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Evaluation of Irrigation Experiments with GGE Biplot Method and Economic Analysis of Drip Irrigation System: A Case Study of Peanut Production

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ABSTRACT

Besides irrigation water (IW) quantity and quality, there is a decrease also in soil quality and fertility. Agricultural production lands are decreasing both in quantity and quality. There is a search for different operational alternatives in sandy soils with low production potentials. Drip irrigation is primarily practiced attain get greater yields per unit area. This study was conducted under sand soil conditions, commonly preferred for peanut farming, in the 2017-2018 growing seasons. A drip irrigation system was used in production. Halisbey, NC-7, and Sultan cultivars were used as plant materials. Two different irrigation intervals (2 and 4 days) and four different irrigation levels (I_{50}, I_{75}, I_{100} and I_{125}, calculated based on cumulative evaporation from the class-A pan) were applied. The data of five vegetative traits, including grain yield, were evaluated by regression and GGE biplot analysis. In addition, applied IW quantity, evapotranspiration and water use efficiency (WUE) were assessed by econometric analysis. Evapotranspiration values varied between 402-832 mm, applied IW quantities between 313-783 mm, yields between 5,269-8,269 kg ha^{-1}, WUE values between 0.63-1.55 kg ha^{-1} m^{-3}, economic water productivity over gross revenues between 1.29-3.81 \$ m^{-3} and benefit and cost ratios varied between 4.73-10.95. The GGE biplot statistical method is a useful tool in the evaluation of irrigation research where the number of applications and materials is high. As a results of the study, a 2-day irrigation interval and 75% of pan evaporation could be used in the irrigation of peanut plants grown under sandy soil conditions.

Keywords: Evapotranspiration, WUE, EWP, Benefit-cost ratio

1. Introduction

Peanuts, or "groundnuts", as they are known in some parts of the world, are the edible seeds with high oil content from the legume plant family (Leguminosae, Fabaceae). In addition to its high oil content, peanuts are also a very rich nutrient in terms of protein and fiber (Suchoszek-Lukaniuk et al. 2011). They are widely used around the world in a variety of forms such as the production of oil, snacks (peanut butter, roasted peanuts etc.), and as fillers for meat products, soups, and desserts. In addition to oil, peanuts are widely used in the production of peanut butter, sweets, roasted peanuts, snacks, and fillers in recipes for meat products, soups and desserts. Peanuts are eaten around the world in a variety of forms, most of which are traditional cuisine. Moreover peanuts are also used as a complete dietary source for people on expeditions to various areas such as Antarctica, outer space and trekking. This is, in particular, the source of the elimination of malnutrition among the population in many African countries in recent years (Guimon & Guimon 2012; Arya et al. 2015). In addition, postharvest vegetative parts constitute an important source of animal feed.

Irrigation water (IW) is the basic input of agricultural production and it is getting worse both in terms of quantity and quality. It is also getting harder and harder to supply proper quality and sufficient quantity of water for production. The correct management of existing water resources is a vital issue and the highest income and benefit per unit of water has become a critical issue. According to 2020 Food and Agriculture Organization data, the world annual peanut production is about 47 million tons. China, with an annual production of 17.5 million tons, is the leading peanut producer in the world. It is respectively followed by India with approximately 6.7 million tons of production and Myanmar with 1.6 million tons. In Turkey, annually 215,928.53 tons of peanuts are produced from 54,775 ha land area and the average yield is 3,942.1 tons ha^{-1} (FAOSTAT, 2022).

The existing literature reviews have revealed that through the use of drip irrigation significant savings can be obtained especially in water, fertilizer, pesticides and energy (Soni et al. 2019; Halim et al. 2016). In addition to these savings, drip irrigation offers increases in product yield and quality. In a study conducted by Narayanamoorthy and their team in 2020, the efficiency and viability of the drip irrigation method in peanut cultivation were investigated. The results show that compared to traditional border irrigation, drip irrigation provided about 34% savings in production costs and 36% savings in IW and electrical energy, and approximately 79% increase in yield levels. An additional income of 862 $ ha-1 has also been obtained (Narayanamoorthy et al. 2020). A similar case is valid also in peanut production. For instance, Narayanamoorthy et al. (2020) conducted a study on peanuts and reported that as compared to traditional border irrigation, drip irrigation provided about 34% savings in production costs, and 36% savings in IW and electrical energy and approximately 79% increase in yield levels. In addition, with the use of drip irrigation, an additional income of 862 $ ha^{-1} was achieved.

Rathod and Trivedi (2011) used the drip irrigation method at 6 different IW/class a pan evaporation (CEP) ratio (0.6, 0.7, 0.8, 0.9, 1.0 and 1.2) in peanut production in the Junagadh region of India for 3 years. The lowest yield was measured as 1,917 kg ha^{-1} at an IW/CEP ratio of 0.6 and the highest as 2,927 kg ha^{-1} at an IW/CEP ratio of 0.9. The amount of IW applied to relevant treatments was measured as 502 and 757 mm, respectively. The highest water use efficiency (WUE) was obtained as 4.148 kg ha^{-1} mm^{-1} at an IW/CPE ratio of 0.8. This treatment (IW/CPE ratio of 0.8) was determined as the economic water application level. It was determined that drip irrigation was not a profitable application under excessive (IW/CPE=1.2) and insufficient water (IW/CPE=0.6) conditions. Similarly, Sri Ranjitha et al. (2018) used drip and furrow irrigation methods at 5 different IW/CEP ratios (0.4, 0.6, 0.8, 1.0 and 1.2) in peanut production. The lowest yield (1,223 kg ha^{-1}) was obtained from the IW/CEP ratio of 0.4 and the greatest yield (4,005 kg ha^{-1}) obtained from the IW/CEP ratio of 1.0. In terms of optimum water and economical water use, an IW/CEP ratio of 0.8 (3,765 kg ha^{-1}) was identified as the most appropriate treatment. The highest WUE (21.0 kg ha^{-1} mm^{-1}) was observed in the IW/CEP ratio of 0.8.

Regression analysis is used in agricultural research to determine the most appropriate dose in different agronomic applications (Sharma et al., 2022; Akçura, 2019). GGE biplot analysis is a method used to test hypotheses such as which genotype is better adapted to which environment and which environment is more effective in genotype selection, by using the quantitative features examined in trials established in many different environments (Akçura et al. 2019). In this study, the GGE biplot method was used to determine the interaction of the ideal irrigation level and irrigation dose with the changes of the investigated characteristics according to the combination of irrigation level and irrigation interval.

In this study, peanuts were produced by the drip irrigation method in sandy soil conditions. Two different irrigation intervals (2 and 4 days) and four different irrigation levels based on cumulative evaporations from a Class-A evaporation pan (I_{50}, I_{75}, I_{100} and I_{125}) were used. Effects of these experimental treatments on plant morphological traits and yield levels were investigated. An economic analysis of production with drip irrigation was also performed.

2. Material and Methods

2.1 Study area and climate

Experiments were conducted in the research fields of the Farmer's Training Branch of the Rural Affairs Department of Balkesir Greater City Municipality in the years 2017 and 2018. The research fields are located at 39°.52'N latitude and 27°.01'E longitude and have an average altitude of 12.0 m. Soil samples were taken from 0-120 cm soil profile in 30 cm intervals and samples were analyzed for soil physical properties (Table 1). Groundwater was used in irrigation and the IW quality class was identified as (C_3S_1) (USSL, 1954) (Table 2).

Table 1- Soil physical characteristics

Soil depth	*Sand (%)*	*Silt (%)*	*Clay (%)*	*Texture*	*FC_{Pw} (%)*	*PWP_{Pw} (%)*	*BD (g/cm³)*	*Available water (mm)*
0-30	60.7	24.0	15.3	SL	16.87	7.98	1.54	41
30-60	95.0	2.4	2.6	S	10.87	4.83	1.59	29
60-90	58.7	30.1	11.2	SL	17.78	8.21	1.56	45
90-120	57.8	20.8	21.4	SCL	16.75	8.67	1.36	33

FC: Field capacity, PWP: Permanent wilting point, BD: Bulk density

Table 2- Irrigation water quality parameters

Cations	*Results (me/L)*	*Anions*	*Result (me/L)*
Na	2.96	CO_3	-
K	0.17	HCO_3	4.12
Ca	3.94	Cl_2	1.55
Mg	4.02	SO_4	5.41
Total	11.09	Top	11.08
pH	6.86	RSC	<1.24
EC (dS/m)	1241	SAR	1.49

Long-term (1938–2017) climate data of the research site are provided in Table 3. Meteorological data for the experimental years are provided in Table 4.

Table 3- Long-term climate data (1938-2017)

Months	*Temperature (°C)*			*Relative humidity RH (%)*	*Wind speed R (m/s)*	*Precipitation P (mm)*
	T_{aver}	T_{min}	T_{max}			
January	7.1	-12.1	22.9	70.1	2.5	82.1
February	7.5	-8.8	25.5	67.3	2.7	78.5
March	10.1	-5.6	28.5	64.3	2.6	58.2
April	14.3	-2.5	32.1	62.1	2.4	49.8
Mat	19.3	2.1	36.1	57.1	2.4	36.2
June	24.1	4.7	40.2	51.1	2.4	18.7
July	26.5	10.1	43.1	47.1	2.8	8.6
August	26.3	10.1	41.8	49.2	3.1	9.2
September	22.3	0.1	39.1	54.1	2.4	24.8
October	17.2	1.3	35.2	62.6	2.5	49.8
November	12.2	-3.8	28.2	69.4	2.6	103.1
December	8.5	-6.4	24.3	71.1	2.5	110.4
Average	16.2	-12.1	43.1	60.3	2.6	629.1

Table 4- Climate data for the experimental years (2017-2018)

Months	*T (°C)*			*RH (%)*	*R (m/s)*	*P (mm)*	*T (°C)*			*RH (%)*	*R (m/s)*	*P (mm)*
	T_{aver}	T_{min}	T_{max}				T_{aver}	T_{min}	T_{max}			
	2017						***2018***					
January	2.2	-6.1	14.2	70.1	2.4	172.3	5.5	-3.4	16.2	70.1	2.1	37.4
February	6.8	-5.6	19.3	67.3	2.3	52.3	8.9	-2.4	19.1	67.3	2.3	70.2
March	10.2	-1.5	25.2	64.3	2.3	58.8	12.3	-0.2	23.9	64.3	2.4	100.8
April	13.1	1.8	31.1	62.1	2.1	34.7	16.1	2	30.6	62.1	2.1	17.6
Mat	18.1	7.1	34.5	57.1	2.5	40.5	20.2	6.6	34.3	57.1	2.7	32.6
June	23.7	13.8	41.5	51.1	2.5	13.1	23.6	11.3	37.5	51.1	2.7	64.7
July	25.8	16.1	41.1	47.1	3.8	7.3	26.5	17	38.4	47.1	2.7	38.9
August	25.5	14.5	36.9	49.2	4.2	11.3	26.7	16.8	34.9	49.2	4.3	0.7
September	22.8	8.8	38.9	54.1	2.5	3.4	22.2	12.8	35.5	54.1	3.2	19.4
October	15.1	2.5	29.5	62.6	2.2	37.2	17.2	0.1	27.8	62.6	2.8	26.3
November	10.3	-1.5	22.5	69.4	1.4	50.1	12.5	5.7	26.7	69.4	3.1	84.9
December	9.3	-1.8	20.9	71.1	2.5	85.1	5.5	-3.4	16.2	70.1	2.1	114.3
Average	15.2	-6.3	41.5	60.5	2.6	566.1	16.4	-2.4	19.1	60.4	2.7	607.8

2.2 Irrigation and irrigation system

A drip irrigation system with inline emitters (2 Lh^{-1}, spaced 20 cm apart, operated at 2 atm) was designed for peanut irrigation. Gravimetric soil moisture measurements were performed through 0-120 cm soil profiles in 30 cm intervals. Experiments were conducted in a split-split-plot experimental design with three replications. The main plots included cultivars, sub-plots included irrigation intervals, and sub-sub-plots included irrigation. Irrigation intervals (2 and 4 days) were placed into main plots and irrigation levels (Kcp1=0.50, Kcp2=0.75, Kcp3=1.00 and Kcp=1.25) were placed into subplots. A Class-A Pan was placed within the meteorological station next to the experimental plots. Evaporations from the pan were measured daily. The amount of IW to be applied was calculated by using the following equation (Sezen et al. 2005);

$$I = A \, x \, Epan \, x \, Kcp$$

Where;

I = Amount of IW to be applied (L),

A = Plot area (m^2),

E pan = Cumulative evaporation from the pan during the irrigation interval (mm),

Kcp = Plant-pan coefficient.

About 2 m spacing was provided between the plots and 4 m between the blocks. Experimental plots were 5 m long and each plot had 4 rows. Sowing was performed at 70x20 cm (row spacing x on-row plant spacing) spacing.

2.3. Water use efficiency and irrigation water use efficiency

With the use of IW and yield data, WUE and IW use efficiency (IWUE) values were calculated through the use of the following equations (Maximov 1929; Viets 1962; Howell et al. 1990).

$$IWUE = \frac{Y}{I}$$

$$WUE = \frac{Y}{ETa}$$

Where;

IWUE: Irrigation water use efficiency (kg ha mm^{-1}),

Y = Yield (kg ha^{-1}),

I = Amount of irrigation water applied (mm),

WUE = Water use efficiency (kg ha mm^{-1}),

ETa: Actual evapotranspiration (mm).

2.4. Crop water productivity

Crop water productivity (CWP) is defined differently by various researchers (French & Schultz 1984, Bessembinder et al. 2005; Passioura 2006). CWP could be defined as the production quantity or value per unit of consumed or diverted water. It is calculated as the ratio of actual yield to the volume of water utilized:

$$CWP = \frac{Y}{ETa}$$

CWP = Crop water productivity (kg m^{-3})

Y = Yield (kg ha^{-1})

ETa = Actual evapotranspiration (m^3 ha^{-1})

2.5. Economic water productivity

Economic water productivity (EWP) was calculated with the equation given in Mengiste (2015) and Tewelde (2019):

$$EWP = \frac{GI}{IW}$$

$$GI = (PTG * YLDg) + (PTS * YLDg)$$

Where;

EWP = Economic water productivity (\$ m^{-3})

GI: Gross income (\$ ha^{-1})

IW: Irrigation water (m^3 ha^{-1})

PTG: Peanut sale price (\$ ton^{-1}),

YLDg: Yield (ton ha^{-1}),

PTS: Herbage price (\$ kg^{-1})

2.6. Agronomic practices

Halisbey, NC-7, and Sultan cultivars with Virginia-type peanut seeds commonly grown in Turkey were used as the plant material of the study. Pod yield (t ha^{-1}), seed yield (t ha^{-1}), branch length (cm), number of branches per plant, and number of pods per plant were investigated.

Sowing was performed on the 20th of April in 2017 and the 23rd of April in 2018 to have two seeds in each seedbed. Following the emergence, the number of plants was thinned to one in each seedbed. Before sowing, 250 kg ha^{-1} DAP (45 kg ha^{-1} N, 115 kg ha^{-1} P_2O_5) fertilizer was applied to experimental plots. Then, 50 kg ha^{-1} ammonium nitrate was applied through 3rd and 4th irrigations. For weed control, Befuraline active-ingredient herbicide (60% w/w) was applied, and hoeing was practiced after emergence. Harvest was practiced manually on the 15th of October in 2017 and the 20th of October in 2018.

2.7. Statistical analysis

Experimental data were subjected to analysis of variance with the use of JMP software (SAS Institute 2014). Regression analyses were conducted for morphological traits Biplot analyses were generated through the use of of GGE biplot software to see the effects of different irrigation interval x irrigation level combinations on morphological traits of different cultivars (Yan 2001).

3. Results

3.1. Irrigation water use efficiency, economic analysis, and evaluation

The amount of IW applied in experimental treatments of I_{50}, I_{75}, $I_{100,}$ and I_{125} was respectively measured as 319, 478, 637, and 796 mm in 2017 and as 308, 462, 616, and 770 mm in 2018 (Table 1). However, in Table 5, evapotranspiration values varied between 412-827 mm at 2-day irrigation intervals and between 431-849 mm at 4-day irrigation intervals in 2017; values varied between 393-789 mm at 2-day irrigation intervals and between 417-815 mm at 4-day irrigation intervals in 2018. The change in soil moisture increased with decreasing IW at both irrigation intervals of both years. The greatest water uptake from the root zone has been observed at 4-day irrigation intervals in both years.

Table 5- Irrigation water quantity, evapotranspiration and moisture change in root zone

Irrigation interval (day)	*Irrigation water level (%)*	*Seasonal irrigation (mm)*		*Soil water depletion (mm)*		*Evapotranspiration (mm)*	
		2017	*2018*	*2017*	*2018*	*2017*	*2018*
2	I_{50}	319	308	93	85	412	393
2	I_{75}	478	462	76	69	554	531
2	I_{100}	637	616	49	41	686	657
2	I_{125}	796	770	31	19	827	789
4	I_{50}	319	308	112	109	431	417
4	I_{75}	478	462	96	91	574	553
4	I_{100}	637	616	79	70	716	686
4	I_{125}	796	770	53	45	849	815

Since there were no significant differences in the yields of both growing seasons, an average of two years was used in the economic analysis (Table 6). The irrigation labor cost was calculated over the number of irrigations and hourly labor costs. For IW costs, traditional sprinkler irrigation was taken into consideration and 4 irrigations were practiced throughout the growing season. Total IW was adapted to drip irrigation over the volume of water (m^3). Peanut production costs (sowing, maintenance, harvest, etc.) and irrigation system costs were calculated over a 1 ha land area. As Enciso et al. (2005), recommended irrigation system cost was taken as 2,100 \$ ha^{-1} and system economical service-life was taken as 7 years. The annual cost was then calculated as 2,100/7=300 \$ $year^{-1}$. In addition to seed yield in peanut cultivation, post-harvest grass yield was also considered as an important source of income.

The lowest IWUE and WUE values (0.67 and 0.63 kg ha^{-1} m^{-3}) were obtained from I_{125} irrigation treatments of the Sultan cultivar at 4-day irrigation intervals and the greatest values (1.99 and 1.55 kg ha^{-1} m^{-3}) were obtained from I_{50} irrigation treatments of the Sultan cultivar at 2-day irrigation intervals. Similarly, the lowest EWP value (1.29 \$ m^{-3}) was obtained from I_{125} irrigation treatments of the Sultan cultivar at 4-day irrigation intervals and the greatest value (3.81 \$ m^{-3}) was obtained from I_{50} irrigation treatments of the Sultan cultivar at 2-day irrigation intervals. This was also observed in the CWP parameter and calculations were made on net profit. As it was in gross incomes, the lowest value (1.02 kg m^{-3}) and the greatest value (3.46 kg m^{-3}) were obtained from the same treatments of the same cultivar. The lowest gross income (10,133 \$) was obtained from I_{125} irrigation treatments of Sultan cultivar at 4-day irrigation intervals and the greatest value (15,773 \$) was obtained from I_{75} irrigation treatments of Sultan cultivar at 2-day irrigation intervals. Similarly, the lowest net income (7,991 \$) was obtained from the I_{125} irrigation treatments of the Sultan cultivar at 4-day irrigation intervals and the highest value (14,332 \$) was obtained from the I_{75} irrigation treatments of Sultan cultivar at 2-day irrigation intervals. Benefit-cost ratios (B/C) varied between 4.73-10.95.

Table 6- Applied irrigation water quantity, evapotranspiration, water use efficiency and economic analysis results

Treatments	*Amount of irrigation water (mm)*	*Irrigation water (m^3 ha^{-1})*	*Irrigation duration for the irrigation season (h)*	*Labor cost for irrigation (\$ h^{-1})*	*Total cost for irrigation labor (\$) (4x5)*	*Water price (\$ m^{-3})*	*Water cost (\$ ha^{-1}) (3x7)*	*Crop production costs (\$ ha^{-1})*
1	2	3	4	5	6	7	8	9
Two-HalisBey-I_{50}	313	3,130	44	1.70	75	0.20	626	89
Two-HalisBey-I_{75}	470	4,700	66	1.70	112	0.20	940	89
Two-HalisBey-I_{100}	627	6,270	88	1.70	150	0.20	1,254	89
Two-HalisBey-I_{125}	783	7,830	110	1.70	187	0.20	1,566	89
Two-NC7-I_{50}	313	3,130	44	1.70	75	0.20	626	89
Two-NC7-I_{75}	470	4,700	66	1.70	112	0.20	940	89
Two-NC7-I_{100}	627	6,270	88	1.70	150	0.20	1,254	89

Table 6- Continued

Treatments	***Amount of irrigation water (mm)***	***Irrigation water (m³ ha⁻¹)***	***Irrigation duration for the irrigation season (h)***	***Labor cost for irrigation ($ h⁻¹)***	***Total cost for irrigation labor ($) (4x5)***	***Water price ($ m⁻³)***	***Water cost ($ ha⁻¹) (3x7)***	***Crop production costs ($ ha⁻¹)***
Two-NC7-I_{125}	783	7,830	110	1.70	187	0.20	1,566	89
Two-Sultan-I_{50}	313	3,130	44	1.70	75	0.20	626	89
Two-Sultan-I_{75}	470	4,700	66	1.70	112	0.20	940	89
Two-Sultan-I_{100}	627	6,270	88	1.70	150	0.20	1,254	89
Two-Sultan-I_{125}	783	7,830	110	1.70	187	0.20	1,566	89
Four-HalisBey-I_{50}	313	3,130	44	1.70	75	0.20	626	89
Four-HalisBey-I_{75}	470	4,700	66	1.70	112	0.20	940	89
Four-HalisBey-I_{100}	627	6,270	88	1.70	150	0.20	1,254	89
Four-HalisBey-I_{125}	783	7,830	110	1.70	187	0.20	1,566	89
Four-NC7-I_{50}	313	3,130	44	1.70	75	0.20	626	89
Four-NC7-I_{75}	470	4,700	66	1.70	112	0.20	940	89
Four-NC7-I_{100}	627	6,270	88	1.70	150	0.20	1,254	89
Four-NC7-I_{125}	783	7,830	110	1.70	187	0.20	1,566	89
Four-Sultan-I_{50}	313	3,130	44	1.70	75	0.20	626	89
Four-Sultan-I_{75}	470	4,700	66	1.70	112	0.20	940	89
Four-Sultan-I_{100}	627	6,270	88	1.70	150	0.20	1,254	89
Four-Sultan-I_{125}	783	7,830	110	1.70	187	0.20	1,566	89

Treatments	***Irrigation system cost for 1 ha ($ ha⁻¹)***	***Yearly cost of the irrigation system ($ ha-1) (10/7 years)***	***Total cost for 1 year ($ ha⁻¹) (6+8+9+11)***	***Yield (kg ha⁻¹)***	***Product sale price ($ kg⁻¹)***	***Gross peanut kernel income per ha ($ ha⁻¹ year⁻¹) (13x14)***	***Net income ($ ha⁻¹ year⁻¹) (15-12)***	***Straw yield (kg/ha⁻¹)***
1	10	11	12	13	14	15	16	17
Two-HalisBey-I_{50}	2,100	300	1,090	5,915	1.88	11,120	10,030	3,250
Two-HalisBey-I_{75}	2,100	300	1,441	8,269	1.88	15,546	14,105	3,250
Two-HalisBey-I_{100}	2,100	300	1,793	6,501	1.88	12,222	10,429	3,250
Two-HalisBey-I_{125}	2,100	300	2,142	6,421	1.88	12,071	9,929	3,250
Two-NC7-I_{50}	2,100	300	1,090	5,537	1.88	10,410	9,320	3,250
Two-NC7-I_{75}	2,100	300	1,441	6,053	1.88	11,380	9,938	3,250
Two-NC7-I_{100}	2,100	300	1,793	6,082	1.88	11,434	9,642	3,250
Two-NC7-I_{125}	2,100	300	2,142	5,452	1.88	10,250	8,108	3,250
Two-Sultan-I_{50}	2,100	300	1,090	6,224	1.88	11,701	10,611	3,250
Two-Sultan-I_{75}	2,100	300	1,441	7,213	1.88	13,560	12,119	3,250
Two-Sultan-I_{100}	2,100	300	1,793	6,790	1.88	12,765	10,973	3,250
Two-Sultan-I_{125}	2,100	300	2,142	6,218	1.88	11,690	9,548	3,250
Four-HalisBey-I_{50}	2,100	300	1,090	5,937	1.88	11,162	10,072	3,250
Four-HalisBey-I_{75}	2,100	300	1,441	6,934	1.88	13,036	11,595	3,250
Four-HalisBey-I_{100}	2,100	300	1,793	6,571	1.88	12,353	10,561	3,250

Treatments	Irrigation system cost for 1 ha ($ ha^{-1})	Yearly cost of the irrigation system ($ ha-1) (10/7 years)	Total cost for 1 year ($ ha^{-1}) (6+8+9+11)	Yield (kg ha^{-1})	Product sale price ($ kg^{-1})	Gross peanut kernel income per ha ($ ha^{-1} year^{-1}) (13x14)	Net income ($ ha^{-1} year^{-1}) (15-12)	Straw Yield (kg/ha^{-1})
1	10	11	12	13	14	15	16	17
Four-HalisBey-I_{125}	2,100	300	2,142	6,140	1.88	11,543	9,401	3,250
Four-NC7-I_{50}	2,100	300	1,090	5,358	1.88	10,073	8,983	3,250
Four-NC7-I_{75}	2,100	300	1,441	5,818	1.88	10,938	9,497	3,250
Four-NC7-I_{100}	2,100	300	1,793	5,684	1.88	10,686	8,893	3,250
Four-NC7-I_{125}	2,100	300	2,142	5,446	1.88	10,238	8,096	3,250
Four-Sultan-I_{50}	2,100	300	1,090	6,192	1.88	11,641	10,551	3,250
Four-Sultan-I_{75}	2,100	300	1,441	6,621	1.88	12,447	11,006	3,250
Four-Sultan-I_{100}	2,100	300	1,793	5,724	1.88	10,761	8,969	3,250
Four-Sultan-I_{125}	2,100	300	2,142	5,269	1.88	9,906	7,764	3,250

Treatments	Straw sale price ($ kg^{-1})	Straw income per ha ($ ha^{-1} year^{-1}) (17x18)	Gross total income per ha ($ ha^{-1} year^{-1}) (15+19)	Net income ($ ha^{-1} year^{-1}) (20-12)	ET (mm)	Irrigation water use efficiency (kg ha^{-1} m^{-3})	Water use efficiency (kg ha^{-1} m^{-3})	Economic water productivity over gross income ($ m^{-3})	Crop water productivity (kg m^{-3})	The benefit-to-cost (B/C) ratio
1	18	19	20	21	22	23	24	25	26	27
Two-HalisBey-I_{50}	0.07	227.5	11,348	10,258	402	1.89	1.47	3.63	3.28	10.4
Two-HalisBey-I_{75}	0.07	227.5	15,773	14,332	542	1.76	1.53	3.36	3.05	10.9
Two-HalisBey-I_{100}	0.07	227.5	12,449	10,657	672	1.04	0.97	1.99	1.70	6.9
Two-HalisBey-I_{125}	0.07	227.5	12,299	10,157	808	0.82	0.79	1.57	1.30	5.7
Two-NC7-I_{50}	0.07	227.5	10,637	9,547	402	1.77	1.38	3.40	3.05	9.8
Two-NC7-I_{75}	0.07	227.5	11,607	10,166	542	1.29	1.12	2.47	2.16	8.1
Two-NC7-I_{100}	0.07	227.5	11,662	9,869	672	0.97	0.91	1.86	1.57	6.5
Two-NC7-I_{125}	0.07	227.5	10,477	8,335	808	0.70	0.67	1.34	1.06	4.9
Two-Sultan-I_{50}	0.07	227.5	11,929	10,839	402	1.99	1.55	3.81	3.46	10.9
Two-Sultan-I_{75}	0.07	227.5	13,788	12,347	542	1.53	1.33	2.93	2.63	9.6
Two-Sultan-I_{100}	0.07	227.5	12,993	11,200	672	1.08	1.01	2.07	1.79	7.2
Two-Sultan-I_{125}	0.07	227.5	11,917	9,775	808	0.79	0.77	1.52	1.25	5.6
Four-HalisBey-I_{50}	0.07	227.5	11,389	10,299	424	1.90	1.40	3.64	3.29	10.5
Four-HalisBey-I_{75}	0.07	227.5	13,263	11,822	563	1.48	1.23	2.82	2.52	9.2
Four-HalisBey-I_{100}	0.07	227.5	12,581	10,788	701	1.05	0.94	2.01	1.72	7.0
Four-HalisBey-I_{125}	0.07	227.5	11,771	9,629	832	0.78	0.74	1.50	1.23	5.5
Four-NC7-I_{50}	0.07	227.5	10,301	9,211	424	1.71	1.26	3.29	2.94	9.5
Four-NC7-I_{75}	0.07	227.5	11,165	9,724	563	1.24	1.03	2.38	2.07	7.7
Four-NC7-I_{100}	0.07	227.5	10,913	9,121	701	0.91	0.81	1.74	1.45	6.1
Four-NC7-I_{125}	0.07	227.5	10,466	8,324	832	0.70	0.65	1.34	1.06	4.9
Four-Sultan-I_{50}	0.07	227.5	11,868	10,779	424	1.98	1.46	3.79	3.44	10.9
Four-Sultan-I_{75}	0.07	227.5	12,675	11,234	563	1.41	1.18	2.70	2.39	8.8
Four-Sultan-I_{100}	0.07	227.5	10,989	9,196	701	0.91	0.82	1.75	1.47	6.1
Four-Sultan-I_{125}	0.07	227.5	10,133	7,991	832	0.67	0.63	1.29	1.02	4.7

3.2. The effect of the treatments on marketable yield and morphological traits

The irrigation intervals and IW levels had significant effects on seed yield, pod yield, and the number of pods per plant of the peanut cultivars ($p<0.01$) (Table 7). The values of all three parameters were higher at 2-day irrigation interval than at 4-day irrigation interval. The highest values in terms of morphological traits of the cultivars, were obtained from the Halisbey cultivar, followed by the Sultan cultivar. In irrigation treatments, the lowest values were obtained from I_{50} and I_{125} treatments at both irrigation intervals and the greatest values were obtained from I_{75} treatments, followed by I_{100} treatments.

Table 7- Morphological traits of the peanut cultivars under different irrigation intervals and levels

Irrigation interval (day)	***Cultivar***	***Irrigation levels***	***Pod yield (t ha^{-1})***	***Seed yield (t ha^{-1})***	***Branch length (cm)***	***Number of branches per plant***	***Number of Pods per plant***
Two	HalisBey	I_{50}	5.92±0.18	3.77±0.12	46.67±1.45	27.67±2.10	53.17±5.90
Two	HalisBey	I_{75}	8.27±0.12	5.67±0.11	41.50±1.14	43.67±2.98	66.67±3.16
Two	HalisBey	I_{100}	6.50±0.14	4.31±0.10	43.33±1.66	25.67±2.11	65.00±3.55
Two	HalisBey	I_{125}	6.42±0.11	4.39±0.15	42.17±2.05	29.17±2.45	55.17±2.05
Two	NC7	I_{50}	5.54±0.14	4.26±0.11	51.50±1.78	24.00±1.51	55.67±2.70
Two	NC7	I_{75}	6.05±0.09	4.56±0.06	44.33±3.38	39.83±1.79	64.17±2.25
Two	NC7	I_{100}	6.08±0.09	4.49±0.05	45.33±2.54	24.17±1.90	65.83±3.01
Two	NC7	I_{125}	5.45±0.13	4.16±0.10	42.50±2.21	28.00±2.23	51.83±2.27
Two	Sultan	I_{50}	6.23±0.25	4.17±0.17	48.67±1.15	19.67±1.44	44.50±2.14
Two	Sultan	I_{75}	7.21±0.19	4.89±0.16	41.17±2.57	35.17±2.37	71.67±4.73
Two	Sultan	I_{100}	6.79±0.13	4.67±0.10	40.00±2.28	24.00±1.31	55.33±2.44
Two	Sultan	I_{125}	6.22±0.16	4.14±0.10	41.50±1.65	25.67±0.68	52.50±2.86
Four	HalisBey	I_{50}	5.94±0.05	3.84±0.05	34.00±1.50	22.83±0.88	48.50±2.78
Four	HalisBey	I_{75}	6.93±0.10	4.71±0.07	32.67±1.81	23.83±1.23	65.50±2.33
Four	HalisBey	I_{100}	6.57±0.09	4.24±0.06	36.33±0.39	21.67±1.60	55.50±1.63
Four	HalisBey	I_{125}	6.14±0.19	4.10±0.13	37.67±1.44	22.67±1.29	49.17±2.25
Four	NC7	I_{50}	5.36±0.14	3.78±0.10	34.83±1.39	25.67±1.48	48.00±3.09
Four	NC7	I_{75}	5.82±0.15	4.44±0.12	35.33±1.04	32.00±3.25	65.50±5.06
Four	NC7	I_{100}	5.68±0.09	4.06±0.08	43.67±1.59	17.33±1.36	48.00±2.44
Four	NC7	I_{125}	5.44±0.14	3.92±0.11	36.67±2.23	18.00±1.75	39.33±2.98
Four	Sultan	I_{50}	6.19±0.07	4.13±0.06	33.83±0.88	20.00±0.58	47.83±1.72
Four	Sultan	I_{75}	6.62±0.10	4.56±0.07	32.33±1.35	18.33±1.45	67.33±1.88
Four	Sultan	I_{100}	5.73±0.09	3.89±0.07	33.67±0.60	21.00±1.62	51.83±1.77
Four	Sultan	I_{125}	5.27±0.05	3.49±0.06	33.50±1.40	15.17±1.53	40.00±2.30

There R^2 values for the regressions between seed yield and irrigation levels were quite high at both irrigation intervals of the Sultan cultivar (0.955 and 0.842, respectively). In the NC7 cultivar, a high R^2 value (0.993) observed at the 2-day irrigation interval, but a low R^2 value (0.659) observed at the 4-day irrigation interval (Figure 1).

The regression analysis results for changes in the number of branches with irrigation levels are presented in Figure 2a. The cultivars exhibited trends for changes in the number of branches with irrigation treatments at 2-day irrigation intervals. In general, the lowest number of branches per plant was obtained from I_{50} treatments and the greatest from I_{75} treatments. However, at a 4-day irrigation interval, cultivars had different trends for the changes in the number of branches per plant with irrigation levels. In the NC-7 cultivar, the greatest value was obtained from the I_{75} treatment and the lowest from the I_{125} treatment. A distinctive change in the number of branches per plant was not encountered in Halisbey and Sultan cultivars (Figure 2a).

Figure 2b shows branch lengths of the cultivars under different irrigation intervals and levels A distinctive change has been observed in branch lengths of the Halisbey cultivar with irrigation intervals. The highest value in the 2-day irrigation interval was obtained from I_{50} treatment, and no significant change was found in branch lengths at the other three irrigation levels. There was an increase from I_{50} to I_{125} in the 4-day irrigation interval. In the NC-7 cultivar, significant changes were observed in branch lengths with irrigation levels. At the 2-day irrigation interval, there was a decrease from I_{50} to I_{125}. At the 4-day irrigation interval, there was an initial increase from I_{50} to I_{125}, peaked at I_{100} and then decreased. In Sultan cultivar, branch lengths at 2-day irrigation interval first decreased then, increased from I_{50} to I_{125}. At the 4-day irrigation interval of this cultivar, there was no significant change in branch lengths with irrigation levels (Figure 2b).

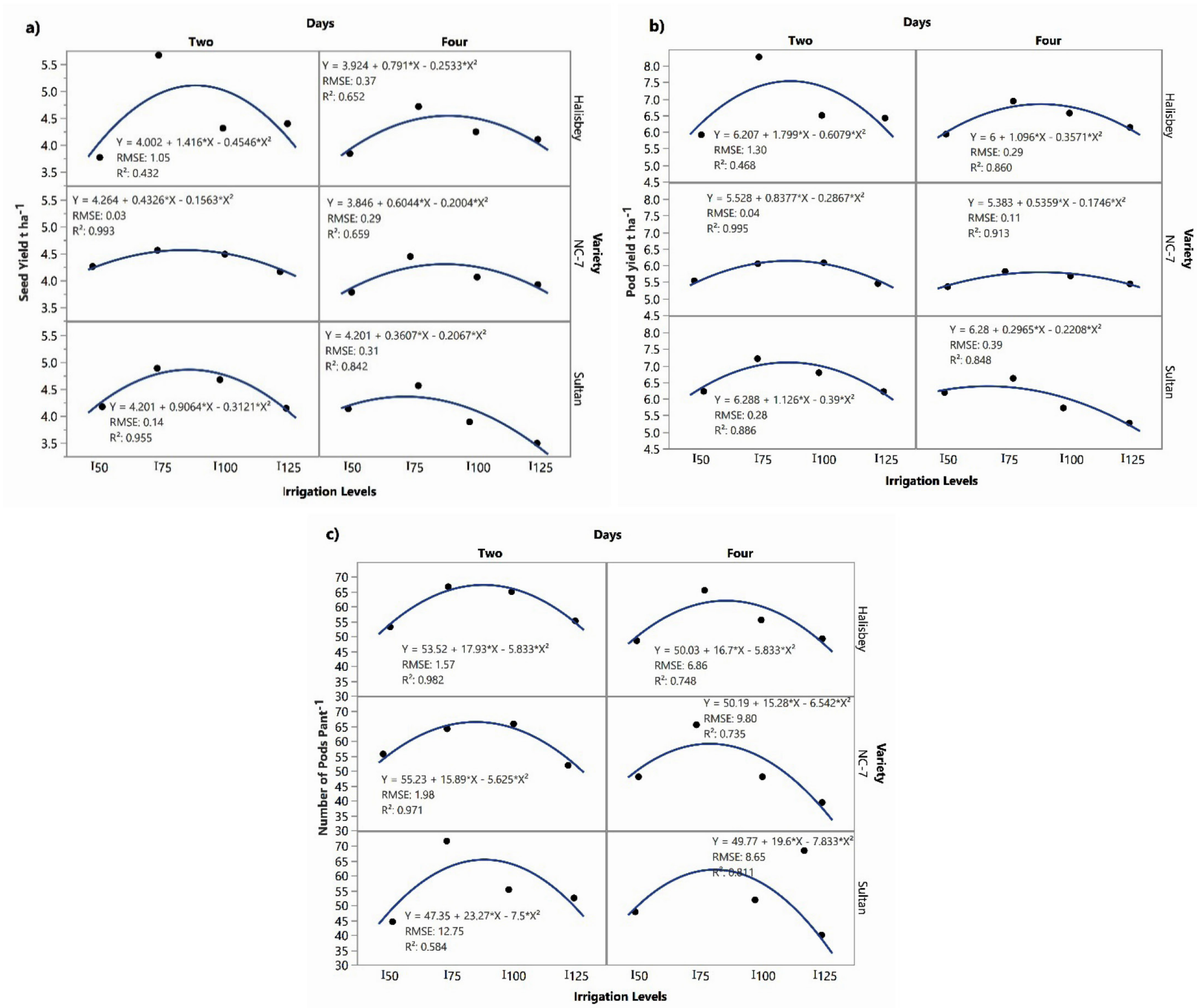

Figure 1. Regression graphs for changes in a) seed yield, b) pod yield and c) number of pods per plant with the cultivars, irrigation intervals and levels

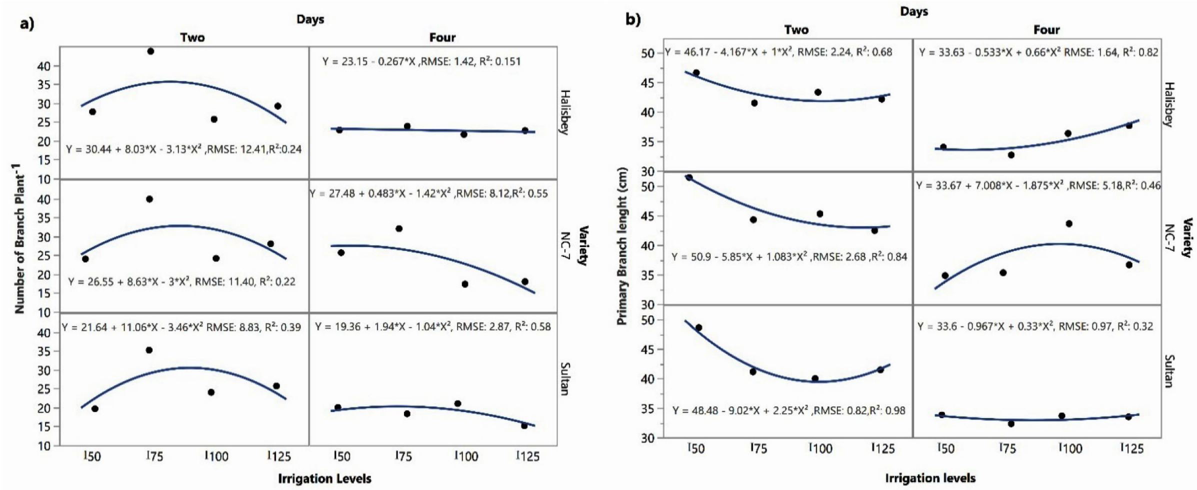

Figure 2. Regression graphs for changes in a) number of branches per plant and b) branch lengths with the cultivars, irrigation intervals and levels

The irrigation interval x trait biplot explained 83.2% of the total variation (Figure 3). Two basic groups were created on the biplot. While there was a main branch length in one of these groups, the I_{50} IW level was located diagonally at a 2-day irrigation interval. This shows that in three peanut cultivars, the highest branch length was obtained from the I_{50} IW level of a 2-day irrigation interval.

All the other traits examined formed a group and a 2-day irrigation interval and I_{75} IW level were located as diagonal. In this case, it was determined that there was a positive and significant correlation between seed yield and pod yield, number of branches per plant and number of pods per plant. All these traits had high values in the I_{75} irrigation level of the 2-day irrigation interval (Figure 3).

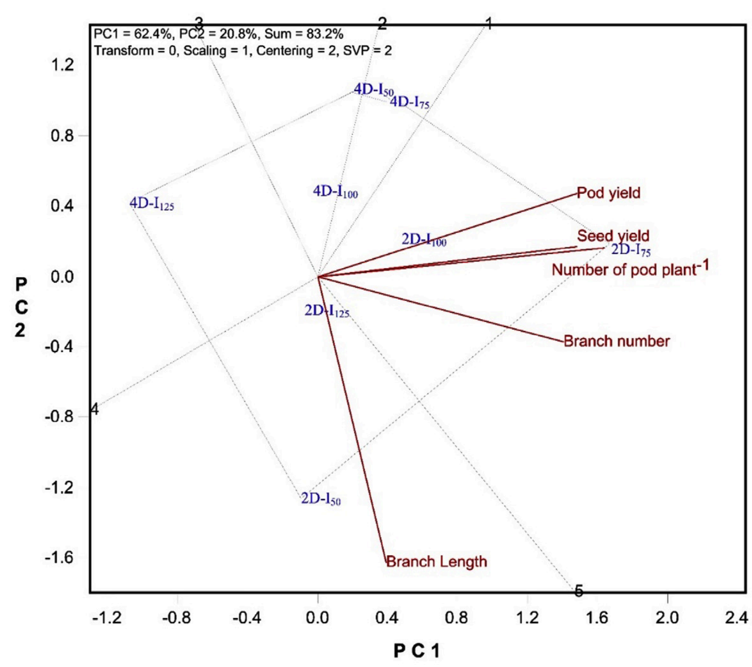

Figure 3. Visual evaluation of morphological traits of peanut cultivar under different irrigation intervals and levels
D: Irrigation interval (day), I: Irrigation level

For the interaction of interval x IW level (Figure 4) obtained over the years in three peanut cultivars, it was determined that the 2-day irrigation interval and I_{75} irrigation level of the Halisbey cultivar (H-2DI_{75}) were placed in the ideal interaction zone. In addition, it was determined that the 2-day irrigation interval and I_{75} irrigation levels of Sultan and NC-7 cultivars were placed close to the ideal interaction zone.

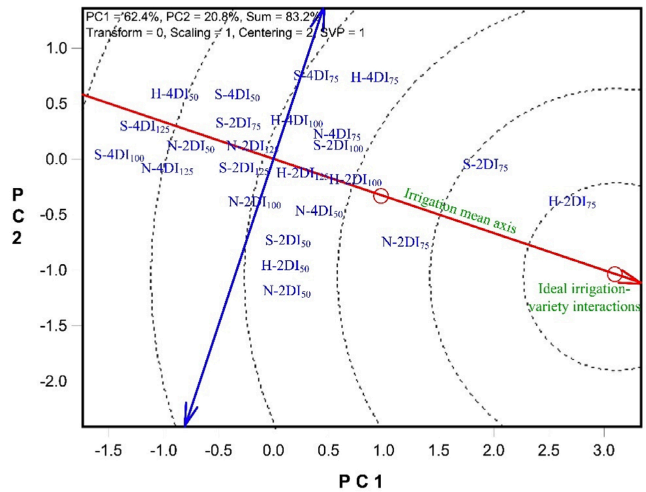

Figure 4. Biplot created for ideal irrigation interval x irrigation level x cultivar interaction
H: Halisbey, N: NC-7, S: Sultan, D: Irrigation interval (day), I: Irrigation level

3. Results and Discussion

Drip irrigation offers significant water savings in irrigations. Soni et al. (2019) used to drip, micro-sprinkler and surface irrigation methods in India and reported that as compared to surface irrigation, 40.08-55.0% water savings were achieved in drip irrigation and 25.10-43.83% in micro-sprinkler. Halim et al. (2016) conducted a study in Egypt and reported that 6-11% water saving was achieved in drip irrigation as compared to sprinkler irrigation. With the use of drip irrigation, significant cost reductions are achieved in fertilizers, pesticides, and labour.

Rathod and Trivedi (2011) conducted a 3-year study on peanuts in the Junagadh region of India and reported applied IW quantities as between 502-1,011 mm, seed yields as between 1,917-2,586 kg ha^{-1}, pod yields as between 3,710-6,640 kg ha^{-1} and IWUE values as between 0.26-0.41. Sorensen and Butts (2014) used a sub-surface drip irrigation system with different lateral spacings and IW levels (50, 75 and 100% of ET_0 values calculated by the Jensen-Haise method) for 10 years and indicated that there were no significant differences in seed yields of 75 and 100% irrigation treatments. Seed yields were reported as between 2,711-4,272 kg ha^{-1}. While the average rainfall in the ten-year production season was 477 mm, the average amount of IW applied was 295 mm in 100%, 213 mm in 75% and 154 mm in 50% of irrigation treatments. Sri Ranjitha et al. (2018) reported peanut seed yields as between 1,234-4,005 kg ha^{-1} and WUE values as between 0.80-2.1 kg ha m^{-3}. Yield levels decreased to 3805 kg ha^{-1} when 1.2 times of cumulative Epan value was applied. On the other hand, WUE values were determined to vary. Choudhary et al. (2020) reported WUE values as between 0.47-0.56 kg ha m^{-3} in the Rajasthan region of India, Kh (2017) used sprinkler irrigation under Egyptian conditions and reported WUE values as between 0.53-0.58 kg m^{-3}. Shoman and Bughdady (2018) reported WUE values as between 0.64-0.81 kg m^{-3}. Manzano Jr (2020) used the drip irrigation method and reported applied IW quantities as between 375 - 600 mm, yields as between 2,220-6,130 kg ha^{-1} and WUE values as between 0.47-0.66 kg m^{-3}. El-Metwally et al. (2020) conducted a similar study in Egypt under sandy soil conditions and reported applied IW quantities as between 154-386 mm, yields as between 3287-5391 kg ha^{-1} and WUE values as between 1.32-2.14 kg m^{-3}. El- Borai et al. (2009) reported evapotranspiration as 983 mm, yield as 4382 kg ha^{-1} and WUE values as between 0.17-0.53 kg m^{-3}. Sezen et al. (2019) reported evapotranspiration values as between 516-1067 mm, applied IW quantities as between 406-1,059 mm, yields as between 1,960-5,300 kg ha^{-1}, IWUE values as between 0.40-1.05 and WP values as between 0.32-0.74 kg m^{-3}. Bandyopadhyay et al. (2005) reported that WUE values of peanuts grown for two seasons in India varied between 0.48-0.60 kg m^{-3}. Kheira (2009) conducted a deficit irrigation study in Egypt and reported WUE values as between 0.45-0.61 kg m^{-3}. Aydınşakir et al. (2016) conducted a study in the South of Turkey and reported evapotranspiration values as between 193-809 mm, applied IW quantities as between 95-892 mm and WUE values as between 4.7-7.5 kg ha^{-1} mm^{-1}. Soni et al. (2019) used surface, micro-sprinkler and drip irrigation methods and reported applied IW quantities as between 165.12-367.44 mm and WUE values as between 5.18-19.28 kg ha^{-1} mm^{-1}. For morphological traits, Aydınşakir et al. (2016) reported branch lengths as between 33-76.7 cm, number of branches per plant as between 6.5-12.4 and number of pods per plant as between 17.3-51.8; Shoman and Bughdady (2018) reported number of pods per plant as between 33.16-44.47; Sri Ranjitha et al. (2018) reported number of pods per plant as between 11.78-24.78; El-Metwally et al. (2020) reported number of branches per plant as between 17.80-24.17 and number of pods per plant as between 23.16-37.80; Canavar and Kaynak (2013) (2013) reported branch lengths as between 41.33-55.23 cm, number of branches per plant as between 10.33-11.33 and number of pods per plant as between 28-71.77; Wang et al. (2016) reported branch lengths as between 24.8-33.9 cm, number of branches per plant as between 7.1-14.2, number of pods per plant as between 20.3-35; Jin et al. (2021) reported branch lengths as between 35.82-47.30 cm, number of branches per plant as between 5.18-7.57 and number of pods per plant as between 11.14-16.59.

In terms of economic analysis, the present findings comply with the results of earlier studies. Manzano (2020) reports that as compared to furrow irrigation, drip irrigation increased the pod yields by 31.45%. It was determined that drip irrigation increased the pod yields up to 70.21% in dry season as compared to furrow irrigation. These increases in pod yields were mainly attributed to more homogeneous water application and less water stress. However, fixed costs were 58.75% and operating costs were 75.32% higher in drip irrigation. In the long run, the benefits of drip irrigation include increased efficiency as well as water savings. Choudhary et al. (2020) reported benefit-cost ratios (B/C) as between 1.50-1.95; Mishra et al. (2008) as between 2.46-3.10 and Soni et al. (2019) as between 1.66-2.41. Sorensen and Butts (2014) reported gross revenue as between 1,804-1,899 \$ ha^{-1} in subsurface drip irrigation and as 1,478 \$ ha^{-1} in non-irrigated treatments. The current findings were higher than some of aforementioned researchers' results and lower than some others. These differences were attributed to differences in cultivars, climate, ecological conditions, and cultural practices.

4. Conclusion

It has been found that 2-day irrigation intervals and I_{75} irrigation levels had the greatest yield levels in all three cultivars of peanut cultivation with drip irrigation in sandy soil conditions. Thus, a 2-day irrigation interval and 75% of pan evaporation could be used in the irrigation of peanut plants grown under sandy soil conditions. The GGE biplot statistical method can be used safely in the evaluation of irrigation experiments. It has been determined that it is a very useful method in determining the most appropriate doses/levels, especially in research where the number of applications and materials is high. Since the method reveals the effect and applications visually, compared to classical statistics it offers a more easily understandable explanation. The method reveals the effect and differences of the applications visually. Compared to classical statistics, the GGE biplot method offers more easily understandable explanations.

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