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Review of Crop Water Productivity for Tomato, Potato, Melon, Watermelon and Cantaloupe in Iran

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Abstract: Population increase and the improvement of living standards brought about by development will result in a sharp increase in food demand during the next decades. Most of this increase will be met by the products of irrigated agriculture and this increase needs to be accomplished under increasing scarcity of water. This challenge has lead to the notion that Crop Water Productivity (CWP) needs to be increased. The current investigation was planned to review the measured crop water productivity values for irrigated tomato, potato, melon, watermelon and cantaloupe in Iran. The review based on of 39 literature sources with results of experiments not older than 20 years. The range of CWP is very large, i.e. tomato (2.58-11.88 kg m^{-3}), potato (1.92-5.25 kg m^{-3}), melon (2.46-8.49 kg m^{-3}), watermelon (2.70-14.33 kg m^{-3}) and cantaloupe (4.18-8.65 kg m^{-3}) and thus offers tremendous opportunities for maintaining or increasing agricultural production with 20-40% less water resources. The variability of CWP can be ascribed to climate and irrigation water management among others. The vapor pressure deficit is inversely related to CWP. Vapor pressure deficit decreases with latitude and thus favorable areas for water wise irrigated agriculture are located at the higher latitudes.

Key words: Crop water productivity · Tomato · Potato · Melon · Watermelon · Cantaloupe · Iran

INTRODUCTION

Today's world population of 6000 million is expected to reach about 8100 million by 2030, an increase of 35%. The growing population will result in considerable additional demand of food. Simultaneously, the water demand from non-agricultural sectors will keep growing in both developed and developing countries. A recent FAO analysis of 93 developing countries expects agricultural production to increase over the period 1998-2030 by 49% in rain fed systems and by 81% in irrigated systems [1]. Therefore, much of the additional food production is expected to come from irrigated land, three quarters of which is located in developing countries. The irrigated area in developing countries in 1998 has nearly doubled than that of 1962. There are many reasons to believe that such rapid rate of expansion will not continue in the next decades. FAO estimated that the irrigated area in the selected 93 developing countries will only grow by 23% over the 1998-2030 periods. However, the effective harvested irrigated area (considering the increase in cropping intensity) is expected to increase by 34% [2]. Total food production needs to increase to feed a growing world population and this increase needs to be accomplished under increasing scarcity of water resources. The challenge to produce more food under increasing water scarcity has lead to the notion that crop water productivity (CWP) needs to increase [3, 4]. Productivity, in general is a ratio referring to output per unit of input. The term crop water productivity is defined as the physical mass of production or the economic value of production measured against gross inflows, net inflow, depleted water, process depleted water, or available water [5, 6]. The expression is most often given in terms of mass of produce, or monetary value, per unit of water. Depending on how the terms in the numerator and

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denominator are expressed, water productivity can be expressed in general physical or economic terms. The four physical levels of crop water productivity defined are expressed by the following equations [5, 7]:

$$CWP_{Y-I_g} = C\frac{Y}{I_g} \quad (1)$$

$$CWP_{Y-I_{rr}} = C\frac{Y}{I_{rr}} \quad (2)$$

$$CWP_{Y-ET_{act}} = C\frac{Y}{ET_{act}} \quad (3)$$

$$CWP_{Y-T_a} = C\frac{Y}{T_a} \quad (4)$$

where:

CWP = crop water productivity, kg m^{-3}
Y = actual yield, kg ha^{-1}
I_g = difference of gross inflow and storage in the water balance equation, mm
I_{rr} = irrigation requirements water, mm
ET_{act} = actual evapotranspiration, mm
T_a = transpiration alone, mm
C = conversion factor, 0.10 ha mm m^{-3}

When considering CWP relation from a physical point of view, one should consider transpiration only. The partitioning of evapotranspiration in evaporation and transpiration in field experiments is, however, difficult and therefore not a practical solution. Moreover, evaporation is always a component related to crop specific growth, tillage and water management practices. This water is no longer available for other use or reuse in the basin. Since evapotranspiration is based on root water uptake, supplies from rainfall, irrigation and capillary rise are integrated. Therefore, in this study CWP is defined as the crop yield over actual evapotranspiration that shows in equation 3.

MATERIALS AND METHODS

Many researches have been done regarding water use and yield relationship of specific crops, on specific locations, with specific agricultural and water management practices which shows crop water productivity (CWP) for staple crops such as wheat, barley, rice and etc. [3, 7]. However, there is little information about vegetable crops. The current investigation summarizes the results of field experiments that have been conducted over the last 20 years and tries to find arrange of plausible values for five major vegetable crops including tomato (*Lycopersicon esculentum*), potato (*Solanum tuberosum*), melon (*Cucumis melo*), watermelon (*Citrullus lunatus*) and cantaloupe (*Cucumis melo*) and to find some first order explanatory variables for the CWP in Iran. In this investigation, data collected from research reports of Agricultural Research, Education and Extension Organization Ministry of Agricultural Research and Education Organization (AREEO) of Iran, conference proceedings and other technical reports have been used. These data were of Y and ET_{act} for the mentioned five important vegetables crops in Iran. The majority of filed experiments were conducted at experimental sites under changeable growing conditions, including variations in irrigation, fertilization, soils and other agricultural practices. As the purpose of this research was to find plausible CWP ranges under farm management conditions, all measured CWP values were included in the database. To be included in the database, the results of the experiments should provide minimally the total seasonal measured actual evapotranspiration (ET_{act}) and the crop yield (Y). Yield is defined as the marketable part of the total above ground biomass production. Results from greenhouse experiments, pot experiments and water balance simulation models were excluded. A total of 39 publications have been included in this study. Summary of the contents of the database and crop water productivity (CWP) analyses are given in Table 1. Figs. 1-5 show the frequency distribution histograms of CWP for tomato, potato, melon, watermelon and cantaloupe. For the purpose to exclude extreme values, the CWP range is determined by taking the 5 and 95 percentiles of the cumulative frequency distribution (Table 1). The SPSS software was used for statistical analyses and the Excel software was used for drawing histograms.

RESULTS

Tomato: Among the five vegetable crops, tomato has the largest number of experimental points (n = 181). The CWP range of tomato is between 2.58 and 11.88 kg m^{-3} (Table 1). In addition, Fig. 1 shows that maximum frequencies of CWP range from 3.5 to 5.5 kg m^{-3}.

Potato: The CWP range of potato is between 1.92 and 5.25 kg m^{-3} for 131 experimental points (Table 1). Also, Fig. 2 shows that maximum frequencies of CWP range from 4.0 to 5.5 kg m^{-3}.

Table 1: Summary of the database and crop water productivity (CWP) analyses

Crop	Number of publications	CWP range (kg m^{-3})	n	Minimum	Maximum	Mean	Median	S.D.	CV
Tomato	11	2.58-11.88	181	1.35	13.30	7.09	6.52	2.90	0.41
Potato	9	1.92-5.28	131	1.25	5.95	3.76	4.06	1.16	0.31
Melon	6	2.46-8.49	89	2.07	9.22	5.34	5.23	1.88	0.35
Watermelon	7	2.70-14.33	77	1.90	15.11	8.28	8.35	3.61	0.44
Cantaloupe	6	4.18-8.65	83	4.08	9.10	6.18	5.80	1.38	0.22

CWP range defined as the 5 and 95 percentiles of the entire range

Table 2: Summary of the yield and ET_{act} analyses

		Yield (kg)				ET_{act} (mm)			
Crop	R^2	Minimum	Maximum	Mean	CV	Minimum	Maximum	Mean	CV
Tomato	0.1035	9630	55340	32973.15	0.32	203.08	1054.30	517.32	0.38
Potato	0.1534	18300	39060	26215.19	0.19	319.49	1757.65	789.01	0.43
Melon	0.1958	15700	31890	23953.37	0.21	227.09	1444.93	518.82	0.49
Watermelon	0.1029	14630	47420	31621.82	0.28	174.48	1191.69	472.94	0.56
Cantaloupe	0.4436	15270	39100	22013.75	0.24	201.65	685.96	371.67	0.30

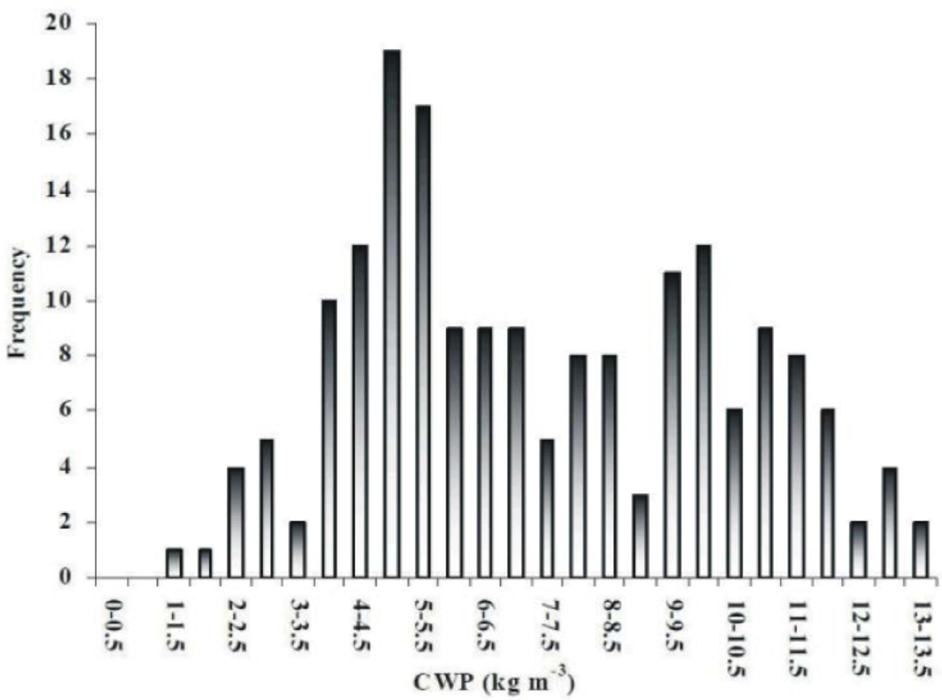

Fig. 1: Frequency of crop water productivity (CWP) per unit water depletion for tomato

Melon: The CWP range of melon is between 2.46 and 8.49 kg m^{-3} for 89 experimental points (Table 1). Moreover, Fig. 3 shows that maximum frequencies of CWP range from 3.5 to 6.0 kg m^{-3}.

Watermelon: Among the five vegetable crops, watermelon has the fewest number of experimental points (n = 77). The CWP range of watermelon is between 2.70 and 14.33 kg m^{-3} (Table 1). Besides, Fig. 4 shows that maximum frequencies of CWP range in two parts of histogram, i.e. from 3.0 to 5.0 kg m^{-3} and from 10.0 to 11.5 kg m^{-3}.

Cantaloupe: The CWP range of cantaloupe is between 4.18 and 9.10 kg m^{-3} for 83 experimental points (Table 1). As well, Fig. 5 shows that maximum frequencies of CWP range from 4.0 to 6.0 kg m^{-3}.

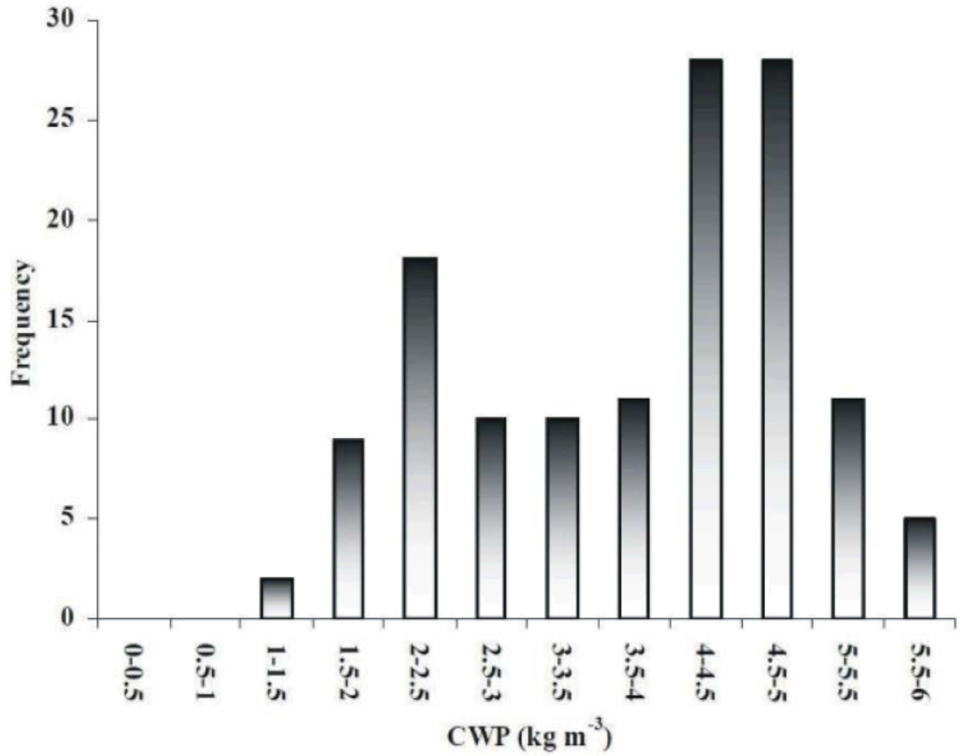

Fig. 2: Frequency of crop water productivity (CWP) per unit water depletion for potato

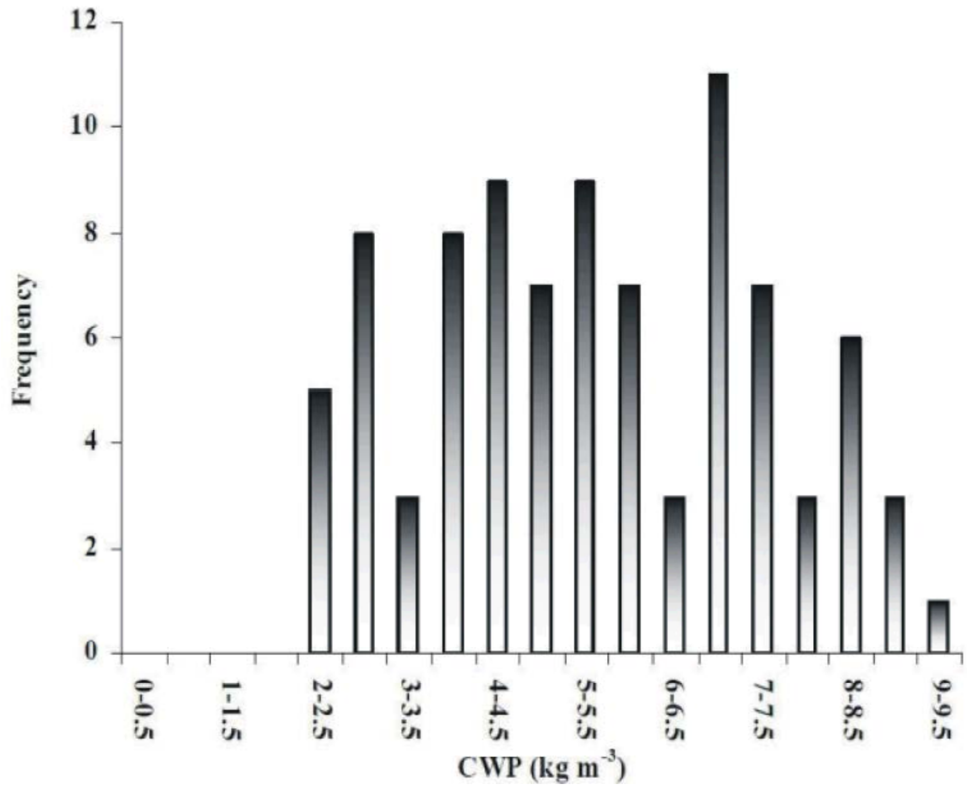

Fig. 3: Frequency of crop water productivity (CWP) per unit water depletion for melon

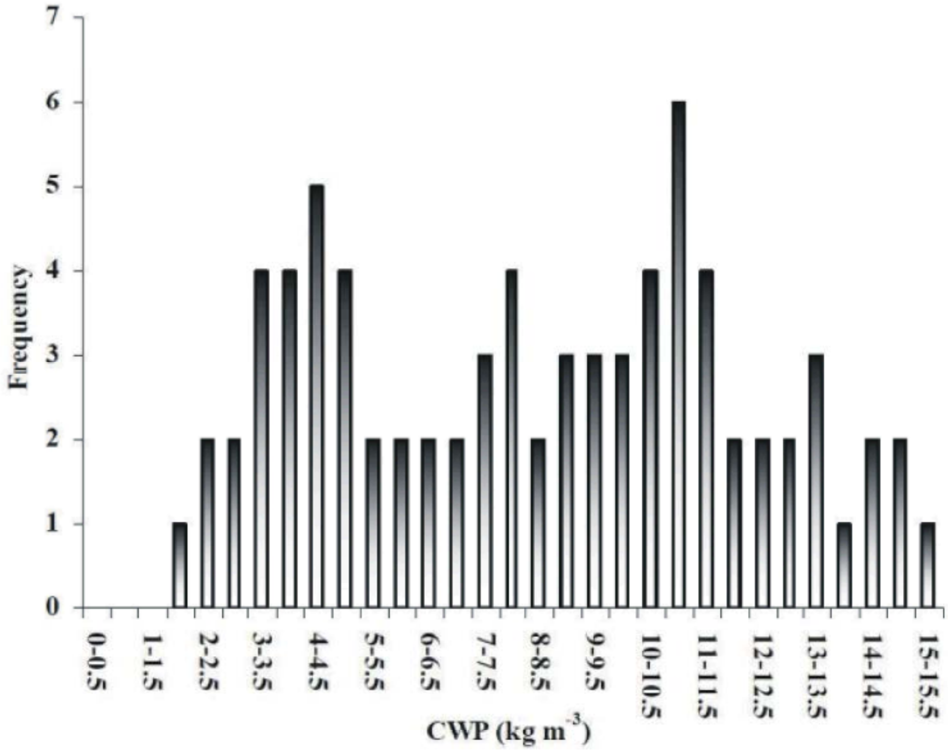

Fig. 4: Frequency of crop water productivity (CWP) per unit water depletion for watermelon

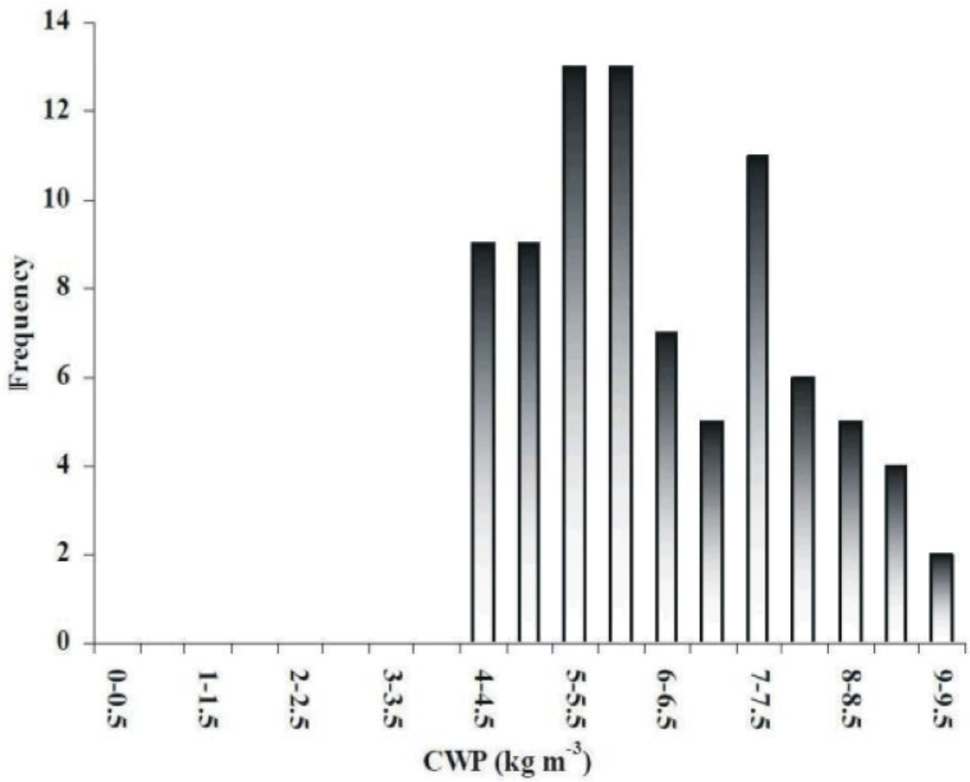

Fig. 5: Frequency of crop water productivity (CWP) per unit water depletion for cantaloupe

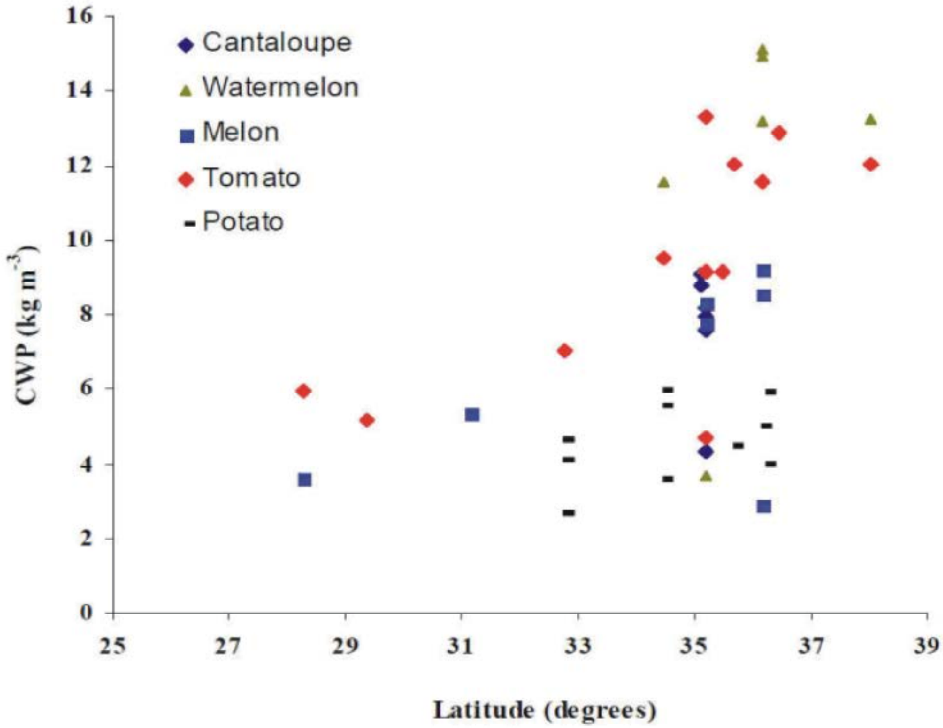

Fig. 6: Relation between latitude and maximum crop water productivity (CWP) values

Coefficient of Determination: The yield was plotted against the ET_{act} for each of the five vegetable crops for obtaining coefficient of determination (R^2). These values are shown in Table 2. Among the five vegetable crops, cantaloupe had the highest coefficient of determination ($R^2 = 0.4436$) followed by melon ($R^2 = 0.1958$), potato ($R^2 = 0.1534$), tomato ($R^2 = 0.1035$) and watermelon ($R^2 = 0.1029$).

DISCUSSION

Tomato: The minimum values of CWP were found by Seilsepour and Ghaemi [8] in application of Fe and Zn led to higher production and water quantities regime conditions. CWP ranges for the experiment based on 80% evaporation from standard U.S. weather bureau class-A open-pan were from 1.35 to 4.71 kg m^{-3}. The maximum values (9.26 to 13.3 kg m^{-3}) were measured by Sadreghaen *et al.* [9] in a combination of alternate micro irrigation and deficit irrigation. Tomato yield in 79.5% of reports was lower than the range given in FAO33; this range for arid and semiarid region is 45000-65000 kg ha^{-1}.

Potato: Yaghmaei [10] reported the maximum values exceed 5.43 kg m^{-3} in experiment, which potato 12 varieties were planted in furrows and compared together. Akbari [11, 12] reported the lowest range (4.31 to 4.94 kg m^{-3}) of CWP in using sprinkler irrigation systems and different irrigation levels conditions. Soltani *et al.* [13] found the highest yield value of 39060 kg ha^{-1} in a field trial with deficit irrigation, while seasonal ET_{act} was relatively low with 765 mm. Besides it, Soltani *et al.* [13] reported the minimum value of CWP of 1.25 kg m^{-3} with 19560 kg ha^{-1} yield and 1560 mm seasonal ET_{act} under surface irrigation methods.

Melon: Baghani and Khazaei [14] are found the maximum value 9.22 kg m^{-3} in an experiment that melon was irrigated with trickle and furrow systems that have different of irrigation scheduling. Irrigation scheduling was based on the cumulative pan evaporation and calculated as sum of the daily evaporation from standard U.S. weather bureau class-A open-pan installed nearby the experimental plots. The maximum value found in treatment that was irrigated with trickle system and 50% evaporation of the pan. Rostami [15] are found the minimum values for melon. The minimum values that reported by were under 2.46 kg m^{-3} that founded for furrow irrigation with polyethylene mulches. Besides the lowest range from 2.46 to 2.07 kg m^{-3} has reported by Rostami [15] in using polyethylene mulches with irrigation method.

Watermelon: The CWP range of watermelon almost was similar to tomato; the shape of the frequency distribution of watermelon is not as smooth as for tomato because fewer points (n = 77) are available. The maximum CWP value of 15.11 kg m^{-3} for watermelon given by Baghani and Hoosiniyazdi [16] is obtained in a research that was evaluation of effective trickle and furrow irrigations yield component of watermelon (Table 1). The maximum value found in treatment that was irrigated with trickle system and 50% of the crop water requirement. Jafari and Ghaemi [17] in Varamin region in center of Iran obtained the minimum values in experiment that watermelon was planted in several arrangement and furrow irrigation depth. In this experiment minimum ranges were measured under 3.66 kg m^{-3} where water was applied during with deep furrow and far planting arrangements, thus rising soil evaporation and reducing soil water status of the root zone. Minimum value (1.90 kg m^{-3}) obtained in the deep furrow with 55 cm depth and 100 cm wide. Watermelon yield in 28.82% of points was lower than the range given in FAO33 and in 61.98% of points was upper than range given in FAO33; this range for arid and semiarid region is 25000-35000 kg ha^{-1}.

Cantaloupe: The maximum value (9.1 kg m^{-3}) was measured by Seyfi and Rashidi [18] in a combination of drip irrigation and plastic mulch and measured yield value of 29900 kg ha^{-1} in a field trial, while seasonal ET_{act} was relatively low with 329 mm. Rashidi and Seyfi [19] reported the highest range from 5.2 to 8.8 kg m^{-3} in crop water stress conditions. The minimum ranges were measured by Arabsalmani [20] in a combination of alternate furrow irrigation and plastic mulching with management of organic fertilizer (under 4.33 kg m^{-3}).

Coefficient of Determination: Table 2 shows that the Y-ET_{act} relation is not as straightforward as often as assumed and R^2 values are very low. Cantaloupe has the highest coefficient of determination (R^2 = 0.4436) followed by melon (R^2 = 0.1958), potato (R^2 = 0.1534), tomato (R^2 = 0.1035) and watermelon (R^2 = 0.1029). The lesson learnt here is that Y (ET_{act}) functions are only locally valid and cannot be used in country-scale planning of agricultural water management.

Effects of Latitude on CWP: Many researches describe the relation between vapor pressure deficit of the air and CWP [21, 22]. As the vapor pressure deficit generally decreases when moving away from the equator, CWP is expected to increase with increasing latitude. This proposition was tested for the current dataset: for each experimental site (defined as each unique geographic location), the maximum CWP of each crop is plotted against the latitude value of the experimental site. The maximum value is being taken to approach the optimal growing conditions with respect to soil fertility management and irrigation water application at a certain location. The result, depicted in Fig. 6, confirms that CWP decreases with lower latitude. It also shows that the highest CWP values occur between 35 and 37 degrees latitude, where a factor 8-14 difference in CWP of tomato, melon, watermelon and cantaloupe is detected when compared to areas between 31 and 33 degrees.

CONCLUSION

Comparison showed that the CWP range 4 to 5 kg m^{-3} is the commonplace range among the crops investigated. The CWP ranges for the five crops investigated were large as indicated by the high CV of 22-44% and are a logical consequence of the low coefficient of determination between ET_{act} and crop yield (R^2 = 0.1029-0.4436). Therefore, the wide ranges in CWP, high CV and the low coefficient of determination between ET_{act} and crop yield suggest that agricultural production can be maintained with 20-40% less than water resources provided that new water management practices are adopted.

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