**0.50**
Low, vase (< 800 pl/ha)	0.25–0.40	3.0–4.0	Ini	1.7	0.95	–	–	0.25	0.40	**0.30**	**0.45**
			Mid	1.5	0.85	–	–	0.55–0.65	0.60–0.70	**0.55**	**0.65**
			End	1.5	0.75	–	–	0.35–0.50	0.45–0.55	**0.40**	**0.50**
Medium to High (vig. Rootstock), vase (< 800 pl/ha)	0.40–0.70	> 4.0	Ini	1.7	0.85	–	–	–	–	**0.35**	**0.50**
			Mid	1.7	0.85	–	–	–	–	**0.80**	**0.85**
			End	1.5	0.55	–	–	–	–	**0.45**	**0.60**
Low to Medium (semi vigorous), central leader (800–1250 pl/ha)	0.40–0.50	4.0–5.0	Ini	1.8	0.95	–	–	–	–	**0.35**	**0.50**
			Mid	1.7	0.85	0.76	–	–	–	**0.75**	**0.85**
			End	1.6	0.66	–	–	–	–	**0.50**	**0.60**
Medium to High (semi-dwarf rootstock), central leader (> 1200 pl/ha)	0.40–0.70	> 2.5	Ini	1.8	0.95	–	–	0.30–0.45	0.50–0.55	**0.45**	**0.55**
			Mid	1.7	0.88	0.61	–	0.55–1.10	0.60–1.15	**0.85**	**0.90**
			End	1.6	0.66	–	–	0.35–0.75	0.45–0.80	**0.55**	**0.65**
High (dwarf rootstock), central leader (> 1200 pl/ha)	0.70–0.90	2.0–3.5	Ini	1.8	0.95	–	–	0.30	0.50	**0.50**	**0.60**
			Mid	2.0	0.85	–	–	1.00–1.10	1.05–1.15	**0.95**	**1.00**
			End	2.0	0.55	–	–	0.65–0.75	0.70–0.80	**0.60**	**0.70**

Table 6 (continued)

Degree of ground cover, plant density and training	f_c [a]	h [b]	Crop stage	M_L [c]	F_r [d]	Observed values ranges		Previously tabulated values ranges		Proposed values	
						K_{cb}	K_c	K_{cb}	K_c	K_{cb}	K_c
Peach and nectarine (*Prunus persica* L.; Batsch)											
Young (< 4 years)	< 0.30	< 2.0	Ini	1.5	1.00	0.15	0.15–0.25	0.20	0.40	**0.20**	**0.35**
			Mid	1.6	1.00	0.60	0.55–0.85	0.50–0.55	0.55–0.60	**0.50**	**0.60**
			End	1.3	1.00	0.10	0.15–0.30	0.35–0.40	0.45–0.50	**0.25**	**0.40**
Low, vase (400–600 pl/ha) (high vig.)	0.30–0.50	2.0–3.5	Ini	1.5	0.85	0.10–0.15	0.10–0.20	0.25–0.45	0.45–0.55	**0.25**	**0.35**
			Mid	1.7	0.85	0.70–0.80	0.85–0.95	0.60–0.95	0.65–1.00	**0.70**	**0.80**
			End	1.6	0.60	0.10–0.20	0.15–0.50	0.40–0.65	0.50–0.70	**0.40**	**0.50**
Medium, vase (400–700 pl/ha) (medium vig.)	0.50–0.65	3.5–4.5	Ini	1.5	0.75	0.25	–	0.25–0.45	0.45–0.55	**0.30**	**0.45**
			Mid	1.7	0.85	1.10	–	0.85–0.95	0.90–1.0	**0.90**	**0.95**
			End	1.5	0.6	0.20	–	0.60–0.65	0.65–0.70	**0.50**	**0.60**
High, vase (> 700 pl/ha) (low vig.)	> 0.65	> 4.0	Ini	1.5	0.75	0.10–0.15	0.10–0.20	0.30	0.50	**0.35**	**0.45**
			Mid	2.0	0.90	0.90–1.05	0.85–1.10	1.00–1.15	1.05–1.20	**1.00**	**1.05**
			End	2.0	0.55	0.10–0.15	0.20–0.40	0.65–0.80	0.70–0.85	**0.60**	**0.70**
Medium, trellis (> 1100 pl/ha) (medium vig.)	0.30–0.60	3.5–4.5	Ini	1.5	0.95	–	0.10–0.30	0.25–0.45	0.45–0.55	**0.30**	**0.40**
			Mid	1.7	0.90	–	0.50–1.00	0.60–0.95	0.65–1.00	**0.80**	**0.85**
			End	1.5	0.60	–	0.30–0.65	0.40–0.65	0.50–0.70	**0.45**	**0.55**
High, trellis (> 1500 pl/ha) (low vig.)	0.60–0.75	> 3.5	Ini	1.5	0.90	0.27	0.20–0.40	0.30	0.50	**0.35**	**0.45**
			Mid	1.7	0.95	1.15	1.00–1.20	1.00–1.10	1.05–1.15	**1.05**	**1.10**
			End	1.6	0.60	–	0.60–1.40	0.65–0.75	0.70–0.80	**0.55**	**0.65**
Very high, trellis (> 2000 pl/ha) (low vig.)	> 0.75	> 3.5	Ini	1.8	0.90	0.27	–	0.30	0.50	**0.40**	**0.50**
			Mid	2.0	0.95	1.10	–	1.15	1.20	**1.10**	**1.15**
			End	2.0	0.60	–	–	0.80	0.85	**0.65**	**0.75**

Bold values indicate the most relevant information from the review article, i.e., the proposed (updated) K_c and K_{cb} values

[a] f_c: the fraction of ground cover

[b] h: crop height

[c] M_L: a multiplier for fc describingthe effect of canopy density on shading and on maximum relative ET per fraction of ground shaded [1.0–2.0]

[d] F_r: an adjustment factor relative to crop stomatal control [0.0–1.0]

Table 7 Characteristics of the selected nut tree orchards

Author	Cultivar (rootstock)	Location & *main climate*	ET$_{c\ act}$ method (ET$_o$ equation)	Irrigation & strategy	Plants/ha (Spacing m)	Training system	Age (years)	Height (m)	f$_c$ or f$_{IPAR}$ ^{a}
Almond (*Prunus dulcis* (Mill) D.A. Webb)									
Stevens et al. (2012)	Nonpareil (Nemaguard)	Loxton, Australia *Dry Semi-arid*	EC (advection) (FAO-PM-ET$_o$)	Micro-spr & FI	286 (7.0×5.0)	n/r	8	5.50	0.65
Espadafor et al. (2015)	Guara (GF-677)	Córdoba, Spain *Med. Semi-arid*	WL, SF (FAO-PM-ET$_o$)	Drip & FI	238 (6.0×7.0)	Vase	1–2 3–4	1.50–4.80	0.10–0.23 0.36–0.48
Bellvert et al. (2018)	Nonpareil & Carmel (n/r)	Madera, CA, USA *Med. Semi-arid*	RS -VI, microlys, SR (CIMIS-PM-ET$_o$)	Micro-spr & FI	249 (5.5×7.3)	Vase	18	n/r	0.85
López-López et al. (2018)	Guara (GF-677)	Córdoba, Spain *Med. Semi-arid*	WL, SF, SWB-neut (FAO-PM-ET$_o$)	Drip & FI	238 (6.0×7.0)	Vase	5–7	n/r	0.55 to 0.59
Sánchez et al. (2021)	Lauranne (GF-677)	Albacete, SE Spain *Med. Semi-arid*	EC, STSEB model (FAO-PM-ET$_o$)	Drip & FI	238 (6.0×7.0)	Vase	2, 3, 4	1.8, 3.0, 3.8	0.21, 0.35 0.39
Drechsler et al. (2022)	Nonpareil (75%) & Monterey (25%) (n/r)	Sacramento Valley, CA *Med*	EC, SWB-neutron (ASCE-PM-ET$_o$)	Miro-spr & DI	348 (6.7×4.3)	n/r	1–5	2.00–5.00	0.09–0.55
Ramos et al. (2023)	Monterey (n/r)	Aljustrel, Portugal *Med*	SWB-TDR, SIMDualKc (FAO-PM-ET$_o$)	Drip & FI	391 (n/r)	Vase	5–6	4.00	0.41
Hazelnut (*Corylus avellana L.*)									
Mingeau and Rousseau (1994)	Ennis and Fertile de Coutard (n/r)	Clermont-Ferrand, France, *Continental sub-humid*	DL (Penman ET$_o$)	Drip & FI	n/r	n/r	1–2 3–4 5–6 7–8	n/r	0.13–0.23 0.38–0.48 0.56–0.72 0.81–0.84
Mačkić et al. (2016)	n/r	Vojvodina, Serbia *Temperate*	SWB (FAO-PM-ET$_o$)	Micro-spr & FI	833 (4.0×3.0)	n/r	3–4	1.52–1.84	n/r
Ortega-Farias et al. (2020)	Tonda di Giffoni (n/r)	Maule Region, Chile *Med. Semi-arid*	EC (FAO-PM-ET$_o$)	Drip & FI	333 (5.0×6.0)	Multiple stem	7–8	4.60 ± 0.76	n/r
Silvestri et l. (2021)	Negret (n/r)	Tarragona, Spain *Med*	DL (Pan evap ET$_o$)	n/r	500 (n/r)	n/r	n/r	n/r	n/r
Vinci et al. (2023)	Tonda Francescana (*Corylus colurna*)	Perugia, Italy *Med*	A&P (FAO-PM-ET$_o$)	n/r	625 (4×4)	Open center vase	5–6	1.6–2.25	0.74
					1250 (4×2)			2.1–2.7	0.80
					2500 (4×1)			n/r	0.90

Table 7 (continued)

Author	Cultivar (rootstock)	Location & *main climate*	$ET_{c\ act}$ method (ET_o equation)	Irrigation & strategy	Plants/ha (Spacing m)	Training system	Age (years)	Height (m)	f_c or f_{IPAR} ^{a}
Pecan (*Carya illinoinensis* L.)									
Sammis et al. (2004)	Wester Schley (n/r)	Las Cruces, Nmexico, *Semi-arid*	EC (Penman ET_o)	Surface & FI	106 (9.7×9.7)	n/r	21 22	12.80	0.65–0.7
Samani et al. (2011)	n/r	Low Rio Grande, USA *Semi-arid*	EC and REEM (HS or PM-ET_o)	Surface & FI	n/r	n/r	Mature	n/r	0.40–0.80
Ibraimo et al. (2014)	'Choctaw' ('Barton')	Cullinan, S. Africa Sub-topical	SF, EC, SWB-TDR (FAO-PM ET_o)	Micro-spr & FI	142 (9×9)	n/r	34–37	13.00	0.80–0.98
Abudu et al. (2016)	n/r (n/r)	El Paso, TX, USA *Semi-arid*	EC (FAO-PM-ET_o)	Surface & FI	120 (9.1×9.1)	n/r	Mature	10.60	0.74
Ibraimo et al. (2016)	Choctaw (Barton)	Gauten, S Africa *Semi-arid subtrop*	EC, SF, Es model (FAO-PM-ET_o)	Micro-spr & FI	285 (4.5×7.8)	n/r	34 to 36	> 13.00	0.95 to 0.98
Mokari et al. (2021)	Western Schley (n/r)	Low Rio Grande, USA *Semi-arid*	EC (HS-ET_o)	Surface & FI	n/r	n/r	Mature	n/r	n/r
Mashabatu et al. (2023)	'Choctaw' ('Barton')	Gauteng, S. Africa *Sub-topical*	EC, SWB-TDR (FAO-PM-ET_o)	Micro-spr & FI	142	n/r	34–37	13.00	0.80
Pistachio (*Pistacia vera* L.)									
Kanber et al. (2003)	Uzun (n/r)	Gaziantep, Turkey *Med. Semi-arid*	SWB- neutron (FAO-PM-ET_o)	Drip & FI and SDI	100 (10.0×10.0)	n/r	27	n/r	0.35
Iniesta et al. (2008)	Kerman (n/r)	Madera, CA, USA *Med. Semi-arid*	SWB- neutron (FAO-PM-ET_o)	Micro-spr & FI and RDI	332 (5.8×5.2)	Vase	12	3.80	0.57
Jin et al. (2018)	n/r	Hanford, CA, USA *Med. Semi-arid*	EC, SR, METRIC (FAO-PM-ET_o)	Drip & FI	332 (5.8×5.2)	Vase	26	4.29	0.74
Bellvert et al. (2018)	Kerman (n/r)	Madera, CA, USA *Med. Semi-arid*	EC, SR (FAO-PM-ET_o)	Drip & FI	332 (5.8×5.2)	Vase	14	n/r	0.60
Walnut (*Juglans regia L.*)									
Goldhamer (1998)	n/r	Chico, San Joaquín, CA *Med. Semi-arid*	SWB (FAO-PM-ET_o)	Localized & n/r	193 (7.2×7.2)	n/r	19	n/r	0.57
Fulton et al. (2013)	n/r	Tehama, CA, USA *Med*	BREB (FAO-PM-ET_o)	Mini-spr & FI	235 and 445	n/r	Mature	n/r	0.77–0.89

Table 7 (continued)

Author	Cultivar (rootstock)	Location & *main climate*	$ET_{c\ act}$ method (ET_o equation)	Irrigation & strategy	Plants/ha (Spacing m)	Training system	Age (years)	Height (m)	f_c or f_{IPAR} [a]
Villalobos et al. (2013)	Chandler (n/r)	Córdoba, Spain *Med. Semi-arid*	SF (FAO-PM-ET_o)	Drip & FI	156 (8.0×8.0)	Vase	7	6.0–7.0	0.66
Fulton et al. (2017)	Chandler (n/r)	Sacramento Valley, CA *Med. Continental*	EC (FAO-PM-ET_o)	Micro-spr & FI	235 (6.5×6.5)	n/r	7–19	n/r	0.81
					445 (6.6×3.3)				0.90

[a] f_c or f_{IPAR}: the fraction of ground cover or intercepted radiation

offers various perspectives that favour the analysis of the appropriate standard K_c and K_{cb} values for all the crops. In addition, the cultivars to which each crop refers to are also diverse.

Table 7 shows the methods used to determine actual ET_c and/or plant transpiration, to create new or updated K_c and K_{cb} values for nut trees. These methods mainly include different types of lysimeters, EC, SF, RSEB and SWB. A particular case refers to a pecan study by Samani et al. (2011), in which crop ET was computed using a regional ET estimation model (Samani et al. 2009). In almost all the studies, ET_o was estimated using the FAO-PM equation, although a few isolated studies used other equations, such as Penman, Hargreaves-Samani, CIMIS-PM ET_o, ASCE-PM ET_o and the pan evaporation ET_o method. Most of the selected studies used drip or microsprinkler irrigation systems under full irrigation strategies corresponding to well-watered conditions. Only three studies reported mild and controlled water stress in selected periods of the growing season, thus corresponding to the eustress conditions defined for standard K_c and K_{cb} values. There is great variability in plant density and spacing. Most of the studies on nut trees report a vase training system, although there was a hazelnut orchard using a multiple stem-shrub system (Ortega-Farias et al. 2021). However, information on the training system was not reported in some papers. Similarly to the previous tree crops, there is great variability in the f_c and h data collected, which is related to age, pruning and crop management conditions.

Table 8 shows that the majority of the selected studies refer to bare soil conditions, although some studies report the use of AGC, sometimes only partially covering the soil (Stevens et al. 2012) and during given periods of the year (Drechsler et al. 2022; Ramos et al. 2023). In an almond study (Bellvert et al. 2018), the authors reported a cover crop coefficient of 0.10–0.15 throughout the growing season, which is considered in the K_c value. The final columns of Table 8 list the actual K_c and K_{cb} values derived from field observations for all the cultivars and rootstocks of the selected studies, which exhibit significant variability related to differences in f_c and h; these depend on the training system, pruning and tree age.

Table 9 shows the standard initial, mid- and end-season single and basal crop coefficient values for almond, hazelnut, pecan, pistachio and walnut trees, which are grouped according to the degree of ground cover, plant density and training system. The DGC varies from very low or low for young tree orchards to very high values for mature orchards. For almond trees, a category has been included for hedgerow/super-intensive orchards, which are expanding, despite observed K_c/K_{cb} data not yet being available. The groups described are also distinguished by ranges of f_c and h, which may help the reader determine the most appropriate group for the case under consideration.These values of f_c and h, together with the tabulated M_L and F_r parameters, can be used to compute the values of $K_{cb\ ini}$, $K_{cb\ mid}$ and $K_{cb\ end}$ using the A&P approach (Allen and Pereira 2009; Pereira et al. 2021c).

The proposed standard K_c and K_{cb} values for initial, mid- and end-season for nut trees are shown in the last two columns of Table 9, which are based on the ranges of K_c/K_{cb} values obtained from field observations reported in the selected papers, on the ranges of K_c/K_{cb} values previously tabulated in FAO56 (Allen et al. 1998), and in the articles published by Allen and Pereira (2009) and Rallo et al. (2021). As previously discussed for pome fruit and stone fruit trees, the crop coefficients increase as f_c increase, due to its direct relationship to basal K_{cb}, which represents plant transpiration, while the soil evaporation component (K_e) is mainly determined by the frequency and depth of rainfall or irrigation events, the ground area receiving solar energy directly, and the energy available for soil water evaporation, which is conditioned by the training system and the intercepted radiation by the canopy, thus being related to the f_c values.

Vine fruit crops and berries

The main information on the selected studies for vines (kiwifruit and hops) and shrubs is shown in Table 10. The kiwi (*Actinidia deliciosa* [A. Chev] C. F. Liang & A. R. Ferguson), a species domesticated in the twentieth century,

Table 8 Field derived single (K_c) and basal (K_{cb}) crop coefficients for nut tree orchards

Author	Cultivar (rootstock)	Training system	f_c or f_{IPAR} [a]	Height (m)	Ground cover	Age	K_c /K_{cb} derived from field observations					
							$K_{c\ ini}$	$K_{c\ mid}$	$K_{c\ end}$	$K_{cb\ ini}$	$K_{cb\ mid}$	$K_{cb\ end}$
Almond (*Prunus dulcis* (Mill) D.A. Webb)												
Stevens et al. (2012)	Nonpareil (Nemaguard)	n/r	0.65	5.50	50% AGC	8	n/r	1.23	0.55	n/r	n/r	n/r
Espadafor et al. (2015)	Guara (GF-677)	Vase	0.36 0.48	n/r 4.80	BS	3 4	n/r	n/r	n/r	0.30 0.15	0.50 0.55	0.18 0.40
Bellvert et al. (2018)	Nonpareil & Carmel	Vase	0.85	n/r	AGC	18	0.40	1.15	0.40	0.20	1.00	0.20
López-López et al. (2018)	Guara (GF-677)	Vase	0.55 0.59 0.55	n/r	BS	5 6 7	n/r	n/r	n/r	0.30 0.15 n/r	0.65 0.80 0.95	0.50 0.60 0.70
Sánchez et al. (2021)	Lauranne (GF-677)	Vase	0.21 0.35 0.39	1.80 3.00 3.80	AGC aut-spr	2 3 4	n/r	0.30 0.33 0.45	n/r	n/r	0.19 0.30 0.36	n/r
Drechsler et al. (2022)	Nonpareil (75%) & Monterey (25%) (n/r)	n/r	n/r n/r	2.00 4.00	AGC aut-spr	1 2	n/r n/r	0.40 0.70	0.20 0.30	n/r	n/r	n/r
			0.09 0.23 0.47	3.00 4.00 4.00		2 3 4	n/r n/r n/r	0.50 0.80 0.90	0.20 0.45 0.40	n/r	n/r	n/r
			0.25 0.22 0.55	4.00 5.00 5.00		3 4 5	0.40 0.50 0.45	0.90 1.10 1.00	n/r n/r n/r	n/r	n/r	n/r
Ramos et al. (2023)	Monterey (n/r)	Vase	0.41	4.00	AGC aut-spr	5–6	0.99	0.65	0.96	0.22	0.58	0.50
Hazelnut (*Corylus avellana L.*)												
Mingeau and Rousseau (1994)	Ennis and Fertile de Coutard (n/r)	n/r	0.13 0.23 0.38 0.56 0.81 0.84	n/r	n/r	1 2 3 5 7 8	0.24 0.32 0.30 0.48 0.74 n/r	0.78 1.14 1.15 1.40 1.45 n/r	n/r	0.12 0.12 0.12 0.12 0.29 n/r	0.18 0.36 0.60 0.84 0.90 n/r	n/r
Mačkić et al. (2016)	n/r	n/r	n/r	1.52–1.84	n/r	3–4	0.80	0.93	0.80	n/r	n/r	n/r
Ortega-Farias et al. (2020)	Tonda di Giffoni (n/r)	n/r	n/r	4.60 ± 0.76	n/r	7–8	0.7	0.8	n/r	n/r	n/r	n/r

Table 8 (continued)

Author	Cultivar (rootstock)	Training system	f_c or f_{IPAR} ^{a}	Height (m)	Ground cover	Age	K_c /K_{cb} derived from field observations					
							$K_{c\ ini}$	$K_{c\ mid}$	$K_{c\ end}$	$K_{cb\ ini}$	$K_{cb\ mid}$	$K_{cb\ end}$
Silvestri et al. (2021)	Negret (n/r)	n/r	n/r	n/r	n/r	n/r	0.30	0.62	0.35	n/r	n/r	n/r
Vinci et al. (2023)	Tonda Francescana (*Corylus colurna*)	Open center vase	0.74 0.80 0.90	1.60–2.25 2.10–2.70 n/r	n/r	5–6	n/r n/r n/r	n/r n/r n/r	n/r n/r n/r	n/r n/r n/r	0.98 0.98 1.04	n/r n/r n/r
Pecans (*Carya illinoinensis* L.)												
Sammis et al. (2004)	Wester Schley (n/r)	n/r	0.65–0.70	12.80	n/r	21 22	0.25 0.10	1.05 0.95	0.15 0.25	n/r	n/r	n/r
Samani et al. (2011)	n/r	n/r	0.80 0.40 0.60 0.73	n/r	n/r	Mature	0.59 0.38 0.42 0.50	1.18 0.66 0.75 0.85	0.84 0.50 0.63 0.70	n/r	n/r	n/r
Ibraimo et al. (2014)	Choctaw (Barton	n/r	0.80–0.98	13.00	n/r	34–37	0.73	1.09	0.94	0.50	1.06	0.90
Abudu et al. (2016)	n/r	n/r	0.74	10.60	AGC	Mature	0.20	0.86	0.10	n/r	n/r	n/r
Ibraimo et al. (2016)	Choctaw (Barton)	n/r	0.95 0.98 0.82	> 13.00	n/r	34 35 36	0.55 0.55 0.55	1.15 1.10 1.12	0.50 0.65 0.40	n/r	n/r	n/r
Mokari et al. (2021)	Western Schley, /r)	n/r	n/r	n/r	n/r	Mature	0.50	1.10	0.40	n/r	n/r	n/r
Mashabatu et al. (2023)	Choctaw, (Barton)	n/r	0.80	13.00	n/r	34–37	0.60	1.00	0.80	n/r	n/r	n/r
Pistachio (*Pistacia vera* L.)												
Kanber et al. (2003)	Uzun (n/r)	n/r	0.35	n/r	BS	27	0.60	1.44	0.20	n/r	n/r	n/r
Iniesta et al. (2008)	Kerman (n/r)	Vase	0.57	3.80	BS	12	0.80	1.30	0.90	n/r	n/r	n/r
Jin et al. (2018)	n/r	Vase	0.74	4.29	n/r	26	0.45	1.00	0.70	n/r	n/r	n/r
Bellvert et al. (2018)	Kerman (n/r)	Vase	0.60	n/r	BS	14	0.30	0.90	0.45	0.20	0.80	0.40

Table 8 (continued)

Author	Cultivar (rootstock)	Training system	f_c or f_{IPAR} [a]	Height (m)	Ground cover	Age	K_c /K_{cb} derived from field observations					
							$K_{c\ ini}$	$K_{c\ mid}$	$K_{c\ end}$	$K_{cb\ ini}$	$K_{cb\ mid}$	$K_{cb\ end}$
Walnut (*Juglans regia L.*)												
Goldhamer (1998)	n/r	n/r	0.57	n/r	n/r	19	0.53	1.05	0.28	n/r	n/r	n/r
Fulton et al. (2013)	n/r	n/r	0.77 0.89	n/r	BS, part AGC	n/r	0.58 n/r	1.01 1.03	0.68 0.60	n/r	n/r	n/r
Villalobos et al. (2013)	Chandler (n/r)	n/r	0.66	6.00–7.00	n/r	7	n/r	n/r	n/r	0.15	1.05	0.50
Fulton et al. (2017)	Chandler (n/r)	n/r	0.81 0.90 n/r	n/r	n/r	7–12 19 7-y avg	0.52 0.49 0.63	1.00 1.01 1.00	0.50 0.58 0.60	n/r	n/r	n/r

[a] f_c or f_{IPAR} the fraction of ground cover or intercepted radiation

is of increasing importance with a world production of 4.5 million tons in near 290,000 ha, mainly cultivated in China, Italy and New Zealand (FAOSTAT 2023). This plant is a vine that is commonly trained in a T-bar or pergola system.

The female inflorescences (hop cones) of the hop plant (*Humulus lupulus* L.), an important product for the brewing industry, are mainly grown in the USA, Germany, Czech Republic and China.

Various berry species, such as *Vaccinium corymbosum* L., *Vaccinium angustifolium* L., *Vaccinium ashei* Reade, and *Rubus* L. subgenus *Rubus* Watson, are produced for fresh or industrial use. In recent years, production and harvested area have increased, particulary in North and South America (USA, Canada and Chile), which account for almost 80% of the cultivated area, while Europe accounts for nearly 17% (FAOSTAT 2023).

In general, few studies focus on determining crop ET to derive new or updated crop coefficients for this group of crops. The kiwifruit studies were carried out in Portugal and Italy, under Mediterranean climate conditions, with one study conducted in China with a subtropical humid climate. In two studies, ET_c was measured using an EC system, SF sensors and micro-lysimeters, and ET_o was computed with the FAO-PM ET_o equation. In the selected studies, micro-sprinkler and sprinkler irrigation systems were used, with a full irrigation strategy being adopted. Kiwi vines grew on a T-bar trellis, or simply a horizontal trellis. Information on canopy cover and crop height is missing; only the study by Jiang et al. (2022) reported h values, which ranged between 1.8 and 2.2 m.

Only two studies on hops were selected, one conducted in the Czech Republic and the other in Spain, both under temperate climate conditions. The reported K_{cb} values were derived from the determination of plant transpiration using SF sensors, while the K_c were derived from ET_c computed with an SWB using the calibrated SIMDualKc model. In these studies, ET_o was calculated with the FAO-PM ET_o equation. In the study by Fandiño et al. (2015), hops were drip-irrigated using a full-irrigation strategy, with hops trained to a hedgerow, whereas, in the experiment by Krofta et al. (2013), hops were not irrigated and were trained to a Y-trellis system.

Table 10 shows characteristics for three species of blueberries (Highbush, Lowbush and Rabbiteye) and one of blackberry. The studies were conducted in USA and Chile in climates ranging from humid subtropical to semi-arid Mediterranean. All reported K_c and K_{cb} values were derived from determinations of ET_c using weighing lysimeters (WL), drainage lysimeters (DL) and the soil water balance (SWB) method. ET_o was calculated using the FAO-PM ET_o equation, although one study used a modified Penman equation. Different irrigation systems were used (sprinkler, micro-sprinkler and drip), but blueberries were irrigated in all studies without water stress, i.e., well-watered conditions, and the shrubs grew in free form, i.e. they were not trained. Overall, there is a lack of h and f_c information. In

Table 9 Initial, mid- and end-season standard K_c and K_{cb} values for nut trees as related to plant density and training, degree/fraction of ground cover and height. The ranges of observed and previously tabulated standard K_c and K_{cb} values are also shown

Degree of ground cover, plant density and training	f_c [a]	h [b]	Crop stage	M_L [c]	F_r [d]	Observed values ranges		Previously tabulated values ranges		Proposed values	
						K_{cb}	K_c	K_{cb}	K_c	K_{cb}	K_c
Almond (*Prunus dulcis* (Mill) D.A. Webb)											
Young (< 4 years)	< 0.30	< 3.0	Ini	1.5	1.00	0.30	0.40	0.15	0.35	**0.15**	**0.30**
			Mid	1.3	1.00	0.19–0.50	0.30–0.90	0.35–0.45	0.40–0.50	**0.40**	**0.50**
			End	1.1	1.00	0.18	0.20–0.45	0.25–0.35	0.35–0.40	**0.30**	**0.45**
Low, vase (< 400 pl/ha) (high vig.)	0.20–0.40	2.0–4.0	Ini	1.5	0.85	0.30	0.50	0.15	0.35	**0.25**	**0.35**
			Mid	1.7	0.75	0.30–0.50	0.33–1.10	0.40–0.45	0.45–0.50	**0.50**	**0.55**
			End	1.7	0.75	0.18	0.45	0.30–0.35	0.40–0.45	**0.35**	**0.45**
Medium, vase (< 400 pl/ha)	0.40–0.55	4.0–4.5	Ini	1.5	0.80	0.15–0.30	0.45–0.99	0.20	0.40	**0.30**	**0.45**
			Mid	1.5	0.90	0.55–0.95	0.65–1.00	0.60–0.85	0.65–0.90	**0.80**	**0.85**
			End	1.4	0.60	0.40–0.70	0.40–0.96	0.40–0.60	0.50–0.65	**0.45**	**0.55**
High, vase (> 200 pl/ha) (low vig.)	0.55–0.65	4.5–5.0	Ini	1.4	0.85	0.15–0.30	0.45	0.20	0.40	**0.35**	**0.45**
			Mid	1.5	0.90	0.65–0.95	1.0–1.23	0.85–0.95	0.90–1.10	**0.95**	**1.00**
			End	1.4	0.60	0.50–0.70	0.55	0.60–0.65	0.65–0.70	**0.55**	**0.60**
Very high, vase (> 200 pl/ha) (low vig.)	> 0.65	4.0–5.5	Ini	1.5	0.80	0.20	0.40	0.20	0.40	**0.35**	**0.45**
			Mid	2.0	0.90	1.00	1.15	0.95–1.10	1.00–1.15	**1.05**	**1.10**
			End	2.0	0.55	0.20	0.40	0.70–0.75	0.75–0.80	**0.60**	**0.70**
Hedgerow/Super-intensive (> 2500 pl/ha) (dwarf rootstock)	0.30–0.45	2.0–2.5	Ini	1.5	0.85	–	–	–	–	**0.25**	**0.35**
			Mid	2.0	0.95	–	–	–	–	**0.80**	**0.90**
			End	1.8	0.55	–	–	–	–	**0.40**	**0.50**
Hazelnut (*Corylus avellana L.*)											
Young (< 6 years)	< 0.35	< 2.0	Ini	1.5	1.00	0.12	0.24–0.80	–	–	**0.20**	**0.35**
			Mid	1.5	1.00	0.18–0.60	0.62–1.15	–	–	**0.55**	**0.65**
			End	1.4	1.00	–	0.35–0.80	–	–	**0.35**	**0.45**
Low to medium, multiple stem-shrub syst	0.35–0.55	2.0–3.5	Ini	1.5	0.75	–	–	–	–	**0.25**	**0.40**
			Mid	1.5	0.85	–	–	–	–	**0.70**	**0.80**
			End	1.4	0.65	–	–	–	–	**0.40**	**0.50**
Medium to high, multiple stem-shrub syst	0.55–0.70	3.5–4.5	Ini	1.7	0.85	0.12	0.48	–	–	**0.35**	**0.45**
			Mid	1.5	0.75	0.84	1.40	–	–	**0.80**	**0.90**
			End	1.1	0.60	–	–	–	–	**0.45**	**0.55**
Very high, multiple stem-shrub syst	> 0.70	> 4.5	Ini	1.8	0.85	0.29	0.70–0.74	–	–	**0.40**	**0.50**
			Mid	2.0	0.78	0.90	0.80–1.45	–	–	**0.90**	**1.00**
			End	1.4	0.50	–	–	–	–	**0.50**	**0.60**

Table 9 (continued)

Degree of ground cover, plant density and training	f_c [a]	h [b]	Crop stage	M_L [c]	F_r [d]	Observed values ranges		Previously tabulated values ranges		Proposed values	
						K_{cb}	K_c	K_{cb}	K_c	K_{cb}	K_c
Pecans (*Carya illinoinensis* L.)											
Young (< 8 years)	< 0.40	< 8.0	Ini	1.8	1.00	–	–	–	–	**0.25**	**0.40**
			Mid	1.4	1.00	–	–	–	–	**0.60**	**0.70**
			End	1.3	1.00	–	–	–	–	**0.40**	**0.50**
Low, vase (> 100 pl/ha)	0.40–0.60	8.0–10.0	Ini	1.7	0.80	–	0.38–0.42	–	–	**0.30**	**0.45**
			Mid	1.4	0.75	–	0.66–0.75	–	–	**0.65**	**0.75**
			End	1.4	0.65	–	0.50–0.63	–	–	**0.45**	**0.55**
Medium to high, vase (100–250 pl/ha)	0.60–0.80	10.0–13.0	Ini	1.8	0.95	–	0.10–0.59	–	–	**0.40**	**0.50**
			Mid	1.4	0.73	–	0.75–1.18	–	–	**0.80**	**0.90**
			End	1.1	0.50	–	0.10–0.84	–	–	**0.55**	**0.70**
Very high, vase (250–300 pl/ha)	> 0.80	> 13.0	Ini	1.8	0.95	–	0.55	–	–	**0.45**	**0.55**
			Mid	1.5	0.80	–	1.10–1.15	–	–	**0.95**	**1.05**
			End	1.4	0.52	–	0.40–0.65	–	–	**0.60**	**0.70**
Pistachio (*Pistacia vera* L.)											
Young (< 10 years)	< 0.35	< 3.0	Ini	1.5	1.00	–	–	0.20	0.30	**0.15**	**0.30**
			Mid	1.3	1.00	–	–	0.40–0.45	0.45–0.50	**0.40**	**0.50**
			End	1.1	1.00	–	–	0.25–0.35	0.35–0.40	**0.25**	**0.35**
Low, vase (> 100 pl/ha)	0.35–0.50	3.0–4.0	Ini	1.5	0.85	–	0.60	0.25	0.35	**0.25**	**0.35**
			Mid	1.5	0.85	–	1.44	0.75–0.85	0.80–0.90	**0.70**	**0.80**
			End	1.3	0.65	–	0.20	0.50–0.55	0.55–0.70	**0.35**	**0.45**
Medium to high, vase (150–350 pl/ha)	0.50–0.70	4.0–4.5	Ini	1.5	0.85	0.20	0.30–0.80	0.20–0.30	0.35–0.40	**0.30**	**0.40**
			Mid	1.5	0.85	0.80	0.90–1.30	0.80–1.05	0.85–1.10	**0.85**	**0.90**
			End	1.3	0.55	0.40	0.45–0.90	0.40–0.65	0.45–0.70	**0.45**	**0.55**
Very high, vase (> 300 pl/ha)	> 0.70	> 4.5	Ini	1.5	0.75	–	0.45	–	–	**0.35**	**0.50**
			Mid	2.0	0.80	–	1.00	–	–	**0.95**	**1.00**
			End	2.0	0.50	–	0.70	–	–	**0.55**	**0.65**
Walnut (*Juglans regia L.*)											
Young, vase (< 7 years)	< 0.55	< 6.0	Ini	1.8	1.00	–	–	0.25–0.35	0.35–0.45	**0.25**	**0.45**
			Mid	1.4	1.00	–	–	0.45–0.85	0.50–0.90	**0.70**	**0.80**
			End	1.2	1.00	–	–	0.25–0.55	0.40–0.60	**0.45**	**0.55**
Low vase (< 200 pl/ha)	0.55–0.75	6.0–10.0	Ini	1.5	0.90	0.15	0.53	0.35–0.40	0.45–0.50	**0.30**	**0.45**
			Mid	1.5	0.90	1.05	1.05	0.80–1.05	0.85–1.10	**1.00**	**1.05**
			End	1.4	0.55	0.50	0.28	0.40–0.60	0.50–0.65	**0.50**	**0.60**

Table 9 (continued)

Degree of ground cover, plant density and training	f_c [a]	h [b]	Crop stage	M_L [c]	F_r [d]	Observed values ranges		Previously tabulated values ranges		Proposed values	
						K_{cb}	K_c	K_{cb}	K_c	K_{cb}	K_c
Medium to very high, vase (200–550 pl/ha)	0.75–0.95	10.0–12.0	Ini	1.5	0.90	–	0.49–0.82	–	–	**0.40**	**0.50**
			Mid	2.0	0.88	–	1.0–1.03	0.90–1.10	0.95–1.15	**1.05**	**1.10**
			End	2.0	0.50	–	0.50–0.72	0.50–0.60	0.55–0.65	**0.60**	**0.70**

Bold values indicate the most relevant information from the review article, i.e., the proposed (updated) K_c and K_{cb} values

[a] f_c: the fraction of ground cover

[b] h: crop height

[c] M_L: a multiplier for fc describing the effect of canopy density on shading and on maximum relative ET per fraction of ground shaded [1.0–2.0]

[d] F_r: an adjustment factor relative to crop stomatal control [0.0–1.0]

addition, Table 10 shows the characteristics for trailing blackberry in a recent study conducted in western Oregon (Carroll et al. 2024).

Table 11 shows that most cases refer to active ground cover (AGC), generally during and immediately after the rainy season, with it thus being necessary to consider the ET both from the crop and from the AGC, as well as soil evaporation (Fandiño et al. 2015; Jiang et al. 2022). Finally, this table shows the actual K_c and K_{cb} values derived from field observations of crop ET and/or its partitioning into plant transpiration and soil evaporation. K_c values show some variability, likely due to differences in plant age, canopy cover and crop height (data not reported in most studies). The most widely used irrigation systems were sprinkler or micro-sprinkler, which wet the entire soil surface or a large portion of it.

Table 12 shows the initial, mid- and end-season standard K_c and K_{cb} values for kiwifruits, hops and different species of berries, which depend upon the degree of ground cover, plant density and training system. For kiwifruits, DGC values range from low in young vines to high density. The training system varies depending on the type of trellis. In the case of hops, there is only one category, which has a common density. For the various berry species, two categories were established, young and mature common density. The categories described are also characterized by f_c and h ranges, which can be helpful in selecting the most appropriate group for the case under study. Furthermore, M_L and F_r parameters are also tabulated to support calculating K_{cb} values using the A&P approach (Allen and Pereira 2009; Pereira et al. 2021c).

The proposed standard K_c and K_{cb} values for the FAO-defined crop growth stages, initial, mid- and end-season, are shown in the last two columns of Table 12. These values are based on the ranges derived from field observations reported in the selected papers and on the ranges previously tabulated (Allen et al. 1998; Rallo et al. 2021). Although it is worth noting the lack of observed or previously tabulated K_c and K_{cb} values in many of the established categories of each crop, most of the proposed values were calculated using the A&P method. As for the other crops examined in this review, K_c/K_{cb} values increase as f_c increases because of its direct relationship to the transpiration component of crop ET, while the soil evaporation component is mainly determined by the frequency and depth of wetting events, the ground area directly exposed to solar radiation, and the energy available for soil water evaporation, which is conditioned by f_c.

Conclusions and recommendations

We reviewed more than 150 scientific articles published after FAO56, and selected 76 papers reporting good quality research on crop coefficients for pome fruit trees, stone fruit trees, nut trees, kiwi, hop and blue- and blackberries. This facilitated a good collection of studies following

Table 10 Characteristics of kiwifruit, hop, blueberries and blackberries

Author	Cultivar	Location & main climate	$ET_{c\ act}$ method (ET_o equation)	Irrigation method & strategy	Plants/ha (Spacing m)	Training system	Age (years)	Height (m)	f_c or f_{IPAR}[a]
Kiwifruit (*Actinidia deliciosa*)									
Silva et al. (2008)	Hayward Male (cv. Matua &Tomuri)	Guimarães, Portugal *Med. Atlantic*	SF, EC, mic-lys (FAO-PM-ET_o)	Micro-spr FI	400 (5.0×5.0)	T-bar	14–15	n/r	n/r
Xiloyannis et al. (2012)	Hayward	Southern Italy *Med*	n/r	Micro-spr FI	n/r	n/r	n/r	n/r	n/r
Jiang et al. (2022)	Jin Yan	Pujiang, China *Subtrop. humid*	SF, EC, mic-lys (FAO-PM-ET_o	Sprinkler FI	445 (5.0×4.5)	Trellis	15	1.80–2.20	n/r
Hop (*Humulus lupulus* L.)									
Krofta et al. (2013)	Premiant	Zatec, Czech Rep *Temperate*	SF (FAO-PM-ET_o)	Rainfed	3333 (3.0×1.0)	Y trellis	1	7.00	n/r
Fandiño et al. (2015)	Nugget	Galicia, Spain *Temperate Atlantic*	SWB-TDR, SIM-DualKc (FAO-PM-ET_o)	Drip FI	1667 (3.0×2.0)	Hedgerow	6 7 8	6.00	0.08 0.09 0.08
Highbush Blueberry (*Vaccinium corymbosum* L.)									
Dourte et al. (2010)	Star, Misty and Jewel	Island Grove, Florida *Humid, subtropical*	SWB-TDR, DL (ASCE-PM ET_o)	Sprinkler FI	3500 (n/r)	Free form	8	n/r	n/r
Williamson et al. (2015)	Emerald	Citra, Florida, USA *Subtropical humid*	DL (mod Penman)	Micro-spr FI	3703 (3.0×0.9)	Free form	4–6	n/r	0.50–0.60
Lagos et al. (2023)	Legacy	Ñuble Region, Chile *Med. temperate*	EC (ASCE-PM ET_o)	Drip FI	3333 (3×1)	Free form	6–9	1.20 – 1.30	0.55–0.61
Lowbush Blueberry (*Vaccinium angustifolium* L.)									
Hunt et al. (2008)	n/r	Jonesboro, Maine US *Humid continental*	WL (FAO-PM-ET_o)	Sprinkler FI	n/r	Free form	3–4	n/r	n/r
Rabbiteye Blueberry (*Vaccinium ashei* Reade)									
Ortega-Farias et al. (2021)	Tifblue	Colbún, Maule, Chile *Med semiarid*	SWB (FAO-PM-ET_o)	Drip FI	3333 (3.0×1.0)	n/r	5–6	n/r	n/r
Blackberry (*Rubus* L. *subgenus Rubus* Watson)									
Carroll et al. (2024)	Columbia Star	Aurora, Oregon, USA *Warm-summer Med*	WL (FAO-PM-ET_o)	Drip FI	2153 (1.5×3.0)	Vertical 2-wire trellis system	1 2 3	n/r	0.11 0.45 0.81

[a] f_c or f_{IPAR}: the fraction of ground cover or intercepted radiation

recommended practices for measuring ET_c and deriving K_c values and data handling that explained water use and requirements for these temperate fruit trees and shrub crops. The selected studies indicate good knowledge about the water requirements of those crops despite water management practices needing to be improved to enable more efficient use of water without negative impacts on yields and fruit quality.

The optimization of water use requires not only proper irrigation scheduling based on standard crop coefficients, but also the design, operation and use of irrigation systems to achieve high technical and economic performance. This involves adopting application practices and irrigation scheduling that allow for good control of the water applied and avoid excesses in water use and water losses. In this regard, whenever possible, we should monitor the plant and/or the soil water status to optimize irrigation scheduling and update (adjust) the K_c/K_{cb} values if necessary. Many studies aim to implement irrigation management practices, including regulated or sustained deficit irrigation strategies, which are in line with eustress. The application of such deficit irrigation practices means that farmers, technicians and farm advisors should have adequate knowledge on these issues, on the use of meteorological information, and on using models that support decision-making. The tabulated standard coefficients are developed for these purposes. In addition, the field estimation of crop coefficients using the A&P approach based on simple observations of f_c and h, and on the respective parameterization (Pereira et al. 2021c), also provide much valuable information for irrigation management and scheduling, namely when comparing the obtained values with the tabulated standard ones. This is shown in a previous study (Pereira et al. 2020) where the method is in operational use in California as a tool of the Satellite Irrigation Management Support (SIMS) framework (Melton et al. 2018).

Table 11 Field derived single (K_c) and basal (K_{cb}) crop coefficients of kiwifruit, hops, blueberry and blackberry orchards

Author	Cultivar	Training system	f_c or f_{IPAR} [a]	Height (m)	Ground cover	Age	K_c /K_{cb} derived from field observations					
							$K_{c\ ini}$	$K_{c\ mid}$	$K_{c\ end}$	$K_{cb\ ini}$	$K_{cb\ mid}$	$K_{cb\ end}$
Kiwifruit (*Actinidia deliciosa*)												
Silva et al. (2008)	Hayward Male (cv. Matua &Tomuri)	T-bar	n/r	n/r	AGC Aut-Spr	14–15	n/r	0.95	n/r	n/r	0.70	n/r
Xiloyannis et al. (2012)	Hayward	n/r	n/r	n/r	Partially AGC	n/r	0.50	1.10	0.80	n/r	n/r	n/r
Jiang et al. (2022)	Jin Yan	Trellis	n/r	1.80–2.20	Partially AGC	15	0.98	1.36	n/r	0.21	0.68	n/r
Hop (*Humulus lupulus* L.)												
Krofta et al. (2013)	Premiant	Y trellis	n/r	7.00	AGC	1	n/r	n/r	n/r	0.19	0.70	n/r
Fandiño et al. (2015)	Nugget	Trellis	0.08 0.09 0.08	6.00	AGC	6 7 8	0.69	1.02	0.85	0.16	0.97	0.83
Highbush blueberries (*Vaccinium corymbosum* L.)												
Dourte et al. (2010)	Star, Misty and Jewel	Free form	n/r	n/r	BS	8	0.77	0.93	0.67	n/r	n/r	n/r
Williamson et al. (2015)	Emerald	Free form	0.50–0.60	n/r	Organ M	4–6	0.62	0.75	0.70	n/r	n/r	n/r
Lagos et al. (2023)	Legacy	Free form	0.55–0.61	1.20–1.30	n/r	6–9	0.70	0.75	0.65	n/r	n/r	n/r
Lowbush Blueberry (*Vaccinium angustifolium* L.)												
Hunt et al. (2008)	n/r	Free form	n/r	n/r	n/r	3–4		0.68	n/r	n/r	n/r	n/r
Rabbiteye Blueberry (*Vaccinium virgatum* Aiton)												
Ortega-Farias et al. (2021)	Tifblue	n/r	n/r	n/r	n/r	5–6	0.10	0.75	n/r	n/r	n/r	n/r
Blackberry (*Rubus* L. *subgenus Rubus* Watson)												
Carroll et al. (2024)	Columbia Star	Vertical 2-wire trellis	0.11 0.45 0.81	n/r	n/r	1–2 3	0.30 0.36	0.45 0.89	0.35 0.48	n/r	n/r	n/r

[a] f_c or f_{IPAR} the fraction of ground cover or intercepted radiation

Table 12 Initial, mid- and end-season standard K_c and K_{cb} values kiwi, hop, blueberry and blackberry orchards as related to plant density and training, degree/fraction of ground cover and height. The ranges of observed and previously tabulated standard K_c and K_{cb} values are also shown

Degree of ground cover, plant density and training	f_c[a]	h[b]	Crop stage	M_L[c]	F_r[d]	Observed values ranges		Previously tabulated values ranges		Proposed values	
						K_{cb}	K_c	K_{cb}	K_c	K_{cb}	K_c
Kiwi (*Actinidia deliciosa*)											
Young (< 6 years), trellis	< 0.60	< 2.0	Ini	1.6	1.00	–	–	–	–	**0.20**	**0.35**
			Mid	1.5	1.00	–	–	–	–	**0.65**	**0.75**
			End	1.1	1.00	–	–	–	–	**0.40**	**0.50**
Medium density, T-bar trellis (< 800 pl/ha)	0.60–0.80	2.0–2.2	Ini	1.4	0.70	0.21	0.50–0.98	0.20	0.40	**0.25**	**0.40**
			Mid	2.0	0.80	0.68–0.70	0.95–1.36	1.00	1.05	**0.85**	**0.95**
			End	2.0	0.70	–	0.80	1.00	1.05	**0.70**	**0.75**
High density, pergola trellis (> 800 pl/ha)	0.60–0.95	2.0–2.5	Ini	1.5	0.70	–	–	–	–	**0.30**	**0.45**
			Mid	2.0	0.80	–	–	0.90–1.00	0.95–1.05	**0.90**	**1.00**
			End	2.0	0.70	–	–	0.80–0.90	0.90–1.00	**0.75**	**0.85**
Hops (*Humulus lupulus* L.)											
Common density, trellis (< 3500 pl/ha)	0.08–0.12[e]	6–7	Ini	2.0	1.00	0.16–0.19	0.69	0.15	0.30	**0.15**	**0.30**
			Mid	2.0	1.00	0.70–0.97	1.02	1.00	1.05	**0.95**	**1.00**
			End	2.0	1.00	0.83	0.85	0.80	0.85	**0.80**	**0.90**
Small fruits – Highbush blueberry intensive (*Vaccinium corymbosum* L.)											
Young (< 3 years)	< 0.50	< 1.50	Ini	1.5	1.00	–	–	–	–	**0.20**	**0.30**
			Mid	1.3	1.00	–	–	–	–	**0.55**	**0.65**
			End	1.0	1.00	–	–	–	–	**0.35**	**0.45**
Common density (2500 to 5000 pl/ha)	0.50–0.80	1.50–2.00	Ini	1.6	1.00	–	0.62–0.77	0.20	0.30	**0.45**	**0.55**
			Mid	2.0	0.85	–	0.75–0.93	1.00	1.05	**0.85**	**0.90**
			End	2.0	0.65	–	0.67–0.70	0.40	0.50	**0.65**	**0.75**
Small fruits–Lowbush blueberry (industry) (*Vaccinium angustifolium* L.)											
Young (< 2 years)	< 0.50	< 0.60	Ini	1.5	1.00	–	–	–	–	**0.20**	**0.30**
			Mid	1.5	1.00	–	–	–	–	**0.55**	**0.65**
			End	1.1	1.00	–	–	–	–	**0.40**	**0.55**
Common density (> 5000 plants/ha)	0.50–0.80	0.60–1.00	Ini	1.6	1.00	–	–	–	–	**0.35**	**0.45**
			Mid	2.0	0.90	–	0.63–0.69	–	–	**0.75**	**0.80**
			End	2.0	0.75	–	–	–	–	**0.60**	**0.65**

Table 12 (continued)

Degree of ground cover, plant density and training	f_c[a]	h [b]	Crop stage	M_L [c]	F_r [d]	Observed values ranges		Previously tabulated values ranges		Proposed values	
						K_{cb}	K_c	K_{cb}	K_c	K_{cb}	K_c
Small fruits–Rabbiteye blueberry (*Vaccinium virgatum* Aiton)											
Young (< 3 years)	< 0.50	< 0.60	Ini	1.5	1.00	–	–	–	–	**0.20**	**0.30**
			Mid	1.5	1.00	–	–	–	–	**0.55**	**0.65**
			End	1.1	1.00	–	–	–	–	**0.40**	**0.55**
Common density (2500 to 5000 plants/ha)	0.50–0.80	0.60–1.00	Ini	1.6	1.00	–	0.10	–	–	**0.35**	**0.45**
			Mid	2.0	0.85	–	0.75	–	–	**0.70**	**0.75**
			End	2.0	0.75	–	-	–	–	**0.60**	**0.65**
Blackberry (*Rubus* L. *subgenus Rubus* Watson)											
Young (< 3 years)	< 0.50	< 1.00	Ini	1.5	1.00	–	0.30	–	–	**0.20**	**0.30**
			Mid	1.3	1.00	–	0.45	–	–	**0.35**	**0.45**
			End	1.0	1.00	–	0.35	–	–	**0.25**	**0.35**
Common density (2000–5000 pl/ha)	0.50–0.85	1.00–2.00	Ini	1.5	0.95	–	0.35	–	–	**0.25**	**0.35**
			Mid	2.0	0.90	–	0.90	–	–	**0.85**	**0.90**
			End	2.0	0.65	–	0.50	–	–	**0.40**	**0.50**

Bold values indicate the most relevant information from the review article, i.e., the proposed (updated) K_c and K_{cb} values

[a] f_c: the fraction of ground cover

[b] h: crop height

[c] M_L: a multiplier for fc describing the effect of canopy density on shading and on maximum relative ET per fraction of ground shaded [1.0–2.0]

[d] F_r: an adjustment factor relative to crop stomatal control [0.0–1.0]

**[e] when using A&P approach a correction must be performed to the f_c values to be multiplied by 3 to account for the vertical growth

When water availability is limited, the standard K_c and K_{cb} values must be used as the upper limits for irrigation water use, therefore ensuring water needs are met in all places. Users should apply a reduction of the standard K_c and K_{cb} values when water deficit is required, e.g. under drought and in water scarce regions. The use of simulation models is then particularly interesting.

Quality control of the measured actual K_c and K_{cb} values is required. A simple and useful approach is comparing the standard K_c/K_{cb} values tabulated in this article with the newly measured K_c/K_{cb}. This simple comparison could avoid K_c values larger than 1.4, up to 2.0 or greater, being found with no justification other than research and monitoring errors. If the search for the actual K_c and K_{cb} values is successful, it will support sustainable water use, improving crop and economic water productivity, and achieving progressive adaptation to, and mitigation of, climate change.

Users are encouraged to study and analyse the cited publications in addition to the information supplied and tabulated in the current article. It is especially necessary to raise awareness about water conservation and saving, particularly under conditions of water supply shortage. Users are expected to recognize the usability of the standard crop coefficients and of the conditions required for the transfer of K_c/K_{cb} values for use in other locations and climate conditions.

Looking ahead to future studies, these should focus on high-accuracy ET_c measurements of less widely studied crops, such as plum, cherry, pistachio, hops, blue- and blackberries, using well-established water and energy balance methods. Future studies are also required on the use of practices to reduce non-beneficial water use, e.g., controlling soil evaporation. Finally, the impacts of fruit load, thinning, mulches, intercropping and cover crops on evapotranspiration and water use, and thus on K_c and K_{cb} values, are among the topics requiring further research. These topics should be combined with other agronomic practices that influence yields and production quality.

Appendix 1: List of symbols, abbreviations, and acronyms

Symbols

E_s: Soil evaporation [mm d^{-1} or mm h^{-1}]
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 [-]
h Crop height [m]
K_c: (standard) crop coefficient [-]
$K_{c\ act}$: Actual crop coefficient (non-standard conditions) [-]
$K_{c\ ini}$: 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_e: Soil evaporation coefficient [-]
K_s: Water stress coefficient [-]
M_L: Multiplier relative to the canopy transparency [-]
T_c: Crop transpiration [mm d^{-1} or mm h^{-1}]

Abbreviations and acronyms

A&P: Allen and Pereira (2009) approach
AGC: Active ground cover
Avg.: Average
ASCE-PM: ET_oASCE Standardized grass ET_o equation
Aut: Autumn
BPlast M: Black plastic mulch
BREB: Bowen ratio energy balance

Abbreviations and acronyms

FDR: Frequency Domain Reflectometry
FI: Full irrigation
gravim.: Gravimetric method
HS: Hargreaves-Samani ET_o equation
KAC: VKearney Agricultural Center Perpendicular V
LAI: Leaf area index
Lys: Lysimeter
Mod: central leader Modified central leader
Med: Mediterranean
METRIC: Energy Balance model for Mapping
Evapo: Transpiration with Internalized Calibration
Micro-spr.: Micro-sprinkler or micro-sprayer
Mini-spr.: Minisprinklers
Micro lys: Mini or micro lysimeters
n/r: Not reported
Organ M: Organic mulch
PAR: Photosynthetically active radiation
Pl/ha: Plants/ha
RDI: Regulated Deficit Irrigation
REEM: Regional ET estimation model
RS: Remote sensing
RSEB: Remote sensing from energy balance
RSVI: Remote sensing from vegetation indices
RS-SEB: Remote sensing surface energy balance
S-W: Shuttleworth and Wallace double source model
SDI: Sustained Deficit Irrigation
SF: Sap flow
SIMS: Satellite irrigation Management Support
Spr: Spring
SR: Surface renewal
STSEB: Symplified two source energy balance
Sum: Summer
Subtrop.: Subtropical
SWB: Soil water balance

Symbols	Abbreviations and acronyms
BS: Bare soil	SWB-neutr: Soil water balance-neutron probe
C. leader: Central leader	SWC: Soil water content
CIMIS-Penman ET_o: The California Irrigation Management Information	Syst.: System
System Penman grass ET_o equation	T: Transpiration
DGC: Degree of ground cover	TDR: Time domain reflectrometer
DI: Deficit Irrigation	Temp: Temperate
DL: Drainage lysimeters	Tensiom.: Tensiometers
EC: Eddy covariance	VI: Vegetation index
ET: Evapotranspiration	Vig: Vigour
FAO56: Guidelines for computing crop water requirements -	WPlast M: White plastic mulch
FAO: Irrigation and drainage paper 56	Win: Winter
FAO-PM-ET_oFAO: Penman Monteith grass reference ET_o	WL: Weighing lysimeter

Acknowledgements R. López-Urrea and F. Montoya are grateful for 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 NextGenerationEU (TED2021–130405B-I00) co-financing. The study was also funded through an agreement between FAO and the Instituto Superior de Agronomia, Universidade de Lisboa (LoA FAO-ISA-RP- 355071). Finally, this work was supported by national funds through 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. R. López-Urrea is grateful for all the support from his former workplace (Instituto Técnico Agronómico Provincial, ITAP, Albacete, Castilla-La Mancha) while this study was being carried out.

Author contributions Author contributions RLU, FM, PP, LSP designed and contributed to the search and selection of the reviewed articles; RLU wrote the main manuscript text, with the contribution of FM, PP, LSP, 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 thanks to the CRUE-CSIC agreement with Springer Nature.

Data availability No datasets were generated or analysed during the current study.

Declarations

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

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