Vol. 24, No. 1, pp. 81-94 (2024)
Journal of Agricultural Physics
ISSN 0973-032X
http://www.agrophysics.in

Research Article

Assessing Evapotranspiration and Water Productivity in Mango cv. Amrapali under Subtropical Climate

TARUN ADAK* AND NARESH BABU

ICAR- Central Institute for Subtropical Horticulture, Rehmankhera, Lucknow-226101, Uttar Pradesh

ABSTRACT

Soil and climate play significant role on the water use and its productivity of mango. In this connection, water use and productivity of Amrapali mango grown under subtropical condition of Lucknow, Uttar Pradesh was quantified. Recent information of weather factors was analyzed and it was inferred that variability of climatic factors do exists in subtropical orchards. The estimated incoming net shortwave radiation varied between 7.91±1.57 to 19.45±0.60 $MJ/m^2/day$ whereas net longwave radiations of 1.61±0.72 to 4.63±0.28 $MJ/m^2/day$ during Amrapali production at subtropical climate. The estimated net radiation stands at 5.27±0.65 to 16.07±1.82 $MJ/m^2/day$ and reference evapotranspiration of 1.40±0.22 to 5.8±0.39 mm/day for Amrapali production stages. The variability of ET_0 at flowering and peanut stage was 2.51 to 3.81, 2.56 to 4.21, 2.60 to 4.45 and 4.00 to 5.18, 4.64 to 5.52, 4.97 to 5.78 mm/day respectively, in 2020 to 2022. Moreover, the variability of the same at marble stage and over the period of maturity, were 3.84 to 6.18, 4.25 to 5.90, 5.40 to 6.12 and 3.81 to 5.07, 3.83 to 5.28, 2.96 to 6.16 mm/day across three seasons respectively. An amount of 10, 20 and 30 L water per tree was applied to the root zone basin of Amrapali mango to meet out the peak atmospheric demands. During the entire period of fruit set to development, total of 160 to 190 L tree of water were applied in Amrapali and variability of 50 to 150.8 kg/tree in fruit yields across 2020 to 2022 seasons was noted. The water productivity of 0.31 to 0.74 g/mm was estimated. Water use of <200 L/tree was observed successful to produce considerable amount of Amrapali fruits under subtropical climate for benefit of farmers.

Key words: Amrapali mango, Net radiation, Reference ET, Water productivity, Innovative technology

Introduction

Resource conservation at subtropical climates is of great importance from view point of increasing efficiency. The precise management of local resources is becoming foremost important issue not only for local but also of national importance. Priority areas include enhancing productivity of fruits with optimized resources and its use in subtropical condition. Technological advancement has emphasized on the practices of conservation agriculture wherein yield improvement, reduction in cost, water savings and ultimately profits were achieved (Pathak *et al.,* 2021). Water conservation policy has tremendous impacts not only in conservation of precise water but also for farm income (Brinegar and Ward, 2009). Actually, economics is associated with it (Prasad *et al.,* 2022). For resource poor farmers, it is very difficult to apply indiscriminate resources to get higher yields. Small and marginal growers adopt the advanced resource conservation and management technologies to suffice yield. However, desired yield was sometimes lower than observed yield. Climatic factors heavily affect the production cycle of fruit crops. Vegetative stage influenced by temperature dynamics while

*Corresponding author,
Email: Tarun.Adak@icar.gov.in

reproductive stage acts as a function of climatic factors. Following field experimentation, estimated 609 to 1016 mm of evapotranspiration and 1170 to 1519 $MJ/m^2/year$ intercepted photosynthetically active radiation in olive orchards (Iniesta *et al.,* 2009). Variability of yield of 6059 to 19747 kg/ha in regulated deficit irrigation and 9289 to 24875 kg/ha in plots having full irrigation to meet out maximum ET. The resultant water use efficiency of 0.45 to 0.50 and 1.43 to 1.63 kg/m^3 respectively in both the situation was obtained. Under deficit irrigation regime coupled with thinning operation is fruitful to early-maturing peach (Vera *et al.,* 2013). Precise estimation of ET is very much crucial to optimize water application and thereby avoiding stress also (Tawegoum *et al.,* 2015) and foliage coverage also taken into consideration for ET estimation and thereby precise water use is decided in vineyards (Kang *et al.,* 2022). In subtropical climates, weather factors undergo systematic changes during each fruit growing season. The resultant impact observed on the flowering and fruitset pattern. The distribution of temperature and relative humidity over the mango growing season has significant role on the production scenario. Statistical dynamics of radiation component-an important factor influences the production scenario. Evapotranspiration always attributes critical response at flowering to fruit development stages. Thus, response of mango tree to existing soil environment is to be assessed scientifically. Adak and Babu (2023) estimated heat use efficiency in Dashehari and a range of 1.87 to 6.08 $g/m^2/°Cd$ was recorded. The rhizosphere is very much sensitive and it offers great challenge to response to any kind of stress. Therefore, understanding soil rhizosphere and climatic interactions adds to scientific knowledge on soil-tree ecosystem services (Kuppe *et al.,* 2022). The response of tree under full irrigation or regulated deficit irrigating or partial root zone drying condition had differential water productivity. In a study in almond, water productivity of 0.175 to 0.330 (FI), 0.205 to 0.421 (RDI) and 0.309 to 0.712 (PRD) was estimated (Egea *et al.,* 2010). Even in cherry orchard, maximum water productivity was obtained by applying fifty per cent of full irrigation (Carrasco-Benavides *et al.,* 2020). The root zone soil moisture dynamics is very crucial to support fruit production. It was inferred from a study that soil moisture level decreased to a minimum level at the highest ET level. Since ET significantly affects moister content, the entire growth season ET estimation is essentially required (Kisekka *et al.,* 2022). The climatic factors along with water thus impacting on the water foot prints across region (Gao *et al.,* 2021). Water conservation in soil has always significant impact on the tree fruit load dynamics. Use of optimized water at fruit set, peanut and marble period are critical to yield attenuation. Growers need to apply whatever low quantity of water available at crucial stages to support tree performance. Improving water productivity was thus given topmost priority in all agroclimatic zones. Due to a lack of information on water productivity in Amrapali mango, the present investigation was carried out to develop the latest technology under subtropical conditions

Material and Methods

The location for estimating water productivity in mango was at the research farm of ICAR- Central Institute for Subtropical Horticulture, Rehmankhera, P.O. Kakori, Lucknow, Uttar Pradesh. The latitude and longitude of this place are 26°54′ N and 80°45′ E (Fig. 1). The altitude of this place is about 127 m above mean sea level. The area is characterized by subtropical in nature. Normally, the region is having dry hot summer season with temperature varied between 36 to 47°C; during winter season, lower temperature of 0.1 to 10°C prevailed. Annual rainfall may be around 1000 mm but area is having scattered and widely distributed rainfall pattern. Mostly, during fruit set to developmental stages, almost nil or sometimes a small quantity of rainfall received. The rainfall may not be beneficial for the fruit growth at all. Therefore, trees are highly dependent on water application. After harvesting of fruits, heavy rainfall showered on the trees. Unseasonable rainfall during the vegetative stage was also commonly noticed. Healthy Amrapali mango trees were selected for experimental purpose. General crop protection measures were adopted. Climatic factors were recorded from agrometeorological observatory of the Institute and radiation dynamics was estimated. Incoming net shortwave and outgoing net long wave radiations were estimated following standard equations from which net radiation was estimated.

Fig. 1. The location map of the study area

The reference evapotranspiration (ET_0) was estimated using modified Penman-Monteith equation

$$ET_0 = \frac{0.408\Delta\,(Rn - G) + \gamma(900 / (T + 273))\,u_2\,(e_s - e_a)}{\Delta + \gamma\,(1 + 0.34\,u_2)}$$

Where: ET_0 is the reference crop ET (mm day^{-1}),

Rn is net radiation at the crop surface (MJ m^{-2} day^{-1}),

G is soil heat flux at the soil surface (MJ m^{-2} day^{-1}),

T is mean daily air temperature (°C), 900 is a conversion factor,

u_2 is mean daily wind speed (m s^{-1}),

e_s is mean saturation vapor-pressure (kPa),

e_a is mean actual vapor-pressure (kPa), $e_s - e_a$ is the saturation vapor pressure deficit,

Δ is slope of the saturation vapor-pressure-temperature curve (kPa°C^{-1}),

γ is psychrometric constant (kPa°C^{-1}), e_a was calculated based on temperature and relative humidity, and net radiation was calculated from the difference between the incoming net shortwave radiation and outgoing net long wave radia-tion.

The incoming shortwave solar radiation (Rs) was calculated by the Angstrom's formula

$Rs = Ra \times (0.32 + 0.46 \times n/N)$

Where, n = actual bright sunshine hours for a day and N = Maximum possible sunshine hours for the same day. Where, $N = (24/\pi) \times Ws$

Ws is the sunset hour angle (Radian) = Arc Cosine [-tan (Φ) × tan (α)]

Φ = Latitude in radian, For CISH, Lucknow Φ= (26.54 × π)/ 180

σ = Solar declination angle was calculated as $\sigma = 0.409 \times \text{Sine}\,[(2 \times \pi \times J)/d - 1.39]$

Where J= Julian days (1 to 365/366) and d = No. of days in the year

Mean daily values of extraterrestrial radiation was estimated using

$Ra = [(24\times60)/\pi \times Gsc \times dr \times \{Ws \times \sin(\Phi) \times \sin(\sigma) + \cos(\Phi) \times \cos(\sigma) \times \sin(Ws)\}]$

Where, Ra= Extra terrestrial radiation ($MJ/m^2/day$)

Gsc = Solar Constant = 0.082 $MJ/m^2/min$, dr = Inverse relative distance earth-sun

Ws = Sunset hour angle, Φ = Latitude (radian), σ = Solar declination

drwas estimated by the following equation

dr = {1+0.033 ×Cos (2π/365 ×J)}, Where J is the Julian day

All this information was generated from 1st January to 31st July of the 2020, 2021, and 2022 fruiting seasons. Weekly average data was tabulated and univariate statistical analysis was incorporated. Reference evapotranspiration was estimated on daily basis and standard weekly average data was presented. ET_0 at vegetative, flowering, pea, marble and maturity stages were computed for discussion in three fruiting seasons of 2020 to 2022. The data of consecutive fruiting seasons were used for detailed scientific analysis and discussion. Average temperature and relative humidity on weekly basis were also graphically presented for discussion at Amrapali production under subtropical climate. Critical observation on reproductive stages like flowering, fruit setting and development was observed. Water at fruit set, pea and marble stages of Amrapali fruit was applied at the root zone basin. Water was applied on four to five intervals to ensure proper moisture is being maintained in the Amrapali tree root zone. Amount of water 10, 20 and 30 L/tree were applied to support significant fruit development at this subtropical climate. Irrigation water treatments consisting of 160 to 190 L/tree was imposed. Water productivity was quantified after recording fruit yield per tree.

Results and Discussion

Scientific estimation of critical climatic factors during Amrapali production

The dynamics of incoming shortwave radiation and out going long wave radiations had created radiation regimes. This radiation regime is important for the physiological changes in tree species. The ambient temperature and relative humidity dynamics significantly affects the reproductive cycles in fruit bearing trees. It was observed that three years weekly average temperature were ranges from 12.30±1.50 to 31.87±3.61°C. The average temperature of standard week's from 1 to 30 was recorded and it was found that 10.68 to 35.54, 12.25 to 31.54 and 12.32 to 32.61°C in years of 2022, 2021 and 2020 fruiting season respectively. The average relative humidity across 2020 to 2022 seasons was noted as 84.52±4.62 to 63.90±6.93 per cent. Based on latest information on year wise data, it was recorded and varied from 49.29 to 89.79 per cent in 2022; 63.57 to 83.29 per cent in 2021 and 67.86 to 84.57 per cent in 2020 respectively. Temperature difference was observed across 2020 to 2022 fruiting seasons with higher in 2022 and lower in 2020 was noted (Fig. 2). Similarly, lower relative humidity in 2022 and greater relative humidity in 2020 were observed. The incoming net shortwave radiation varied from 6.32 to 20.47, 8.10 to 20.72 and 7.84 to 19.43 $MJ/m^2/day$ in 2020, 2021 and 2022 (Table 1). Mean values of net shortwave radiation stands at 14.98±3.67, 15.29±3.19 and 15.15±3.75 $MJ/m^2/day$ in 2020 to 2022 seasons. Likewise, net longwave radiation has dynamics of 1.23 to 4.78, 1.34 to 4.58 and 0.78 to 4.80 $MJ/m^2/day$ in 2020, 2021 and 2022 fruiting seasons (Table 2). The seasonal average of 3.05±1.04, 3.16±0.89 and 3.34±0.93 $MJ/m^2/day$ was recorded. In this scientific analysis, the most important component of net radiation during Amrapali production seasons was estimated and it was inferred that 4.67 to 16.84, 5.51 to 17.41 and 5.10 to 15.94 $MJ/m^2/day$ in 2020, 2021 and 2022 respectively. Of course, seasonal average of 11.93±3.66, 12.13±3.43 and 11.81±3.58 $MJ/m^2/day$ were noted. During flowering season, 9.11±0.09 to 12.39±0.12 $MJ/m^2/day$ were estimated while at peanut stage, 12.93±0.010 to 15.13±0.38 $MJ/m^2/day$ were recorded. It was found that net radiations of 14.99±1.63 to 16.07±1.82 $MJ/m^2/day$ were at marble stages of Amrapali production across seasons (Table 3). The seasonal variability of net radiations at vegetative and reproductive stages were also noted and it was found that 8.66 to 12.25, 9.04 to 12.48 and 9.07 to 12.43 $MJ/m^2/day$ was received at flowering stage in 2020, 2021 and 2022 season. In peanut stage, the corresponding values were 11.64 to 15.46, 12.98 to 15.42 and 12.84 to 14.72 $MJ/m^2/day$ whereas net radiation dynamics of 14.34 to 16.84, 12.74 to 17.41 and 13.99 to 15.67 $MJ/m^2/day$ at marble stage. At the maturity stage, 9.25 to 15.54

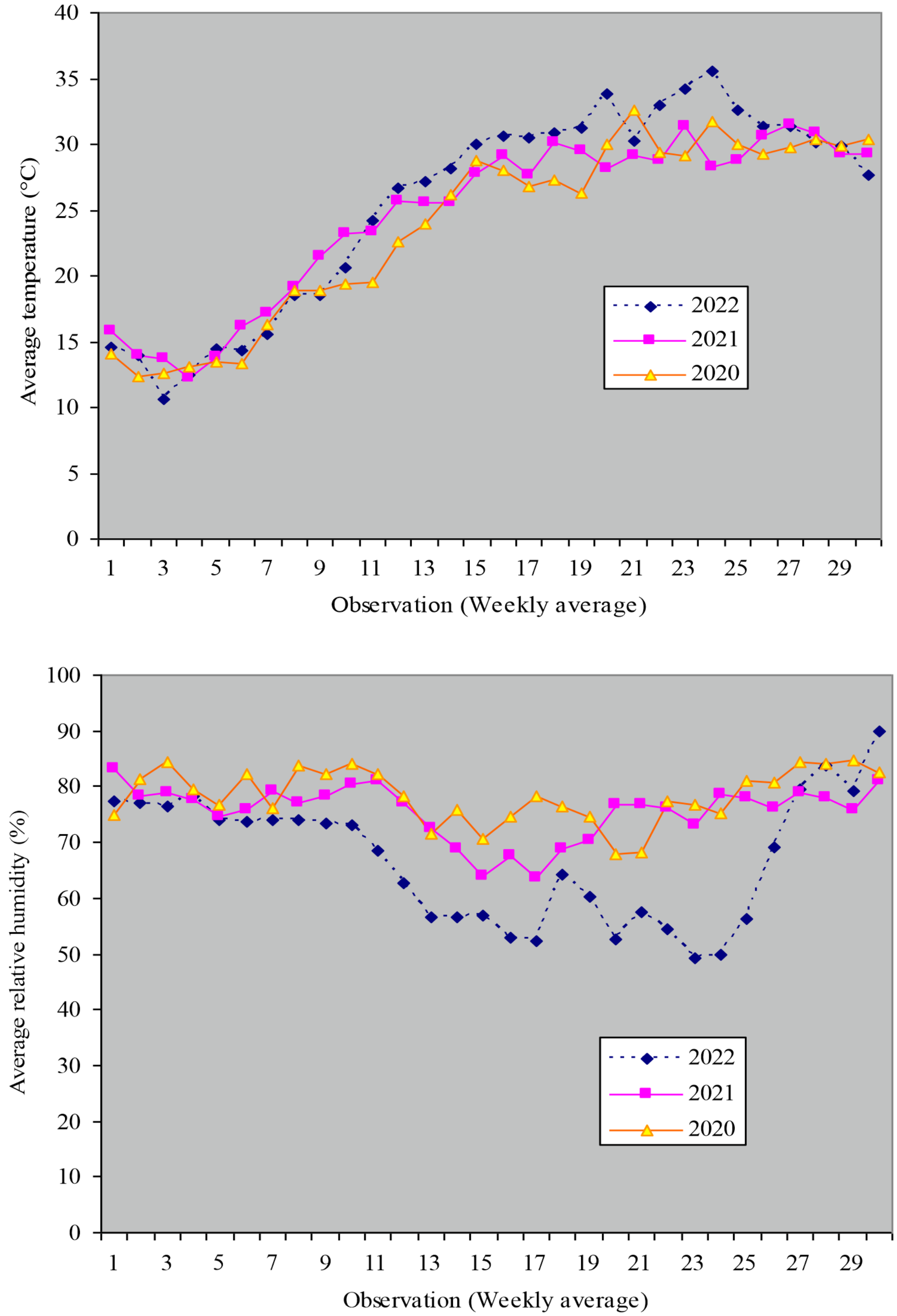

Fig. 2. Distribution pattern of average temperature and relative humidity on weekly basis during Amrapali production in Subtropical condition

MJ/m^2/day were estimated across 2020 to 2022 seasons with average values lies between 12.78±3.16 to 14.55±1.44 MJ/m^2/day.

The radiation or thermal regimes has its own impact on the phenological process of a tree. It is important to estimate the light environment within tree canopies. In this context, light condition in canopies was characterized across fruits and tree architecture (Sinoquet *et al.,* 1998). The radiation dynamics in subtropical climate on mango trees was

Table 1. Estimated incoming net shortwave radiations (MJ/m^2/day) during Amrapali production in Subtropical condition

Std week	2020	2021	2022	Mean	Range Max	Min	Skewness
1	8.46	10.36	8.29	9.03±1.15	10.36	8.29	1.69
2	7.50	10.46	7.84	8.60±1.62	10.46	7.50	1.65
3	6.32	9.46	7.95	7.91±1.57	9.46	6.32	-0.12
4	11.88	8.10	9.07	9.68±1.97	11.88	8.10	1.27
5	12.42	10.91	9.66	11.00±1.38	12.42	9.66	0.28
6	12.88	12.90	11.15	12.31±1.00	12.90	11.15	-1.73
7	14.00	13.35	13.86	13.74±0.34	14.00	13.35	-1.44
8	11.78	14.32	14.16	13.42±1.42	14.32	11.78	-1.71
9	13.50	15.30	14.66	14.49±0.91	15.30	13.50	-0.81
10	13.70	15.08	15.13	14.64±0.81	15.13	13.70	-1.72
11	13.86	14.34	15.78	14.66±1.00	15.78	13.86	1.29
12	16.01	15.69	16.30	16.00±0.31	16.30	15.69	-0.11
13	17.16	16.59	16.94	16.90±0.29	17.16	16.59	-0.69
14	18.12	16.45	17.76	17.44±0.88	18.12	16.45	-1.41
15	18.00	17.75	17.81	17.85±0.13	18.00	17.75	1.32
16	13.75	17.76	18.68	16.73±2.62	18.68	13.75	-1.49
17	17.62	19.67	18.99	18.76±1.04	19.67	17.62	-0.95
18	18.81	18.25	17.68	18.25±0.57	18.81	17.68	-0.04
19	20.11	19.27	18.96	19.45±0.60	20.11	18.96	1.22
20	20.47	14.77	19.39	18.21±3.03	20.47	14.77	-1.49
21	20.16	20.72	17.06	19.32±1.97	20.72	17.06	-1.58
22	17.58	18.74	18.89	18.40±0.72	18.89	17.58	-1.65
23	16.70	18.47	18.48	17.88±1.02	18.48	16.70	-1.73
24	19.47	15.93	17.49	17.63±1.77	19.47	15.93	0.36
25	16.69	15.00	19.43	17.04±2.24	19.43	15.00	0.69
26	12.97	16.82	15.54	15.11±1.96	16.82	12.97	-0.94
27	12.68	17.64	16.51	15.61±2.60	17.64	12.68	-1.37
28	14.44	16.89	14.05	15.12±1.54	16.89	14.05	1.61
29	14.78	12.14	16.90	14.61±2.38	16.90	12.14	-0.33
30	17.46	15.68	10.03	14.39±3.88	17.46	10.03	-1.33

studied in detailed (Adak *et al.,* 2014) and it was observed that indeed variation sin radiation regimes existed over 2011 to 2014 fruiting season affecting flowering, fruit set and other processes. In a detailed study, maximum fruit dry mass, fruit growth rate (89.8 per cent), fruit respiration (93 per cent) and stem reserve mobilization (67.6 per cent) in mango under normal weather condition was estimated (Léchaudel *et al.,* 2005). However, in contrasting environment, the contribution of all source to sink attributes were lower down. Thus climatic factors have to be kept in mind for optimizing production *vis-à-vis* resource use efficiency. In this direction, in a detailed study, the dynamics of radiations in summer, winter and monsoon was recorded over mango growing Malihabad, Uttar Pradesh (Adak *et*

Table 2. Estimated incoming net long wave radiations (MJ/m²/day) during Amrapali production in Subtropical condition

Std week	2020	2021	2022	Mean	Range Max	Min	Skewness
1	3.25	4.03	3.10	3.46±0.50	4.03	3.10	1.55
2	2.51	4.30	2.74	3.18±0.97	4.30	2.51	1.62
3	1.65	3.50	2.77	2.64±0.93	3.50	1.65	-0.60
4	4.74	2.59	3.21	3.51±1.11	4.74	2.59	1.15
5	4.74	3.91	3.31	3.99±0.72	4.74	3.31	0.49
6	4.49	4.58	3.86	4.31±0.39	4.58	3.86	-1.63
7	4.78	4.31	4.80	4.63±0.28	4.80	4.31	-1.73
8	3.13	4.35	4.42	3.97±0.73	4.42	3.13	-1.72
9	3.64	4.12	4.33	4.03±0.35	4.33	3.64	-1.10
10	3.43	3.53	4.04	3.67±0.33	4.04	3.43	1.55
11	3.31	3.07	3.93	3.44±0.45	3.93	3.07	1.17
12	3.76	3.21	3.87	3.62±0.35	3.87	3.21	-1.52
13	4.24	3.55	4.10	3.96±0.37	4.24	3.55	-1.44
14	3.64	3.48	4.21	3.78±0.39	4.21	3.48	1.38
15	3.35	3.83	3.73	3.64±0.25	3.83	3.35	-1.44
16	2.11	3.33	4.19	3.21±1.04	4.19	2.11	-0.50
17	3.09	4.25	4.28	3.87±0.68	4.28	3.09	-1.73
18	3.35	3.04	2.96	3.11±0.21	3.35	2.96	1.45
19	3.66	3.27	3.49	3.47±0.19	3.66	3.27	-0.29
20	3.83	2.03	3.72	3.19±1.01	3.83	2.03	-1.71
21	3.35	3.31	3.07	3.25±0.15	3.35	3.07	-1.57
22	2.57	2.90	3.46	2.98±0.45	3.46	2.57	0.77
23	2.36	2.64	3.60	2.86±0.65	3.60	2.36	1.38
24	2.63	2.17	3.14	2.64±0.49	3.14	2.17	0.13
25	2.02	1.94	3.49	2.48±0.87	3.49	1.94	1.72
26	1.40	2.20	2.11	1.90±0.44	2.20	1.40	-1.66
27	1.23	2.09	1.89	1.74±0.45	2.09	1.23	-1.36
28	1.47	2.15	1.46	1.69±0.40	2.15	1.46	1.73
29	1.59	1.34	2.14	1.69±0.41	2.14	1.34	1.00
30	2.11	1.95	0.78	1.61±0.72	2.11	0.78	-1.63

al., 2021). The variability of evapotranspiration significantly affects the water use. In this context, daily ET_0 was estimated over vineyards for optimizing water application (Semmens *et al.,* 2016). Even, stomatal conductance varied (200 to 545 mmol $m^{-2} s^{-1}$) significantly across cultivars and among water regimes and relative humidly scenario as inferred in another study and suggested low transpiring cultivars may be suited at variable climates (Körner *et al.,* 2021). Regulated deficit water application is known to save water and enhancing water productivity also (Ben-Gal *et al.,* 2021). Water of 1732 to 3243 mm yielded olive fruit yield of 187 to 305.7 kg $tree^{-1}$ with oil yield of 15 to 20.3 t ha^{-1}. The water productivity of 0.68 to 1.28 and 0.6 to 1.05 kg oil m^{-3} was estimated across cultivars and water use. Thus, deficit

Table 3. Estimated net radiations (MJ/m^2/day) during Amrapali production in Subtropical condition

Std week	2020	2021	2022	Mean	Range Max	Min	Skewness
1	5.20	6.33	5.19	5.57±0.65	6.33	5.19	1.73
2	4.99	6.17	5.10	5.42±0.65	6.17	4.99	1.68
3	4.67	5.96	5.19	5.27±0.65	5.96	4.67	0.58
4	7.14	5.51	5.86	6.17±0.86	7.14	5.51	1.41
5	7.68	7.00	6.35	7.01±0.67	7.68	6.35	0.06
6	8.39	8.32	7.29	8.00±0.61	8.39	7.29	-1.71
7	9.21	9.04	9.07	9.11±0.09	9.21	9.04	1.63
8	8.66	9.97	9.74	9.45±0.70	9.97	8.66	-1.53
9	9.86	11.18	10.33	10.46±0.67	11.18	9.86	0.83
10	10.27	11.55	11.09	10.97±0.65	11.55	10.27	-0.79
11	10.55	11.27	11.85	11.22±0.65	11.85	10.55	-0.34
12	12.25	12.48	12.43	12.39±0.12	12.48	12.25	-1.42
13	12.91	13.05	12.84	12.93±0.10	13.05	12.84	0.81
14	14.48	12.98	13.55	13.67±0.76	14.48	12.98	0.70
15	14.65	13.92	14.08	14.22±0.38	14.65	13.92	1.41
16	11.64	14.43	14.49	13.52±1.63	14.49	11.64	-1.73
17	14.54	15.42	14.71	14.89±0.47	15.42	14.54	1.46
18	15.46	15.22	14.72	15.13±0.38	15.46	14.72	-0.94
19	16.45	16.00	15.47	15.97±0.49	16.45	15.47	-0.20
20	16.64	12.74	15.67	15.02±2.03	16.64	12.74	-1.30
21	16.81	17.41	13.99	16.07±1.82	17.41	13.99	-1.52
22	15.01	15.84	15.43	15.43±0.42	15.84	15.01	-0.02
23	14.34	15.83	14.88	15.02±0.75	15.83	14.34	0.78
24	16.84	13.76	14.35	14.99±1.63	16.84	13.76	1.48
25	14.67	13.06	15.94	14.55±1.44	15.94	13.06	-0.34
26	11.58	14.62	13.43	13.21±1.53	14.62	11.58	-0.63
27	11.45	15.54	14.61	13.87±2.15	15.54	11.45	-1.37
28	12.97	14.73	12.59	13.43±1.14	14.73	12.59	1.53
29	13.19	10.80	14.76	12.92±1.99	14.76	10.80	-0.60
30	15.34	13.74	9.25	12.78±3.16	15.34	9.25	-1.24

irrigation is considered as an effective strategy to conserve moisture, saving of precise ground water and enhancing water productivity (Geerts and Raes, 2009).

Dynamics of evapotranspiration and water productivity in Amrapali

It is very much essential to estimate the ET_0 at the time of vegetative and reproductive stages in Amrapali production under subtropical climate. The dynamics of ET_0showed variability in the ranges of 1.20 to 6.18, 1.44 to 5.90 and 1.38 to 6.37 mm/day in 2020, 2021 and 2022 fruiting seasons (Table 4). The seasonal average of standard weekly data suggested values of 3.89±1.47, 4.08±1.41, and 4.24±1.66 mm/day, respectively in 2020 to 2022. At the flowering time in Amrapali, ET_0 of 2.60±0.04 to 4.15±0.32, peanut stage of 4.70±0.25 to 5.46±0.26

Table 4. Estimated reference ET (mm/day) during Amrapali production in Subtropical condition

Std week	2020	2021	2022	Mean	Range Max	Min	Skewness
1	1.50	1.71	1.47	1.56±0.13	1.71	1.47	1.60
2	1.31	1.75	1.42	1.50±0.23	1.75	1.31	1.29
3	1.20	1.64	1.38	1.40±0.22	1.64	1.20	0.59
4	1.93	1.44	1.60	1.66±0.25	1.93	1.44	1.04
5	2.09	1.91	1.98	1.99±0.09	2.09	1.91	0.84
6	2.14	2.41	2.08	2.21±0.18	2.41	2.08	1.50
7	2.64	2.56	2.60	2.60±0.04	2.64	2.56	-0.12
8	2.51	3.03	3.08	2.87±0.31	3.08	2.51	-1.68
9	2.83	3.64	3.12	3.20±0.41	3.64	2.83	0.80
10	2.99	3.69	3.45	3.38±0.36	3.69	2.99	-0.88
11	3.07	3.61	3.97	3.55±0.45	3.97	3.07	-0.59
12	3.81	4.21	4.45	4.15±0.32	4.45	3.81	-0.73
13	4.48	4.64	4.97	4.70±0.25	4.97	4.48	0.96
14	4.88	4.64	5.05	4.86±0.21	5.05	4.64	-0.50
15	5.01	5.25	5.26	5.17±0.14	5.26	5.01	-1.72
16	4.00	5.35	5.57	4.97±0.85	5.57	4.00	-1.61
17	4.79	5.52	5.78	5.36±0.51	5.78	4.79	-1.25
18	5.18	5.49	5.70	5.46±0.26	5.70	5.18	-0.58
19	5.54	5.90	5.76	5.73±0.18	5.90	5.54	-0.63
20	5.85	4.25	6.12	5.41±1.02	6.12	4.25	-1.60
21	6.18	5.81	5.40	5.80±0.39	6.18	5.40	-0.16
22	5.35	5.35	5.86	5.52±0.29	5.86	5.35	1.73
23	4.84	5.56	5.88	5.43±0.53	5.88	4.84	-1.06
24	5.91	4.63	6.37	5.64±0.90	6.37	4.63	-1.24
25	5.01	4.39	6.16	5.19±0.90	6.16	4.39	0.85
26	4.04	4.95	5.21	4.73±0.61	5.21	4.04	-1.39
27	3.81	5.24	5.21	4.76±0.82	5.24	3.81	-1.73
28	4.36	5.28	4.32	4.65±0.55	5.28	4.32	1.72
29	4.37	3.83	5.03	4.41±0.60	5.03	3.83	0.28
30	5.07	4.59	2.96	4.21±1.11	5.07	2.96	-1.37

and in marble stages, 5.41±1.02 to 5.8±0.39 mm/day was recorded. The estimated ET_0values of 4.21±1.11 to 5.19±0.90 mm/day were noted during maturity times. All these average values indicated the variability actually existed over the critical phenophases to influence the growth pattern and fruit load in Amrapali. Seasonal variability of ET_0 was also estimated and it was inferred that ET_0 of 1.20 to 2.14, 1.44 to 2.41 and 1.38 to 2.08 mm/day during vegetative stage at 2020, 2021 and 2022 fruiting seasons. The variability of ET_0 at flowering and peanut stage was of 2.51 to 3.81, 2.56 to 4.21, 2.60 to 4.45 and 4.00 to 5.18, 4.64 to 5.52, 4.97 to 5.78 mm/day respectively in 2020 to 2022. At marble stage and over the period of maturity, 43.84 to 6.18, 4.25 to 5.90, 5.40 to 6.12 and 3.81 to 5.07, 3.83 to 5.28, 2.96 to 6.16 mm/day across three seasons respectively. Such wider dynamics in average ET_0

suggested the role of atmospheric condition at Amrapali production in subtropical climate. Climatic factor was thus very crucial to enhance the water demand of trees to improve the fruit load over tree. Water application is very crucial at the drier months coincides with the reproductive stages. In this experimentation, 10, 20 and 30 L water per tree was applied to the root zone basin of Amrapali mango to meet out the peak atmospheric demands. This condition coincides with the pea and marble stages of fruit development (Fig. 3). During the entire period of fruit set at development total of 160 to 190 L water/ tree of Amrapali was applied at tree basins. It was observed that fruit growth enhances over the periods due to application of smaller quantity of water at the time of need. The scientific basis of life saving irrigation water was to ensure moisture conservation at the tree root zones to support fruit growth. Higher amount of water (30 L/tree) at peak evapotranspiration times improved the sizes of the fruit. At the end of maturity, 50 to 140 kg/tree fruit were harvested. Variability in fruit yields (50 to 150.8 kg/ tree across 2020 to 2022 seasons) was noted (Figure 4). It has been observed that response of each tree was different. The water productivity function indicates yield can be predicted using Y (Yield) = 2.48 × Water applied (L) – 351.9 with R^2 value of 0.8366 i.e. around 84 per cent variability in yield as a function of water application could be predicted (Fig. 5). The water productivity of 0.31 to 0.74 g/ mm was estimated. During the experimentation, it was found that the soils at root zone basin get dried due to high temperature and evapotranspiration. Water is supplied to moisten the root zone on regularly basis. This way a new technology of about <200 L/tree, considerable amount of Amrapali fruit can be harvested. Farmers of this area or water limited areas as well as resource poor growers should adopt

Fig. 3. Dryness in tree basin, water application to root zone depths, Fruit setting and development in Amrapali under subtropical climate

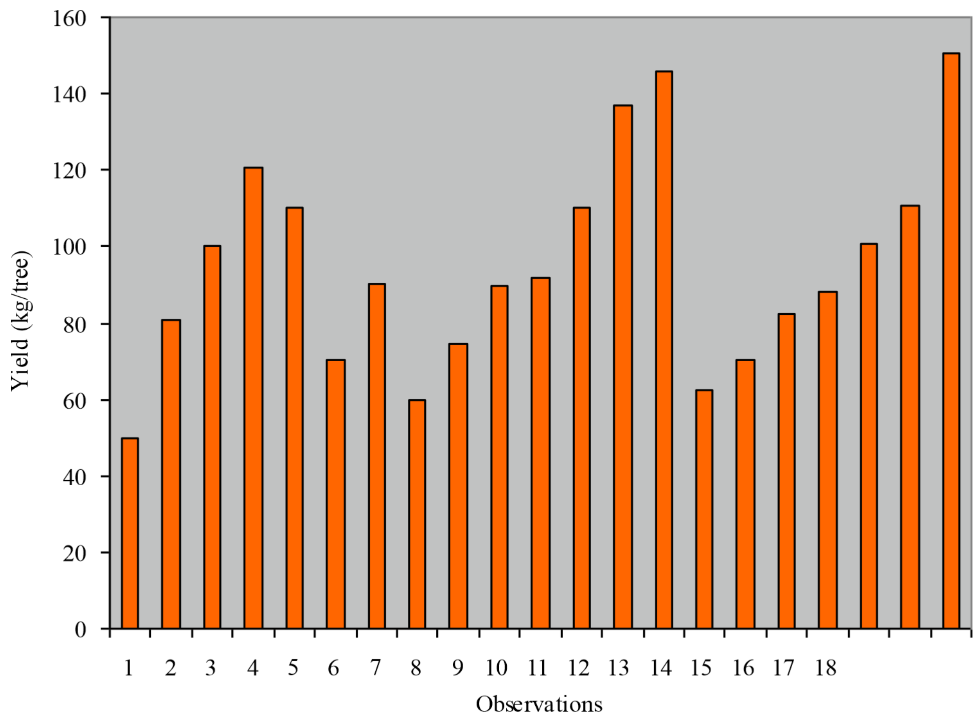

Fig. 4. Yield variability in Amrapali Mango at subtropical climate

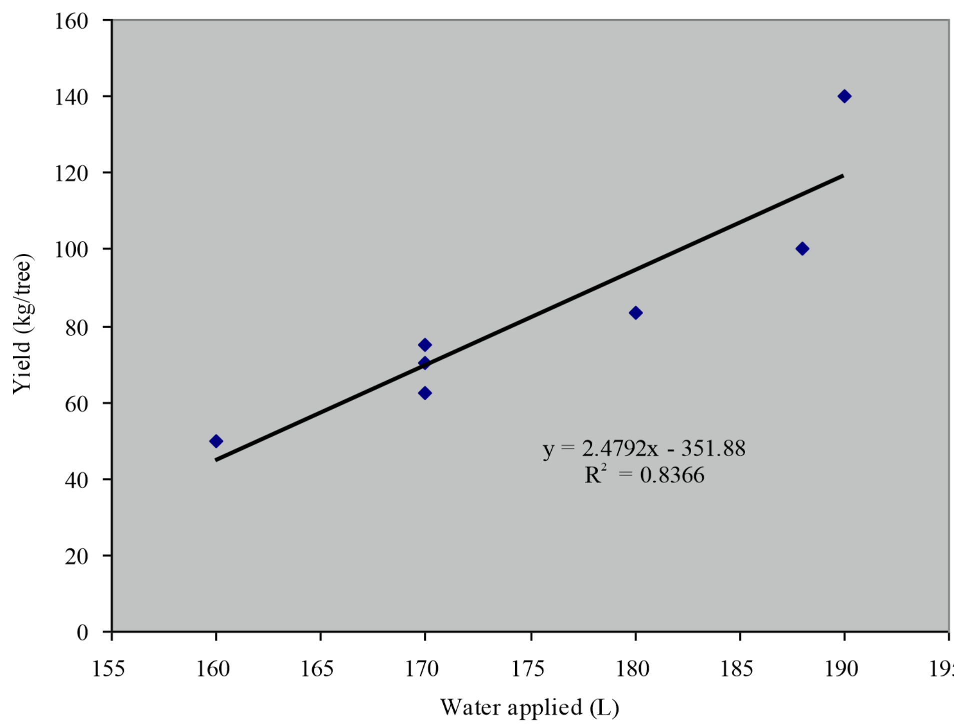

Fig. 5. Water productivity function in Amrapali Mango at subtropical climate

to apply smaller quantity of water i.e.10 to 30 L/ tree/week to full bearing mature Amrapali tree during fruit set to maturity periods. Of course, fruit set, growth and development actually act as a function of climatic-soil-water-tree interactions. Optimum moisture hastens the fruit growth and also reduces the fruit drops.

It was felt necessary to optimize orchard activity for the economic benefits of growers (Batabyal and Yoo, 2007). Reference evapotranspiration act as a function of climatic factors of a location and therefore, its estimation is essential for having understanding its dynamics and impact on the food production system. The water production function in kiwi fruit was estimated with greater fruit production up to 100 percent of pan evaporation level of water application. Moreover, evapotranspiration in kiwi orchards was found to increase with the quantity of water supplied (Holzapfel *et al.,* 2000). In a field study, it was recorded that the mean reference ET varied from 1.87 to 3.74 cm per week in low bush blueberry orchard and estimated mean crop coefficient value of 0.69 to optimize water productivity (Hunt *et al.*, 2008). Even fruit load can enhance the transpiration by fruit trees and it has been observed that roughly thirty per cent higher water transpiration by olive tree loaded with fruits as compare to low or non fruiting trees (Bustan *et al.,* 2016). Following estimation of ET_0 in field experimentation, it was concluded that monthly total ET_0 of 48.61 to 217.3 mm across January to June in apple orchards with estimated water productivity of 4.22 to 5.34 kg/m^3 (Gush *et al.,* 2019). Based on experimentation, it was recorded that fruit load intensity had significant impact on the water use. The highest and lowest yield of date palm was recorded as 225.6 and 81.6 kg/tree with estimated water productivity of 0.464 to 0.943 kg/m^3 (Zhen *et al.,* 2020). In another study, it was concluded that the response of high density olive orchards to water application was different and it was found that with fruit yield variability of 4.7 to 55.6 kg/tree and oil yield variability of 1.3 to 8.9 kg/tree, the water productivity of 5.88 to 4.42 kg/ha/mm at 550 and 392 mm of applied water (Serman *et al.,* 2021). In case of blueberry, the fruit yield of 5.76 to 9.41 kg/tree with estimated water productivity of 3.71 to 4.05 kg/m^3 at 50 to 125 per cent ET_C water levels was inferred (Ortega-Farias *et al.,* 2021).Recently, 1.61 to 4.23 mm/day mean daily evapotranspiration was estimated in greenhouse for sweet pepper cultivation whereas the corresponding values for screen house were 1.42 to 4.43 mm/day to optimize water use in arid region (Hadad *et al.,* 2020). In case of mango, pan evaporation and ET_0 along with pore water conductivity determines the water use efficiency (Adak *et al.,* 2022). The lowest yield of 40.1 to 62.74 kg/tree and water use efficiency of 6.27 to 9.8 kg/m^3 under subtropical condition. Thus, water saving is very much important for fruit production across regimes. Scientific efforts to enhance the water productivity under various agroclimatic zones are of great importance from view point of resource management.

Conclusions

The objective of the present study was to observe the dynamics of climatic factors *vis-à-vis* water use by the Amrapali mango tree at subtropical climates of Lucknow, Uttar Pradesh. Recent information of net incoming shortwave and outgoing long wave radiation was recorded for the years 2020, 2021 and 2022 fruiting cycles. Net radiations at vegetative, flowering, pea, marble and maturity stage of Amrapali production in three consecutive fruiting season of 2020 to 2022 was estimated. Since reference evapotranspiration is very much critical for water use by trees, daily ET_0 was calculated and finally weekly average data was presented at par standard weeks from 1 to 30. All these latest information was noted for 2020, 2021 and 2022 seasons and are correlated at each vegetative and reproductive stages of fruit production. Scientific analysis suggested wide variability of all these climatic factors at each critical phenophases across seasons. Yield variability of 50 to 150 kg/tree was recorded. Water use of 160 to 190 L/tree was noted and water productivity was calculated. The latest water use technology of producing Amrapali fruit with <200 L should be highly beneficial for farmers. Growers of this subtropical or other water scarcity places should adopt the enhancing water productivity technology with aim of having more fruits per drop of applied water.

Acknowledgement

The competent authority of ICAR-CISH, Lucknow was acknowledged. The work was financially supported by Indian Council of Agricultural Research (ICAR) under the project entitled "Evaluation of soil, tree and climatic indicators in Mango orchards". Institute senior colleagues were highly appreciated for providing necessary man power at the time of water application during entire period from fruit setting to developmental stages. Institute facility for recording and sharing weather data was also highly acknowledged.

References

Adak, T., Singh, V.K. and Babu, N. 2021. Extra-terrestrial radiation dynamics over mango orchards. *Kahaar* **8**: 28-30.

Adak, T. and Babu, N. 2023. Estimating heat use efficiency in mango under subtropical climate. *Journal of Natural Resource Conservation and Management* **4**: 1-14.

Adak, T., Singh, V.K. and Babu, N. 2022. Optimizing the Determinants of Water Use Efficiency in Mango. *Journal of Natural Resource Conservation and Management* **3**: 12-16.

Adak, T., Singh, V.K. and Ravishankar, H. 2014. Radiation dynamics and agroclimatic models as a tool to predict impact of climate change on dynamics of flowering in mango. In: *Proceedings of national seminar-cum-workshop on "Physiology of flowering in perennial fruit crops*" held during May 24-26, 2014 at CISH, Lucknow, India. pp 66-68.

Batabyal, A.A. and Yoo, S.J. 2007. A probabilistic approach to optimal orchard management. *Ecological Economics* **60**: 483-486.

Ben-Gal, A., Ron, Y., Yermiyahu, U., Zipori, I., Naoum, S. and Dag, A. 2021. Evaluation of regulated deficit irrigation strategies for oil olives: a case study for two modern Israeli cultivars. *Agricultural Water Management* **245**: 106577.

Brinegar, H.R. and Ward, F.A. 2009. Basin impacts of irrigation water conservation policy. *Ecological Economics* **69**: 414-426.

Bustan, A., Dag, A., Yermiyahu, U., Erel, R., Presnov, E., Agam, N., Kool, D., Iwema, J., Zipori, I. and Ben-Gal, A. 2016. Fruit load governs transpiration of olive trees. *Tree Physiology* **36**: 380-391.

Carrasco-Benavides, M., Espinoza Meza, S., Olguín-C´aceres, J., Mũnoz-Concha, D., von Bennewitz, E., Avila-S´anchez, C. and Ortega-Farías, S. 2020. Effects of regulated post-harvest irrigation strategies on yield, fruit quality and water productivity in a drip-irrigated cherry orchard. *New Zealand Journal of Crop and Horticulture Science* **48**: 97-116.

Egea, G., Nortes, P.A., González-Real, M.M., Baille, A. and Domingo, R. 2010. Agronomic response and water productivity of almond trees under contrasted deficit irrigation regimes. *Agricultural Water Management* **97**: 171-181.

Gao, J., Xie, P., Zhuo, L., Shang, K., Ji, X. and Wu, P. 2021. Water footprints of irrigated crop production and meteorological driving factors at multiple temporal scales. *Agricultural Water Management* **255**: 107014.

Geerts, S. and Raes, D. 2009. Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas. *Agricultural Water Management* **96**: 1275-1284.

Gush, M., Dzikiti, S., Laan, M., Steyn, M., Manamathela, S. and Pienaar, H. 2019. Field quantification of the water footprint of an apple orchard, and extrapolation to watershed scale within a winter rainfall Mediterranean climate zone. *Agricultural and Forest Meteorology* **271**: 135-147.

Hadad, D., Lukyanov, V., Cohen, S., Zipilevitz, E., Gilad, Z., Silverman, D. and Tanny, J. 2020. Measuring and modelling crop water use of sweet pepper crops grown in screen houses and greenhouses in an arid region. *Biosystems Engineering* **200**: 246e258.

Holzapfel, E.A., Merino, R., Mariño, M.A. and Matta, R. 2000. Water production functions in kiwi. *Irrigation Science* **19**: 73-79.

Hunt, J.F., Honeycutt, C.W., Starr, G. and Yarborough, D. 2008. Evapotranspiration rates and crop coefficients for lowbush blueberry (*Vaccinium angustifolium*). *International Journal of Fruit Science* **8**: 282-298.

Iniesta, F., Testi, L., Orgaz, F. and Villalobos, F.J. 2009. The effects of regulated and continuous deficit irrigation on the water use, growth and yield of olive trees. *European Journal of Agronomy* **30**: 258-265.

K¨orner, O., Fanourakis, D., Hwang, MCR., Hyldgaard, B., Tsaniklidis, G., Nikoloudakis, N., Larsen, DH., Ottosen, C.O. and Rosenqvist, E. 2021. Incorporating cultivar-specific stomatal traits into stomatal conductance models improves the estimation of evapotranspiration enhancing greenhouse climate management. *Biosystems Engineering* **208**: 131e151.

Kang, Y., Gao, F., Anderson, M., Kustas, W., Nieto, H., Knipper, K., Yang, Y., White, W., Alfieri, J., Torres-Rua, A., Alsina, M.M. and Karnieli, A. 2022. Evaluation of satellite Leaf Area Index in California vineyards for improving water use estimation. *Irrigation Science* **40**: 531-551.

Kisekka, I., Peddinti, S.R., Kustas, W. P., McElrone, A. J., Bambach-Ortiz, N., McKee, L. and Bastiaanssen, W. 2022. Spatial-temporal modeling of root zone soil moisture dynamics in a vineyard using machine learning and remote sensing. *Irrigation Science* **40**: 761-777.

Kuppe, C.W., Schnepf, A., von Lieres, E., Watt, M. and Postma J.A. 2022. Rhizosphere models: their concepts and application to plant-soil ecosystems. *Plant and Soil* **474**: 17-55.

Léchaudel, M., Génard, M., Lescourret, F., Urban, L. and Jannoyer, M. 2005. Modeling effects of weather and source–sink relationships on mango fruit growth. *Tree Physiology* **25**: 583-597.

Ortega-Farias, S., Espinoza-Meza, S., L´opez-Olivari, R., Araya-Alman, M. and Carrasco-Benavides, M. 2021. Effects of different irrigation levels on plant water status, yield, fruit quality and water productivity in a drip-irrigated blueberry orchard under Mediterranean conditions. *Agricultural Water Management* **249**: 106805.

Pathak, H., Srinivasarao, C.H. and Jat, M.L. 2021. Conservation Agriculture for Climate Change Adaptation and Mitigation in India. *Journal of Agricultural Physics* **21**: 182-196.

Prasad, S.S., Kurubar, A.R., Hugar, A., Ramesh, G., Umesh, M.R. and Meena, M.K. 2022. Cost effectiveness of gladiolus production under drip fertigation and planting geometry. *Indian Journal of Horticulture* **79**: 353-359.

Semmens, K.A., Anderson, M.C., Kustas, W.P., Gao, F., Alfieri, J.G., McKee, L., Prueger, J.H., Hain, C.R., Cammalleri, C., Yang, Y., Xia, T., Sanchez, L., Alsina, M.M. and Vélez, M. 2016. Monitoring daily evapotranspiration over two California vineyards using Landsat 8 in a multi-sensor data fusion approach. *Remote Sensing of the Environment* **185**: 155-170.

Serman, F.V., Orgaz, F., Starobinsky, G., Capraro, F. and Fereres, E. 2021. Water productivity and net profit of high-density olive orchards in San Juan, Argentina. *Agricultural Water Management* **252**: 106878.

Sinoquet, H., Thanisawanyangkura, S., Mabrouk, H. and Kasemsap, P. 1998. Characterization of the light environment in canopies using 3D digitizing and image processing. *Annals of Botany* **82**: 203-212.

Tawegoum, R., Leroy, F., Sintes, G. and Chassteriaux, G. 2015. Forecasting hourly evapotranspiration for triggering irrigation in nurseries. *Biosystems Engineering* **129**: 237e247.

Vera, J., Abrisqueta, I., Abrisqueta, J.M. and Ruiz-S´anchez, M.C. 2013. Effect of deficit irrigation on early-maturing peach tree performance. *Irrigation Science* **31**: 747-757.

Zhen, J., Lazarovitch, N. and Tripler, E. 2020. Effects of fruit load intensity and irrigation level on fruit quality, water productivity and net profits of date palms. *Agricultural Water Management* **241**: 106385.

Received: 10 January 2024; Accepted: 30 March 2024