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Research Article

WATER – YIELD RELATIONS OF DRIP-IRRIGATED PEAS UNDER SEMI-ARID CLIMATE CONDITION

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ABSTRACT. The experiment was carried out in 2016 and 2017 growing seasons to investigate the water-yield relations of drip-irrigated peas under semi-arid climate conditions. There were 5 different irrigation treatments as of: 0% (I0-dry), 25% (I25), 50% (I50), 75% (I75) and 100% (I100-full irrigation). Amount of irrigation water applied to plants varied between 35 - 254.4 mm in 2016 and between 30 - 270.1 mm in 2017. Plant water consumptions (ET) varied between 235 - 525 mm in 2016 and between 220 - 605 mm in 2017. The greatest seed yields (3742 kg ha-1 in 2016 and 3691 kg ha-1 in 2017) were obtained from I100 treatments and the lowest seed yields (959 kg ha-1 in 2016 and 921 kg ha-1 in 2017) were obtained from I0 treatments. In 2016, water use efficiency (WUE) values varied between 0.41 - 0.71 kg m-3 and irrigation water use efficiency (IWUE) values varied between 1.36 – 2.74 kg m-3. In 2017, WUE values varied between 0.42 - 0.61 kg m-3 and IWUE values varied between 1.24 – 3.07 kg m-3. The yield response factor, ky, was calculated as 1.36 and it was found that the pea was sensitive to water stress.

Keywords: *Irrigation, pea, yield, water use*

INTRODUCTION

It is evident that proteins play a great role in human nutrition. Pea (Pisum sativum L.) is an annual legume and grown and consumed as a source of protein. Pea is a good source of vegetable protein since seeds are rich in protein (20-30%), carbohydrates, iron and phosphorus [1]. Following chickpea, lentils, beans, black-eyed peas and broad beans, peas have the 6th place in legumes cultivation of Turkey. According to 2015 statistics of Turkey, 3125 tons peas were produced from 11118 da land area. İzmir is the leading pea producer province of Turkey (3320 da) and Konya province (2510 da) has the second place in pea production of Turkey [2].In terms of pea cultivated lands and amount of productions, Turkey has the 10th rank in the world, but fresh, canned or frozen consumptions are quite common in Turkey [3].

Knowledge on crop response to drought stress plays a significant role in crop management. In general, water stress at any growth stages may result in yield losses. Drought stress encountered in generative stage significantly reduces seed yields. Drought stress in vegetative stage recesses plant growth and shortens growing season. For efficient management of limited water resources in agricultural production, water-yield relations should be well-comprehended [4]. Deficit irrigation, practicing water deficits either throughout the entire growing season or at certain growth stages, may offer significant water savings [5]. Crop response to drought stress varies with the exposure durations and severity of drought exerted on plants at different growth stages [6].

Salter and Wiiliams[7]indicated that irrigations at the beginning of flowering positively influenced yields of fresh peas. Marouelli et al. [8] also reported yield increases in peas with

irrigations. Besides, decreases were observed in morphological traits of free peas with increasing water deficits [9]. Martin et al. [10] conducted a study in New Zealand and reported decreasing yields in peas with increasing drought stress. Duzdemir et al. [11] reported that increasing water stress and salinity reduced yield and several parameters of peas and thus indicated pea as sensitive to water stress. In another study, increasing 1000-seed weight, biomass and yields were reported in peas with increasing irrigation water levels [3].
Principle component analysis (PCA) is a mathematical algorithm reducing dimensionality of the data while preserving majority of the variation in data set [12]. Such a reduction is realized through identification of principle components on which the variation in data is maximum. The method offers visual assessment of similarity and differences between the samples with the use of couple principal components and allows the users to identify whether the could be grouped or not [13].

This study was conducted; 1) to investigate the effects of different irrigation water levels on yield and yield components of peas potentially to be grown in Central Anatolia Region with semi-arid climate, 2) to set up a proper irrigation strategy for semi-arid regions through identification of water-yield relations with the use of PCA technique.

MATERIALS AND METHODS

Climate Characteristics of the Study Area

Experiments were conducted over the experimental fields of Erciyes University Agricultural Research and Implementation Center (ERUTAM) for 2 years. The study area is located between 35^0 30' east longitudes and 38^0 41' north latitudes with an average altitude of 1084 m. Kayseri province has a dominant terrestrial climate with hot and dry summers and cold and snowy winters. Annual average temperature is 10.7 ^{0}C, the lowest average temperature (-1.7 ^{0}C)was observed in January and temperature difference (T_{mak}.-T_{min}.) is 28.9 ^{0}C. The meteorological data of the years 2016and 2017 were taken from an automatic climate station installed in the study area. Long-term meteorological data and data of the experimental years (2016 and 2017) are provided in Table 1. Infiltration tests were conducted on 3 different locations of the study area with the use of a double-ring infiltrometer to determine the infiltration rate of the soils. Test results revealed that soil infiltration rate was 23.3 mmh^{-1}.

Soil and Water Characteristics of the Study Area

Disturbed and undisturbed soil samples were taken from 0-30, 30-60, 60-90 and 90-120 cm soil profiles of three different locations as to represent the entire study area. Soil samples were subjected to texture, field capacity (FC), permanent wilting point (PWP), pH, electrical conductivity (EC), lime, organic matter content, bulk density, available phosphorus, potassium and nitrogen analyses [14]. Irrigation water quality analyses (electrical conductivity, anion, cation contents) were also conducted in accordance with the methods specified in Tuzuner[14]. Results of soil analyses are provided in Table 2 and results of irrigation water quality analyses are provided in Table 3.

***Table 1.** Meteorological data of the study area (long-term and 2016-2017)*

Years	Parameter	Months				
		April	May	June	July	August
Long term	RH_{mean} (%)	62.7	61.5	55.6	50.7	49.5
	T_{mean} (ºC)	10.6	14.8	19	22.4	22.0
	Wind speed (m/sn)	1.76	1.43	1.32	1.3	1.2
	Precipitation (mm)	52.1	51.8	39.5	10.5	8.8
2016	T_{mean} (ºC)	14.0	14.8	20.4	23.3	25.4
	T_{max} (ºC)	20.4	26.7	34.6	37	34.8
	T_{min} (ºC)	4.5	4.4	7.5	10.8	14.5
	Wind speed (m/sn)	1.6	1.9	1.8	1.8	1.8
	Precipitation (mm)	0	151.8	25.6	2	0
	RH_{max} (%)	65.2	80	78.2	66.1	62.4
	RH_{min} (%)	25.5	34.4	30.8	21.1	19.9
2017	T_{mean} (ºC)	24.2	14.9	19.6	23.7	25.3
	T_{max} (ºC)	20.2	21.9	27.9	33.0	34.3
	T_{min} (ºC)	4.4	7.8	11.3	14.4	16.2
	Wind speed (m/sn)	1.6	1.6	1.4	2.0	1.6
	Precipitation (mm)	25.9	57.2	50.6	0	3.3
	RH_{max} (%)	81.9	87.3	87.8	68.5	73.1
	RH_{min} (%)	25.7	30.8	25.5	16.5	22.2

***Table 2.** Soil analysis results*

Depth (cm)	**Texture**	**EC (dS/m)**	**pH**	**FC(%) w/w**	**PWP(%) w/w**	**Bulk Density (g/cm³)**	**Organic Matter (%)**	**Lime (%)**	**N (kg/ha)**	**P_2O_5 (kg/ha)**	**K_2SO_4 (kg/ha)**
0-30	Loamy	0.220	8.13	25.5	10.7	1.27	1.25	2.54	21.5	20.5	271.6
30-60	Loamy	0.173	8.17	23.3	11.3	1.24	1.05	5.83	10.5	11.5	376.4
60-90	Clay Loam	0.258	8.14	26	9.4	1.22	0.69	3.15	4.0	6.0	310.1
90-120	Loamy	0.191	8.23	25	9.4	1.28	0.73	6.20	4.0	2.	310.1

***Table 3.** Irrigation water quality analysis results*

pH	EC (µS/cm)	Na^+ (mg L^{-1})	K^+ (mg L^{-1})	Ca^{+2} (mg L^{-1})	Mg^{+2} (mg L^{-1})	HCO^3 (mg L^{-1})	CO_3^{-2} (mg L^{-1})	SAR
7.60	242	11.6	4.57	26.4	6.63	12.2	< 1.0	2.86

Plant Material of the Experiments

Rondo pea cultivar (*Pisum sativum L.*) was used as the plant material of the experiments. It is an early cultivar with 10-12 cm long smooth pods in dark green color. Seeds are large and smooth. It is available for seasonal production and has a high adaptation capacity. Fruit quality is quite high and number of seeds is also high and dense. Each pot has 7-9 seeds [15].

Experimental Design

Experiments were conducted in randomized blocksdesign with 3 replications. Seeds were sown as to have 40 cm row spacing and 8 cm on-row plant spacing and each plot had 6 plant rows.

Seeds were sown to a depth of 5 cm. A row from each side of the plots were considered as side effects and observations and harvests were performed from middle 4 rows. Each plot had 5×2.4 m dimensions. About 1.2 m spacing was provided between the plots and 2.5 m between the blocks. Based on soil analysis results, 15 $kgda^{-1}$ DAP fertilizer was applied at sowing. Fertilizers were incorporated into the soil with a hoeing machine. Sowing was performed manually on 27.04.2016 in the first year and 25.04.2017 in the second year. Reseeding was made in plots with insufficient emergence. Harvest was performed on 9.07.2016 in the first year and 11.07.2017 in the second year.

Irrigation Program

Drip irrigation system was used for irrigation of pea plants. Each plant row was supplied with a PE lateral line (16 mm) with 2 l/h discharge spaced 25 cm apart. Plant effective root depth was taken as 60 cm [16]. Irrigation treatments were set up through applying certain ratios depleted moisture in rootzone. Irrigations were initiated when the 40% (±5) of the moisture in effective rootzone was depleted. Soil moistures were measured in all treatments of all plots. Measurements were performed with a TDR device at about 10 cm by a plant row. A TDR device with 60 cm probe was used. The device was calibrated in field before to use and the following calibration equation was obtained as to yield soil moisture in volume [17].

$$P_{VM} = 1.922 \times K - 0.2186$$

Eqn.1

In present study, 5 different irrigation levels were experimented:

1- Control treatment (I_{100}): (full irrigation, depleted portion of available water holding capacity at effective root depth was fully supplied and soil moisture was brought to field capacity with each irrigation,

2- I_{75} (75% of control treatment was applied),

3- I_{50} (50% of control treatment was applied,

4- I_{25} (25% of control treatment was applied),

5- I_0 (non-irrigated, rain-feedtreatment).

Irrigation interval was selected as 5 days. Amount of irrigation water to be applied in full irrigation (mm) was calculated with the use of 'Eqn. 2':

$$d = \frac{P_{VTK} - P_{VM}}{100} \times D \times P$$

Eqn.2

where; d: Amount of irrigation water to be applied, mm; P_{vtk}: Soil moisture in volume at field capacity, %; P_{vm}: Soil moisture in volume at permanent wilting point, %; D: Effective root depth, mm, P: Cover ratio (the ratio of plant canopy width to row spacing, maximum taken as 1 indicating full plant cover of soil surface). Calculated value (mm) is multiplied by the area to be irrigated (m^2) to get amount of irrigation to be applied in liters. Irrigation water passed through flow meters.

Soil Moisture and Plant Water Consumption

Water budget equation was used to determine plant water consumptions in experimental treatments [18].

$$ET = I + R + C_r - D_p - R_f \pm \Delta s$$

Eqn.3

where; ET; Plant water consumption (mm), I; Irrigation water quantity (mm), R; Effective precipitation (mm), C_r; Capillary rise (mm), D_p; Deep percolation (mm), R_f; Surface runoff (mm), Δs; Change in moisture within soil profile (mm).

Since irrigation water was applied as to bring the soil moisture to field capacity, deep percolation was considered to be zero; since there was a buffer zone between the plots and drip irrigation was used, surface runoff was also considered to be zero;since water table was not encountered at 5-6 m of soil profile, capillary rise was also assumed to be zero.The change in moisture was monitored with a TDR device.Following each irrigation, soil moisture at 60-90 cm soil profile was monitored and deep percolation was assessed. Soil moisture at 0-90 cm soil profile was determined at the beginning of the experiments and after harvest.

Yield-Response Factor and Water Use Efficiency

Steward model was used to assess the relationship between relative water deficit and relative yield reduction and yield-response factors [19]. Relevant model is expressed in 'Eqn. 4' as a function of water-production:

$$\left(1-\frac{Y_a}{Y_m}\right)=ky\left(1-\frac{ET_a}{ET_m}\right)$$

Eqn. 4

where;Y_a = Actual yield (kgda^{-1}); Y_m = Maximum yield (kgda^{-1}); k_y = Yield-response factor; ET_a = Actual plant water consumption (mm); ET_m = Maximum plant water consumption (mm). The k_y represents plant sensitivity to water deficits. Water productivity and irrigation water productivity were calculated with the use of 'Eqn. 5' [20].

$$WP=\frac{E_y}{ET}\times 100 \qquad IWP=\frac{E_y}{I}\times 100$$

Eqn.5

where; WP = Water productivity (kg m^{-3}); E_y = Economic yield (kgda^{-1}); ET = Seasonal plant water consumption (mm), IWP = Irrigation water productivity (kg m^{-3}); I = Applied irrigation water quantity (mm).

Statistical Analysis

Experimental data were subjected to analysis of variance with the use of SAS 9.0 software. Significant means were compared with the use of Duncan's multiple range test. Principle component analysis (PCA) was conducted with the use of JUMP 13 software.

RESULTS AND DISCUSSION

Effects of irrigation water levels on ET, yield, WUE and IWUE

Effects of different irrigation treatments on ET, yield, WUE and IWUE of peas are provided in Table 4.

Amount of irrigation water applied to pea plants varied between 35 – 254.4 mm in 2016 and between 30 – 270.1 mm in 2017. For reliable emergence, 35 mm irrigation water was applied to all treatment in 2016 and 30 mm in 2017.Apart from emergence irrigation, 6 irrigations were performed throughout the growing season in 2016 and 8 irrigations were performed in 2017. The ET values under different irrigation treatments varied between 235 – 525 mm in 2016 and between 220 – 605 mm in 2017. Increasing ET values were observed with increasing irrigation water quantities. As compared to rain-feed treatments, ET values in full irrigation treatments increased by 123.4% in 2016 and 175% in 2017.Rat [21]conducted a study on peas and reported applied irrigation water quantity and 200 mm and ET value as 433 mm. Increasing ET values were also reported for different plants with increasing irrigation water quantities [22,23].

***Table 4.** Effects of different irrigation levels on ET, yield, WUE and IWUE*

Year	Treatments	I (mm)	ET (mm)	Yield (kg/ha)	WUE (kg/m^3)	IWUE (kg/m^3)
2016	I_0	35	235	959 d	0.41 b	2.74
	I_{25}	89.8	307	1658 cd	0.54 ab	1.85
	I_{50}	144.8	352	1967 bc	0.56 ab	1.36
	I_{75}	199.5	445	2928 ab	0.66 a	1.47
	I_{100}	254.4	525	3742 a	0.71 a	1.47
	Significance	-	-	*	*	-
2017	I_0	30	220	921 e	0.42 c	3.07
	I_{25}	97.6	315	1606 d	0.51 ab	1.65
	I_{50}	150.3	396	1893 c	0.48 b	1.26
	I_{75}	229.7	502	2856 ab	0.57 a	1.24
	I_{100}	270.1	605	3691 a	0.61 a	1.37
	Significance	-	-	**	**	-

I= Irrigation, ET= Evapotranspiration, WUE= Water use efficiency, IWUE= Irrigation water use efficiency

As can be seen from Table4, irrigation water levels had significant effects on yields at $p<0.05$ level in 2016 and at $p<0.01$ level in 2017. The greatest yields were obtained from I_{100} treatments in both years (respectively with 3742 $kgha^{-1}$and 3691 $kgha^{-1}$) and the lowest yields from I_0treatments (respectively with 959 $kgha^{-1}$and 921 $kgha^{-1}$). As compared to full irrigation treatments, yield reductions in I_0, I_{25}, $I_{50}$and I_{75}treatments were respectively measured as 74.4, 55.7, 47.4 and 21.8% in 2016 and respectively as 75.1, 56.5, 48.7 and 22.6% in 2017. Increasing yield reductions were observed with increasing water deficits. Dogan et al. [3] reported the lowest yield in peas for rain-feed treatment (1272 $kgha^{-1}$) and the greatest for full-irrigation treatment (3484 $kgha^{-1}$).Jensen et al. [24]reported pea yields as between 2930 - 4370 $kgha^{-1}$and indicated that irrigation had significant effects on yields.Present findings revealed that 4-fold increase was achieved in pea yield with irrigations.Differences from the other studies were mostly attributed to differences in sowing dates, spacings, cultivars and ecological conditions.

Effects of different irrigation treatments on WUE were found to be significant at $p<0.05$ level in 2016 and at $p<0.01$ level in 2017. The WUE values varied between 0.41 - 0.71 kgm^{-3}in 2016 and between 0.42 - 0.61 kgm^{-3}in 2017. In both growing seasons, the greatest WUE values were obtained from $I_{100}$and the lowest from I_0treatments. Decreasing WUE values were observed with increasing water deficits. The IWUE values varied between 1.36 - 2.74 kgm^{-3}in 2016 and between 1.24 - 3.07 kgm^{-3}in 2017. The lowest IWUE values were obtained from rain-fed treatments (I_0) and the greatest from full-irrigation treatments (I_{100}). Rat [21] reported WUE values of peas as between 0.208-0.421 $kgm^{-3}$and IWUE values as between 0.721-0.834 kgm^{-3}. Dogan et al. [3] reported IWUE values of peas as between 1.06 - 6.03 kgm^{-3}. Previous researchers also reported decreasing IWUE values with increasing irrigation water levels [25-27].

Effects of irrigations on yield-response factor (ky)

Relative yield reduction corresponding to relative reductions in irrigation water quantity is expressed as yield-response factor (ky) and it indicates plant sensitivity to water deficits. The ky values of greater than 1 indicate that the plant was sensitive to water stress and ky values of lower than 1 indicate that the plant was resistant to water stress [19]. Yield-response factor is commonly used in water-yield relations studies to determine yields reductions corresponding to reductions in irrigation water quantity and to develop irrigation strategies accordingly [26]. The ky values for 2016 and 2017 are presented in Fig. 1.

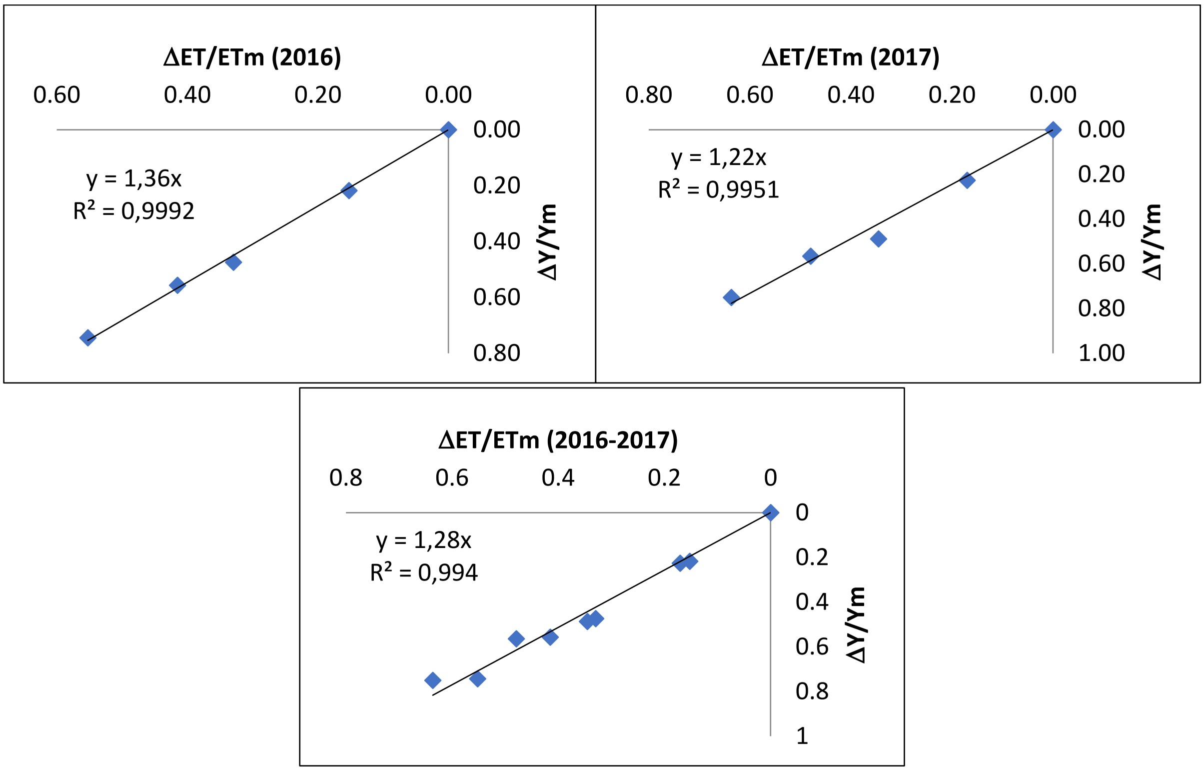

Fig. 1. *The ky graphs for 2016 and 2017*

As can be inferred from Figure 1, ky value was calculated as 1.36 in 2016 and 1.22 in 2017. Average ky value was calculated as 1.28. Present findings revealed that peas were sensitive to water stress.Duzdemiret al. [11] reported ky of peas as 2.2.

Principal Component Analysis (PCA)

Eigen values, variance and total variance values for investigated traits of peas are provided in Table 5 and PCA results are provided in Table 6. In the principal component analysis, components were created by considering their eingenvalues greater than or equal to 1.0 [28]. For a correct interpretation using PCA effectively, the variation of the component ratio should be greater than 25% [29]. The high variance values we obtained in this study showed that te effect of irrigation can be explained by PCA.

Table 5. *Eigen values, variance and total variance for investigated traits*

	PC1		PC2		PC3		PC4	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
Eigen values	4.3743	4.3380	0.6104	0.5937	0.0120	0.0602	0.0033	0.0081
Variance (%)	87.486	86.761	12.209	11.874	0.240	1.204	0.065	0.161
Total variance (%)	87.486	86.761	99.695	98.635	99.935	99.839	100.000	100.000

In terms of investigated parameters, 4 principal components were identified in both years. The first two principal components (PC1 and PC2) explained 99.695% of total variance in 2016 and 98.635% in 2017. Principle component analysis results revealed that eigen values of the traits exhibited parallel trends in both years. In both years, I, ET and yield had close relations with each other (Figure 2-3). The $I_{75}$and I_{100} irrigation treatments had significant positive correlations with ET and yield (Fig. 2-3)

Table 6. *Principle component analysis results*

	PC1		PC2		PC3		PC4	
	2016	**2017**	**2016**	**2017**	**2016**	**2017**	**2016**	**2017**
I	0.47022	0.47155	-0.20177	-0.18440	0.80967	0.43398	0.16321	-0.69284
ET	0.47032	0.47080	-0.22902	-0.22328	-0.13742	0.36405	0.22029	0.33189
Yield	0.46893	0.47027	-0.23577	-0.25111	-0.55897	-0.09881	0.36100	0.56961
WUE	0.47746	0.47052	0.01557	-0.00198	-0.11448	-0.80500	-0.86924	-0.27589
IWUE	0.33139	0.33682	0.92250	0.92362	0.00205	0.14606	0.19732	0.09618

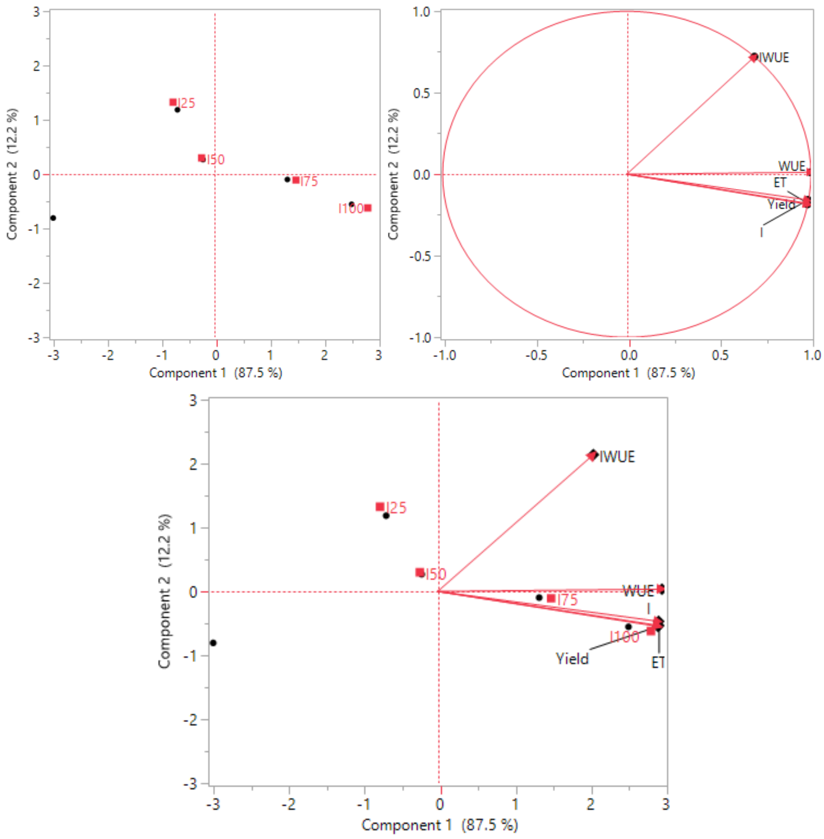

Fig. 2. *Principal component analysis for investigated traits of irrigation treatments in 2016*

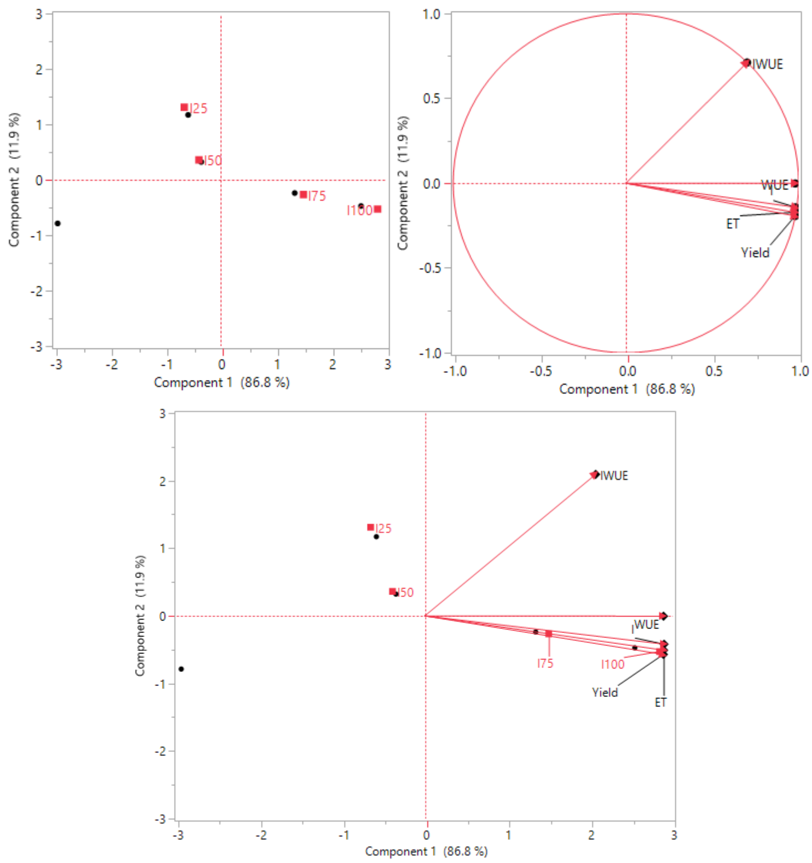

__Fig. 3.__ Principal component analysis for investigated traits of irrigation treatments in 2017

CONCLUSION

Present findings revealed that increasing pea yields were achieved with irrigations. Since there were not significant differences in yields of I_{100} and I_{75} irrigation treatments, I_{75} treatments (25% water deficit) could be recommended in pea irrigation under ecological conditions of Kayseri province. PCA analysis for investigated traits of irrigation treatments revealed highly positive correlations among I, ET and yield of I_{100} and I_{75} treatments. In case of severe water deficits, I_{50}irrigation treatments could also be recommended. However, the decrease in yield should be taken into consideration in such cases.

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