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An Analytical View on Water Use Efficiency of Some Main Crops Grown in the Non-costal Parts of Thrace Region

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

The article contains data obtained from evaluations related to irrigation water use efficiency (IWUE) and water use efficiency (WUE), for the main crops, irrigated at different stages of growth, on the basis of some findings obtained in the Research Institute in Kırklareli. Each of the experimental crops was sown and farmed following procedures applied by the farmers in the region, except of the irrigation applications which were based on the sensitivity of a certain crop to water shortage in the soil, during the specific growth stages. Similar procedures were applied and all the experimental treatments were irrigated at growth stages, as predicted in the research methodology, and water amounts required to fill the 0-90 cm soil depth to field capacity were implied. Evaluation data obtained from the field experiments with three major crops, grown on the non-coastal lands of Thrace Region showed, that the productivity of irrigation water, as well as water use efficiencies of all analysed crops, are growth stage controlled. The highest IWUE and WUE efficiencies of 0.87 and 0.92 kg da^{-1} m^{-3}; and 1.08 kg da^{-1} m^{-3} and 0.81 kg da^{-1} m^{-3}; were determined for wheat and sunflower crops, irrigated at booting and flowering stages, respectively. Each m^3 of irrigation water, applied during the most sensitive fruit formation stage (F_f) of pumpkin crop, provided additionally 8.47 kg da^{-1} fruit yield, 8.09 fruit numbers and 0.28 kg da^{-1} seed yields, more than those of rainfed farming (R).

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1. INTRODUCTION

Soil and water resources are among the most important natural wealths of any country. Rational use of these resources is of primary importance in terms of the socio-economic development of the communities. Water is an indispensable natural factor for living organisms as a whole.

Agriculture, which is the principal user of water, provides foods required for the entire communities by cultivation plants and producing products of vegetal origin, using soil and water resources of the countries. In Turkey, the social and economic aspects, plays an important role in the lives of the people. Agriculture constitutes 19% of total national income and 9% of exports of the country. The mentioned sector provides also employment opportunities to approximately half of the population of the Turkish society.

Thrace covering an area of 24 378 km^2, is one of the major regions of the country producing commodities for nutrition of the population and meeting the needs of food industry of Turkey. The ranking of the provinces according to their land shares in the region is Kırklareli (26.9%), Tekirdağ (26.5%), Edirne (25.7%), Istanbul (12.9%) and Canakkale (8.0%) [1].

Although the territory of Thrace covers only less than 3% of the country's surface area, 5% of the agricultural land of the country is located in the boundaries of Edirne, Kırklareli and Tekirdağ provinces of the region. Polyculture agriculture, consisting mainly of wheat, sunflower, barley, corn, sugar beet, canola and other plants, is spread on about of one million (1 0000 000) ha acreage of agricultural land, located only across the mentioned three provinces. Each year more than 450 000 ha of wheat, 330 000 ha of sunflower, 45 000 ha of rice, 10 000 ha of rapeseed is farmed and 54% of rapeseed, 50% of rice, 47% of the sunflower and 11% of wheat of the total national production is produced by the farmers of the Western Thrace [2]. In addition, a significant part of total sugar beet, barley, corn, forage crops, confectionery pumpkin and a variety of vegetables and fruits are also grown in the region.

As is well known, the most important factor limiting plant development in arid and semi-arid climates is the lack of available for plants water in the root zone of the soil. For this reason, irrigation applications appeared as a main factor increasing the yields on these areas. However, as a region, Thrace is poor in terms of the available (renewable) water resources, and owns less than 4% of the total country's water resources [3,4]. Due to the limited water resources of the region, in recent years irrigated agriculture is applied only on, approximately 12% of total agricultural land of the region. The expansion of the irrigated agricultural lands requires the introduction and exploitation of new water resources or more efficiently use of existing irrigation water resources, which is expected to lead to higher crop yields and more food production in the region.

Although a number of research studies [5,6,7,8,9,10], have been carried out in order to determine the optimum irrigation programs, based on the growth stages of the main grown agricultural crops, in the local Research Institute in Kiklareli, and data on the effects on yields and yield parameters are already published, no analyses on the indicators of the efficiently water use, such as irrigation water use efficiency (IWUE) and water use efficiency (WUE) have been published, neither beneficial use of water have been evaluated.

The objective of this study, was to analyse the matters of irrigation water use efficiency (IWUE) and water use efficiency (WUE) for the main crops, irrigated at different stages of growth or under various irrigation application frequency, using some findings obtained in the local Research Institute in Kırklareli.

2. MATERIALS AND METHODS

All of the evaluated field studies were conducted on fields of the Rural Services Research Institute in Kirklareli (41° 42^{I} N and 27° 12^{I} E). The experimental site is covered with soils of silty loam texture, belonging to Entisol soil (UdicUstifluvent), poor (1.3-1.9%) in organic matter and rich in potassium. Values of some soil physical characteristics related to irrigation and presenting the average soil profile are presented in Table 1.

Meric Basin, which is surrounded by the Marmara and Aegean seas to the south and includes the Thrace Region, is characterized by the “hot-summer-dry” degree of the

Table 1. Physical and chemical characteristics of the model soil profile representing the soil of the experimental locations

Soil depth cm	Field capacity Pw	Wilting point Pw	Bulk density g cm^{-3}	P_2O_5 kg da^{-1}	K_2O kg da^{-1}	Organic matter %	pH	Texture classes**
0-30	22.10	9.10	1.53	7.35*	70.04*	1.93	7.8	L
30-60	23.38	10.03	1.49	9.10*	37.25*	1.66	7.9	L
60-90	19.36	9.85	1.57			1.31	7.9	SCL
90-120	22.37	11.48	1.57			1.49	7.9	SCL

**P_2O_5 and K_20 values are related to depths of 0-20 and 20-40 cm*
***L-Loam, SCL-Silty Clay Loam*

"hot-warm-rainy" climate group, according to W. Köppen's climate classification. Summers in the basin and the region are dry and hot, while winters are cool and rainy.

According to the data of the General Directorate of State Meteorological Affairs [11] the sum of the average 50-year precipitation in the Kırklareli plain where the studies were conducted, is 594.7 mm. Examination of climatic data values included in Table 2 shows that that the total precipitation is distributed irregularly throughout the year. The maximum annual average monthly precipitation observed as 74.6, 71 and 70.2 mm are recorded for December, November and January, respectively. While the months of July, August and September appeared as the driest months of the year, with averages of 30.8, 24.4 and 29.8 mm average perennial precipitation.

According to long-year climatic data, the air average temperature of the Kırklareli plain is 13°C. The highest average air temperatures are measured in July and August (23.2 and 22.5°C), while the lowest average monthly temperatures (2.2 and 4.1°C) are observed in January and February.

The average annual relative humidity detected in the plain of Kırklareli is 73%, with the highest relative humidity averages, in the ranges of 81-85%, are recorded during the winter season (November, December, January and February), and the lowest relative humidity averages (63, 61 and 62%), observed during the dry and hot summer months of June, July and August, respectively.

Considering the precipitation and temperature values, which are the major climate factors used in the C. W. Thorthwaite climate classification, the climate of the research area is characterized as "arid-semi-humid", second "mezothermal" climate type [12].

Each of the experimental crops was sown and farmed following procedures applied by the farmers in the region, except of the irrigation application. The cultivar most popular among the farmers, of any of the crops subject of the evaluation, was used as a biological material of the study.

Irrigation scheduling in most of the evaluated fields trials, was based on the sensitivity of a certain crop to water shortage in the soil, during the specific growth stages. Sowing (S), Booting (Bt) and Milk stage of grain (Mst); Head formation (H), Flowering (F) and Milk stage (Mst); and Blooming (B), Fruit formation (Ff) and Seed formation (Sf) stages of growth were considered, in the case of the irrigation scheduling for winter wheat; sunflower and pumpkin crops, respectively. Rainfed treatment with no irrigations was included in each of the field trials, which was used as a control treatment in the evaluations related to the effects of water, applied with irrigation at any stage of growth.

Similar procedures were applied in all evaluated trials and all the experimental treatments of a certain experiment were irrigated at each growth stage as predicted in the research methodology, with application of water amount required to fill the 0-90 cm soil depth to field capacity.

Irrigation water for these studies was provided from the water reservoir of the irrigation scheme of the Soil and Water Resources Research Institute in Kirklareli. Analysis performed in laboratories of the Research Institute showed that irrigation water applied to experimental plants is of S3A1 quality class, with salinity level (EC) in the ranges of 0.9-1.1 dS m^{-1}, pH 6.8-7.1, SAR value 1.1-1.3 and containing relatively high levels of sodium (2.32-2.72 me l^{-1}) and very high concentration of chloride (2.67-3.08 me l^{-1}).

Water applied to each experimental plot was measured using a water meter, connected to an irrigation pipe. The number of irrigation

Table 2. Fifty (50)–year average values of the climatic parameters for Kirklareli plain (1984)

Climatic Parameters	Months												Yearly averages or totals
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Precipitation, mm	70.2	52.9	47.5	44.7	51.7	45.4	30.8	24.4	29.8	51.7	71.0	74.6	594.7
Relative Humidity,	81	82	78	73	69	63	61	62	68	75	82	85	73
%Wind speed, m/s	3.4	3.2	3.3	2.9	2.8	2.8	3.0	2.4	2.7	2.9	2.9	3.4	3.0
Evaporation, mm	19.2	27.4	48.1	72.9	92.9	116.5	158.6	159.1	108.4	64.5	31.5	23.5	922.6
Air Temperature °C	2.2	4.1	6.6	11.5	17.0	21.2	23.2	22.5	18.8	13.7	9.5	5.1	13.0
Avr. Max Temp.°C	5.0	8.0	11.0	17.4	23.1	27.6	30.3	30.2	26.0	19.6	14.5	8.8	18.4
Ort. Min Temp. °C	-1.4	1.0	2.2	6.8	11.1	14.6	16.9	16.5	13.6	9.4	6.7	2.6	8.4
Average 5 cm	2.1	4.2	7.0	13.4	19.9	24.9	27.5	26.5	21.5	14.6	10.0	5.2	14.7
Soil 10 cm	2.7	4.6	6.4	12.0	19.6	24.9	27.1	26.9	22.4	15.6	10.8	6.0	14.9
Temperature 50 cm	5.3	5.4	7.4	11.9	17.6	22.2	25.0	25.3	22.2	17.1	12.8	8.4	15.1
°C 100 cm	8.2	7.1	8.0	11.0	15.2	18.9	21.9	23.1	21.6	18.0	14.6	10.8	14.9

applications and the total seasonal irrigation water amounts applied to each treatment of the certain evaluated crop are summarized in Tables 3, 4, 5 and 6. Soil moisture content of the plots was monitored gravimetrically (from planting to last harvest) at weekly intervals, for the layers of 0-30, 30-60, 60-90 and 90-120 cm. Water consumption or evapotranspiration (ET) from each plot was determined using the soil water balance equation:

$$ET = P + I + R + SD - D \quad (1)$$

Where,

P is precipitation (mm), I is irrigation water amount (mm), R is runoff/run-on (mm), SD is soil water depletion (mm), and, D is drainage (mm) below the root zone.

Runoff/run-on (R) and drainage (D) parameters were assumed zero because the experimental plots were surrounded with dikes and since water applied with each irrigation was equal to water deficit in the 0-90 cm soil profile of the specific experimental treatment.

Irrigation water use efficiency (IWUE) and total water use efficiency (WUE) were determined following procedures given by [13]

The equations used were as follows:

$$WUE = Y/ET \quad (2)$$

$$IWUE = (Y - Y_o)/IW \quad (3)$$

Where,

Y is the yield of the experimental crop from a certain treatment, kg da^{-1}; Y_o is the yield value for the dry treatment, kg da^{-1}; ET is the seasonal consumptive water use or total evapotranspiration, mm; and IW is the amount of irrigation water applied, mm.

All crops of the evaluated field trials were harvested and weighed after reaching maturity. In order to prevent the edge effect at harvesting, the first and last row, or 50 cm wide band (wheat) of each experimental plot, as well as the first and the last plant of each row from the accounted central part of the plot, were discarded at harvest.

The yield data recorded for each crop, experimental treatment and/or plot were subjected to an analysis of variance using the procedure given by [14] and Duncan mean separation test procedure was applied.

3. RESULTS AND DISCUSSION

Irrigation treatments, irrigation stages, irrigation numbers and total water amounts, as well as yielding data of winter wheat, are included in Table 3. In order to determine water productivity properties of the evaluated crop, the experimental data were subjected to procedures pointed out by Howell et al. [13] and irrigation water efficiency (IWUE) and water use efficiency (WUE) values were also determined and presented in the table.

As could be concluded from data for average 3-year grain yields, booting appeared the most sensitive growth stage of winter wheat plant. Even a single water application on the plots of Bt, provided almost as much yields as the treatments SBt and SBtMst irrigated twice and three times, respectively. Despite the large differences (130.7, 193.2 and 355.7 mm) in the amount of irrigation water applied to the mentioned three treatments, the yield increases compared to rainfed (R) plot, were found very close to each other, and were recorded as 28.1, 34.7 and 35.1% respectively. As expected, the productivity of the water given in the single irrigation application during the sensitive B_t stage, was also much more higher than those of the treatments including 2 and 3 water implications. Consequently, when the data for obtained grain yields are evaluated versus total irrigation water applied, and total water consumption recorded, it could be distinguished that the highest $IWUE_{gy}$ and WUE_{gy} efficiencies of 0.86 and 0.92 kg da^{-1} m^{-3}, respectively are provided from B_t treatment, comprising single irrigation application, during the most sensitive booting stage. The lowest water productivity values of 0.40 and 0.69 kg da^{-1} m^{-3}, respectively for $IWUE_{gy}$ and WUE_{gy} are determined for the most irrigated $SBtM_{st}$ treatment. Similar water production (WP) values of 1.07, 0.94 and 0.98 kg m^3 for dry normal and wet years, respectively were reported by [15] for Changwu County of China.

The highest and the lowest values of 8.7 kg grain ha^{-1} mm^{-1} and 9.2 kg grain ha^{-1} mm^{-1}; and 4.3 kg grain ha^{-1} mm^{-1} and 6.9 kg ha^{-1} mm^{-1}, determined for the various applications of the evaluated study coincide with the results for grain yield per unit water used, under various environments of the world. Sadras et al. [16] analysed water productivity of wheat, using data from different dry environments of the world, and reported that average yields per unit water use were; 9.9 kg grain ha^{-1} mm^{-1}, 9.8 kg grain ha^{-1} mm^{-1}, 8.9 kg grain ha^{-1} mm^{-1}, 7.6 kg grain ha^{-1} mm^{-1} and 5.3 kg grain ha^{-1} mm^{-1}, for the areas of south eastern Australia, the North American Great Plains, the China Loess Plateau, northern Great Plains of North America, and the Mediterranean Basin, respectively. Cossani et al. [17] evaluated the growth and yielding properties of bread wheat, barley and durum wheat grown under various irrigation regimes of Mediterranean environment in Catalonia, and determined that WUE yield and WUE biomass were linearly and closely related in all experiments. The authors reported also, that WUE values ranged in large ranges between 7.3 and 23.0 kg grain ha^{-1} mm^{-1}; 9.5 and 16.8 kg grain ha^{-1} mm^{-1} and 9.1 and 23 kg grain ha^{-1} mm^{-1} for barley, bread wheat and durum wheat, respectively. On the other side, Zhang et al. [18] reported that water-use efficiency for grain yield was increased from 9.7 to 11.0 kg grain ha^{-1} mm^{-1} by supplemental irrigation, although WUE for dry matter was not affected by water application under Mediterranean-type environment.

The various response of the plant to water applied in different growth stages, was much more evident in the case of sunflower plant, studied in the region by Karaata [6].

As could be inferred from data in Table 4, the evaluated plant is much more sensitive to water shortage in the root zone during the flowering, than the periods of head formation and/or milk stage of the seed.

The average seed yields of 377.7 kg da^{-1} recorded for F treatment, irrigated only once at the beginning of flowering, is even higher than that of 347.9 kg da^{-1} obtained from the plots of HM_{st}, irrigated twice during the less sensitive periods of head formation and milk stage of seed.

The information regarding the yield increase rates given in the mentioned table, reveals the effect of water given during different growth stages, even more clearly. Yield increase of 61.0% in result of a single application at the beginning of flowering (F), is much higher than those of 26.3 and 28.7% increase, recorded for the plots with single implications at heading (H) and milk stage (M_{st}), and is relatively close to those of 78.1 and 85.2% determined for twice irrigated FM_{st} and application HFM_st, with water supplied at each of the three growth stages.

Findings related to IWUE and WUE values included in the table, point out the significance of the development stages in terms of the water use efficiency. Owing to high yields obtained as result of a single water application, the highest irrigation water use (IWUE) and water use efficiency (WUE) values of 1.08 kg da^{-1} m^{-3} and 0.81 kg da^{-1} m^{-3}, respectively were assessed for the F treatment, followed by those of 0.60 and 0.71 kg da^{-1} m^{-3} recorded for FM_{st}, irrigated twice during flowering and milk stages. Very low water productivity rates of 0.27 and 0.60 kg da^{-1} m^{-3}; 0.39 and 0.56 kg da^{-1} m^{-3}; and 0.40 and 0.62 kg da^{-1} m^{-3}, were determined for single application at heading (H); for twice irrigation at heading and milk stage (HM_{st}); and single implication during the milk stage (M_{st}), respectively.

Our results related to highest values of IWUE and WUE for water applied during the flowering (F) stage, are very close to those of 7.80 kg $ha^{-1}mm^{-1}$ and 10.19 kg $ha^{-1}mm^{-1}$, published by [19] for sunflower plant, irrigated during the same stage in Marmara region of the country. In a study carried out under semi- arid environment of Konya plain in Turkey, the highest IWUE and WUE rates of 1.51 kg m^{-3} and 0.85 kg m^{-3}, respectively were determined also for sunflower crop, drip irrigated only during the flowering (F) stage [20]. Connor et al. [21] reported that, the efficiency of water use in the production of seed, ranged from 4.0 kg ha^{-1} mm^{-1} for the rainfed control, to 8.0 kg $ha^{-1}mm^{-1}$ for the treatment at 2-weekly watering schedule maintained from budding to maturity. Karam et al. [22] found out that water use efficiency of sunflower varied significantly ($P < 0.05$), under soil and climatic conditions of Tal Amara Research Station in the central Bekaa Valley of Lebanon and the highest and lowest values were 0.83 kg m^{-3} and 0.71 kg m^{-3}, respectively. Sadras et al. [16] reported that, water use efficiency of sunflower crop varied in the ranges of 0.3-0.5 kg m^{-3} and 0.4-0.9 kg m^{-3} for dryland and irrigated farming respectively.

Results from the study, carried out on the effects of water implication at Blooming (B), Fruit formation (F_f) and Seed formation (S_f) stages of the pumpkin plants, are included in Table 5 and data for irrigation water use efficiency (IWUE) and water use efficiency (WUE), on the bases of fruit yield ($_{fy}$), fruit number ($_{fn}$) and seed yield ($_{sy}$) per unit (da) surface area are given in Table 6.

Table 3. Yields and water use data under application at different stages of wheat (3-year averages) P<≤0.05

Water applications	Number irrigation	Grain yield		Water use, mm*		Water use efficiencies kg m^{-3} da^{-1}	
		kg da^{-1}*	Increase %	Irrigation water amount	Consumpt. water use	$IWUE_{gy}$	WUE_{gy}
Rainfed	0	399.3	-	-	436.9	-	0.91
S	1	451.3	13.1	67.9	515.2	0.77	0.88
B_t	1	511.3	28.1	130.7	557.4	0.86	0.92
SB_t	2	537.3	34.7	193.2	647.7	0.71	0.83
$SBtM_{st}$	3	540.0	35.3	355.7	785.8	0.40	0.69

More data for grain yield and water applied are available in [7]

Table 4. The effects of irrigation at different stages on yield and water use of sunflower (2-year avr.) P ≤ 0.05

Water applications stages	Number of irrigations	Average yields kg da^{-1}*	Yield increase, %	Irrigation water, mm*	Water consumptive use, mm	Irrigation water use efficiency $IWUE_y$, kg $m^{-3}da^{-1}$	Water use efficiency, WUE_y, kg $m^{-3}da^{-1}$
Rain fed	0	228.4	-	-	329	-	0.70
H	1	288.5	26.3	146.6	479	0.27	0.60
F	1	367.7	61.0	135.3	455	1.08	0.81
M_{st}	1	293.9	28.7	162.5	474	0.40	0.62
HF	2	353.1	54.6	282.2	600	0.44	0.59
HM_{st}	2	347.9	52.3	309.0	625	0.39	0.56
FM_{st}	2	406.8	78.1	297.7	570	0.60	0.71
HFM_{st}	3	423.0	85.2	444.4	744	0.44	0.57

More data related to yields and water amounts are available in [6]

Table 5. Yields of confectionery pumpkin crop under irrigation applied at different stages (3-year avr.) P≤0.001

Water applications	Number irrigation	Fruit yield		Fruit number		Seed yield	
		kg da^{-1}*	Increase %	per da*	Increase %	kg da^{-1}*	Increase %
Rainfed	0	1 8 33	-	2 1 04	-	50.0	-
B	1	2 6 42	44.1	2 7 12	28.9	66.6	33.2
F_f	1	3 2 87	79.3	3 4 92	66.0	98.1	96.2
S_f	1	2 4 83	35.5	3 1 25	48.5	63.6	27.2
BF_f	2	3 7 78	106.1	3 3 23	57.9	93.7	87.4
BS_f	2	3 3 67	83.4	3 3 70	60.2	84.5	69.0
F_fS_f	2	3 8 46	109.8	3 6 47	73.3	100.2	100.4
BF_fS_f	3	4 789	161.3	3 5 78	70.1	126.8	153.6

More data related to yields and water amounts are available in [8]

F_fS_f	312.1	566.3	6.45	4.94	0.16	6.79	6.44	0.18
BF_fS_f	394.5	610.7	7.49	3.74	0.20	7.84	5.86	0.21

As could be seen from the findings in Table 5, of all of the irrigation programmes containing a single water application, the highest fruit yield, numbers of fruit, and seed yields of 3287 kg da^{-1}, 3492 fruits da^{-1} and98.1 kg da^{-1} respectively, were provided from F_f treatment, irrigated only once at fruit formation stage, appearing approximately 20 days following blooming (flowering). However the increases in the value of the listed yield parameters continued, under application of irrigation programs involving two or three growth stages, one of which is the fruit formation.

While single water implication at blooming (B) or seed formation (S_f) stages, provided only 44.1, 28.9 and 33.2%; or 35.5, 48.5 and 27.5% increases in fruit yield, fruit number and seed yield; the rise rates under single irrigation application during fruit formation stage, achieved up to 79.3, 66.0 and 96.2%, respectively for the listed yielding parameters. Almost the same gain rate in addition to those of the Rainfed (R) plants, was provided also by the treatment F_fS_f, irrigated twice at fruit and seed formation stages, though the maximum increases of 161.3, 70.1 and 153.6% were recorded for BF_fS_f irrigation program, comprising water applications during each of the three followed growth stages.

The findings within the scope of Table 6 indicate that, each m^3 of irrigation water, applied during the most sensitive for water fruit formation stage (F_f), provides 8.47 kg fruit yield, 8.09 fruit numbers and 0.28 kg seed yields per decar (da), in addition to those of rainfed farming (R), or leads to high IWUE values of 8.47 kg m^{-3} da^{-1}, 8.09 fruits m^{-3} da^{-1}, and 0.28 kg m^{-3} da^{-1}, determined on the bases of fruit yield, fruit number and seed yields, respectively. However, the same amount of irrigation water implied about 20 days latter, at seed formation (S_f) stage, adds only 3.71 kg m^{-3} da^{-1} (fruit yield), 5. 81 fruits m^{-3} da^{-1} (fruit number) and 0.08 kg m^{-3} da^{-1} (seed yield), to those obtained from the rainfed control. Owing to increased yields under two and tree water implication conditions, high IWUE rates of 7.54 kg m^{-3} da^{-1},.4.73 fruit m^{-3} da^{-1} and 0.17 kg m^{-3} da^{-1}; and 7.49 kg m^{-3} da^{-1}, 3.74 fruit m^{-3} da^{-1} and 0.20 kg m^{-3} da^{-1}, respectively for fruit yield, fruit number and seed yield, are recorded for BF_f and BF_fS_f treatments.

Evaluation of data in terms of the water use efficiency (WUE) given in the table, point out that the highest values of 7.77 kg m^{-3} da^{-1}, 8.26 fruits m^{-3} da^{-1} and 0.23 kg m^{-3} da^{-1}; and 7.84 kg m^{-3} da^{-1}, 5.86 fruits m^{-3} da^{-1} and 0.21 kg m^{-3} da^{-1}, for WUE based on fruit yield, fruit number and seed yield per da respectively, are detected also in the case of a single water application during the fruit formation stage (F_f) and three irrigations applied at each of the three growth stages (BF_fS_f). Though, the lowest WUE rates of 6.19 kg m^{-3} da^{-1} (fruit yield), 7.78 fruits m^{-3} da^{-1} and 0.16 kg m^{-3} da^{-1} (seed yield), are determined as result of the single application during the seed formation (S_f) stage of the crop.

Very limited number of studies have been conducted on the irrigation of pumpkin crop grown for seed in our country and abroad [23,24,25,26,27] and some findings regarding water use effectiveness have been already published. The average WUE values of 0.2 kg m^{-3},018 kg m^{-3}, 0.17 kg m^{-3}, reported for the crops irrigated at different irrigation intervals by Yavuz et al. [24], are almost the same as those in the ranges of 0.16-0.21 kg m^{-3}, determined in this evaluation, for treatments comprising various irrigation applications. However, data concerning the IWUE, accepted as an important indicator of the irrigation performance, declared by Yavuzet. [25] between 0.23-1.47 kg m^{-3}, and 0.22-0.56 kg m^{-3} for the first and second year of the study, differ in large extent from those in the ranges 0.12-0.28 kg m^{-3} recorded in our evaluation. The contradictions could be explained with the diversity of the soil and climatic conditions of the two compared studies, or could be attributed to different irrigation methods or dissimilarity of the applied irrigation programmes. But, the fact that the highest IWUE figures of 1.47 kg m^{-3} and 0.56 kg m^{-3}, reported for the years of the study, belong to the rainfed treatment, which is supposed to grow without any irrigation application, and low water amounts of 30-40 mm are applied obviously to provide surviving of the plants, and should not be used in the procedure of irrigation water efficiency (IWUE) assessing procedure. Moreover, the irrigation water use efficiency rates (IWUE) detected in the ranges of 0.24-0.28 kg m^{-3} [26] and between 0.18-0.38 kg m^{-3}defined for different nitrogen amounts [27], are fully comparable with those obtained as result of our evaluation.

Table 6. Water use efficiencies of pumpkin crop under various water application regimes (3-yer avr.) P=0.05

Water applications	Irrigation water,mm	Water consumptive use, mm	Irrigation water use efficiency, IWUE kg m^{-3}			Water consumptive use efficiency, WUE kg m^{-3}		
			$IWUE_{fy}$	$IWUE_{fn}$	$IWUE_{sy}$	WUE_{fy}	WUE_{fn}	WUE_{sy}
Rainfed	-	251.3	-	-	-	7.30	8.37	0.20
B	99.5	357.7	8.13	6.11	0.17	7.40	7.58	0.19
F_f	171.6	423.0	8.47	8.09	0.28	7.77	8.26	0.23
S_f	175.2	401.5	3.71	5.83	0.08	6.19	7.78	0.16
BF_f	257.9	505.6	7.54	4.73	0.17	7.47	6.57	0.19
BS_f	277.3	484.1	5.53	4.57	0.12	6.96	6.96	0.18

4. CONCLUSIONS

Evaluation of the yield and water use data from the field experiments with three major crops, grown on the non-coastal lands of Thrace Region of Turkey pointed out, that the productivity of irrigation water, as well as water use efficiencies of all analysed crops, are growth stage controlled.

In each of the plants in the scope of the study, the most efficient use of water occurs when the plant is irrigated during its most susceptible to water stage. Even a single water implication during the booting, the sensitive stage of wheat, leads to 28.1% increase in grain yields, compared to rainfed farming, and provides the highest $IWUE_{gy}$ and WUE_{gy} efficiencies of 0.87 and 0.92 kg $da^{-1}m^{-3}$. The lowest water productivity values of 0.43 and 0.69 kg da^{-1} m^{-3}, respectively for $IWUE_{gy}$ and WUE_{gy} are determined for the treatment, grown under most favourable moisture conditions and irrigated at each of the three growth stages.

Much more pronounced yield and water productivity effects are observed in the case of the sunflower crop. Analysing yield data related to the mentioned plant showed, that single water implication at the beginning of the flowering stage, provides an increase of 61.0% in the seed yield, much higher than those of 26.3 and 28.7% determined for the case of single irrigation, implied at less sensitive heading (H) and milk stage (M_{st}) of growth. Each unit of irrigation water, applied during the most sensitive (F) stage of the crop, provides 1.08 kg m^{-3} more seed yield, in addition to yields obtained from the rainfed application. However, the same unit applied at heading and milk stages, produce only 0.27 and 0.40 kg m^{-3} more yield, compared to rainfed plants.

The determinative effect of the growth stage on yield and yield components is much more evident in the case of the pumpkin crop. Even a single water implication at fruit formation stage, increases the fruit yield, number of fruit and seed yield, obtained from the pumpkin crop by 79.3, 66.0 and 96.2% compared to non-irrigation plots, respectively. Though, single irrigation applied at blooming (B) or seed formation (S_f) stages, provides only 44.1, 28.9 and 33.2%; or 35.5, 48.5 and 27.5% increases in the parameters listed. Each m^3 ofirrigation water, applied during the most sensitive fruit formation stage (F_f), provides 8.47 kg fruit yield, 8.09 fruit numbers and 0.28 kg seed yields, in addition to those of rainfed farming (R).

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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