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Interactive Effect of Deficit Irrigation and Water Quality on Yield and Water Use Efficiency of Red Cabbage (*Brassica oleracea var. capitate L.*) under Drip Irrigation

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Abstract. Deficit irrigation is emerging as a promising management practice to reduce water use with marginal loss in crop yield. Further, limited studies are available on the combined effect of water deficit and water quality on the water use efficiency of leafy vegetables like red cabbage in the semi-arid climate of Kirkuk. Therefore, this study was initiated to unveil the combined effect of varying deficit irrigation levels (0.5, 0.75, 1, and 1.2 of full irrigation) and two types of water quality (fresh and saline water) on water use efficiency of red cabbage under drip irrigation with two types of emitters. The results indicated that there is a steady increase in fruit yield with an increase in the level of irrigation with saline water over the entirerange of applied water. The highest water efficiency was achieved under the combined effect of fresh water and GR and Turbo emitter when the level of applied water at full irrigation was reduced by a factor of 0.5 (20.31 kg/m^3)(21.96kg/m^3) respectively Furthermore, crop response factor analysis revealed that the red cabbage can tolerate deficit irrigation and produce satisfactory under both fresh and saline water were GR emitter with fresh and saline water given best value (0.627) (0.703) compeer with Turbo emitter with fresh and saline water given (0.292)(0.566)respectively. Additionally, further research is proposed to study the water productivity of red cabbage with saline water and take into account the yield of the same piece of land when the experiment is repeated for several years.

Keywords. Red cabbage, Deficit irrigation, Water quality, Water use efficiency, Crop response factor, Kirkuk.

1. Introduction

Increasing demand for food owing to population pressure requires an urgent improvement of productivity per unit of applied water in the agriculture sector [1] The big challenge facing the agricultural sector is to yield more food from less available water [2].

Although water is plentiful on a global scale, only 0.75% is available as freshwater in watersheds, rivers, and lakes. Irrigated agriculture is the main user of available fresh water on a global scale, andits consumption is estimated at 70% of the total consumed freshwater [3]. To cope with freshwater scarcity, emphasis has been placed on its effective use [4]. The efficient use of water in agriculture is a complex topic that includes a wide range of disciplines, covering plant physiology, agronomy, and engineering [5]. Further, they demonstrated that it can be enhanced by modifying both the numerator and denominator of the water use efficiency formula. Agronomic practices aimed at reducing water losses will increase WUE. Likewise, any agronomic measure that will increase crop yield will eventually lead to better water use efficiency. Water productivity is typically used to identify the environments or management strategies by which the yield per unit of water can be maximized. This type of performance indicator is very useful under conditions of scarcity of water resources [6]. Prolonged drought conditions have demanded the use of lower-quality water to supplement irrigation in semi-arid regions [7]. Therefore, understanding plant responses to the couple abiotic stresses of water and salinity and the basic mechanisms of improving WUE from leaf to whole plant scale would be of vital importance to getting stable crop performance and production under both saline drought and conditions in a region subjected to climatic change.

Red cabbage, as a vegetable crop, is typically used as a component in raw vegetable salads, containing a full range of vitamins and minerals with varying useful effects on human health [8]. It has high nutritional values relevant to the antioxidant and anti-inflammatory functions of its ingredients, such as anthocyanin, vitamins, and minerals [9].

Cabbage (Capsicum annum L.) is widely grown in open field conditions in Iraq. It has been classified as moderately susceptible to water stress, with the head formation period being more sensitive [10].

Saline water is a main resource in arid areas and areas with poor-quality groundwater resources. The use of poor-quality water causes serious losses in yield and plant growth [11]. Drip irrigation and frequent irrigation applications over the growing season can maintain a low soil matric tension in the root zone, thus compensating for the increase in osmotic tension introduced by the saline water irrigation, and consequently, a low total water stress is maintained for crop growth [12]. Salinity- tolerant plants can minimize saline stress effects by generating a series of processes at the morphological, physiological, and biochemical levels [29].

Drip irrigation forms a wetting front that reduces the salinity around the root. The dawn of automated irrigation methods such as drip irrigation has played a key role in reducing the amount of water required in agricultural and horticultural crops, but it has also highlighted the need for new methods of accurate irrigation scheduling and control. Scheduling water application is very important to make the most efficient use of drip irrigation systems, as excessive irrigation lessens yield, while falling water deficits below some threshold level may cause water stress and reduce production [13]. In recent years, it has become clear that the maintenance of a slight water deficit can improve crop yields [14]. Deficit irrigation is a management practice in which crops are irrigated with water amounts less than those required for optimum growth [15]. It is worth mentioning that drip irrigation does not fit alltypes of crops, it fits primarily fruitful trees and varieties, and it fits vegetable crops [30]. It includes two types: continuous deficit irrigation (CDI) and regulated deficit irrigation (RDI) [16]. The former isbased on imposing the water deficit uniformly over all the stages of the growing period. In contrast, RDI imposes water stress at a certain stage at which the crop is less sensitive to a water deficit.

An excess of literature is available concerning the responses of red cabbage to levels of salinity and water stress separately; these two stresses take place together; accordingly, the response of the growing crops should be studied under the combined stress conditions [17]. Moreover, there arelimited studies on the response of this crop to management practices in Iraq as a whole and in particular in the semiarid climate of Kirkuk. Therefore, this study was initiated to unveil the combined effect of varying deficit irrigation levels and water quality on the yield and water use efficiency of red cabbage under drip irrigation. The fact that most farmers in Iraq do not use modern production techniques and have little interest in performing beneficial agricultural service activities like composting and irrigation is one of the most significant factors contributing to the crop's lower production rates in Iraq compared to other producing nations [28].

2. Materials and Methods

Before initiating the experiment, a rectangular area of 43.3 m by 3.6 m was demarcated and fenced for the current study. The study was conducted on sandy clay loam soil during the summer season of 2022 at the outskirt of Kirkuk in the village of Hasar Al Kabir, which is about 16 kilometers north of Kirkuk city. The geolocation of the experimental site is 35º36'81N and 44º21'32" E, lying 380 m.

2.1. Land Preparation
Before delineating the experiment layout, a rough grading was performed with minimum disturbance by removing abnormalities and filling minor depressions, and removal of vegetation cover. Afterward, the field was soaked with water and subjected to drying. When the soil water becomes optimum for ploughing, the field was ploughed to a depth of about 0.30 m, disked, harrowed, and subdivided into three blocks, each block was racked smooth and level.

2.2. Experimental Layout
The experiment was conducted on sandy clay loam soil (30.6% clay, 14.0% silt, and 55.4% sand, ECe= 1.07 dSm^{-1}, pH=7.3, and OM=1.51%). Red cabbage (Brassica oleracea L) seeds type (Hybrid red cabbage hannar F1 -AU origin Naughty Scar 99%and Seed Scar 85%) have been planted. The layout was a split-split plot design with 2 levels of emitter type, two sub-treatments of water quality, and 4 sub-sub treatments of deficit irrigation.
As mentioned earlier, a field measuring 43.3 m x 3.60 m was selected for the experiment and this area was divided into three main blocks of 14.43 m x 3.6 m. Each block consisted of 16 plots Each factor was three times replicated. It was decided to use a randomized entire block design. The details of the levels of each factor are as follows:

- Emitter type (A) with two types: A1 = GR and A2= Turbo
- Water quality(salinity) (B) with two levels: B1 = Freshwater (EC= 0.55 dSm-1; pH=7.7, turbidity = 1.5 and Na+= 1.39 meq/L) and B2 = Saline water (EC = 4.41 dSm-1; pH=8.1, turbidity = 6.4 and Na+= 14.9 meq/L)
- Deficit irrigation (C) with four levels: C1= 1.2 IF, where IF= full irrigation, C2= 1 IF, C3= 0.75 IF, and C4= 0.5 IF

This implies that totaling 48 experimental units. The treatment combination was randomly distributed among each block.

2.3. Description of the Irrigation Network Used for Water Distribution
The irrigation unit, or network, was composed of a manifold, 50 mm in diameter, made from polyethylene. A total of 48 laterals were inserted into the manifold; each had a diameter of 16 mm and was 3.6 m in length. The emitter spacing along the lateral was 0.4 m, and the lateral spacing was 0.6 m. Each experimental unit was drip-irrigated with a lateral carrying nine emitters. Two types of emitters have been used, namely, the Turbo type, manufactured in Greece, and the GR type, manufactured in Jordan. Each emitter had a flow rate of 4 L h^{-1}.

2.4. Irrigation Schedule
Equal amounts of irrigation water were added to all treatments during the first two weeks from transplanting and deficit treatments were started after this period. During the first irrigation within the first 2 weeks, the crop was irrigated to bring the soil water content of the root zone to field capacity. Fertilizer application and other cultural practices were conducted based on the recommendations made locally by the relevant authorities.
We used the evaporation from a class A evaporation pan (Epan), the pan coefficient (Kp), the crop coefficients (kc) for growing red cabbage, and the irrigation application efficiency (Ea) to determine how much water would be needed. The calculations can be summarized as follows:
The evaporation pan was set up close to the experimental site for recording daily evaporation (mm/day). The pan evaporation (Epan) was converted to potential evaporation(ETo) through

$$Eto = (Epan \times Kpan) \quad (1)$$

Kpan = pan coefficient =0.75
The crop consumptive use was obtained from;

$$ETc = (ETo \times Kc) \tag{2}$$

Where (Kc) = Crop coefficient for red cabbage that was obtained after establishing the Kc curve over the growing season.
The growth depth of Applied water(dg) in mm calculated from:

$$V = \frac{ETc}{Ea} \tag{3}$$

Where: Ea= Irrigation application efficiency (=0.9 under drip irrigation)

The determination of the volume of applied water in liter/day /plant was based on the following expression:

$$V = ETc \times WA \times A \tag{4}$$

where: WA = wetted area fraction or reduction factor (=0.5); A = area = Sp x Sr =0.40m x 0.6 m

The volume of applied water was based on cumulative evaporation for two and three days during the early stage and the period after this stage depending upon the intensity of external evaporative.
The time of operation (T in hours) was based on an irrigation interval of 3 days at the early stage of growth and 2 days thereafter. The formula takes the following form:

$$T = (V/ q) \tag{5}$$

where q = emitter discharge in l/hr.
The required irrigation water was provided from two storage tanks, one for the freshwater (B_1) and the other for the saline water (B_2). The sources for S_1 and S_2 were the lesser Zab tributary and a well south of Kirkuk respectively.

2.5. Field Water Use Efficiency
The field water efficiency is the ratio of crop yield (Y) to the total amount of water applied in the field [18]. This parameter is expressed mathematically as:

$$FWUE= \frac{Y}{WR} x1000 \tag{6}$$

where:

(FWUE)= Field Water Use Efficiency (kg m^{-3}), Y = Total fresh weight (kg ha^{-1}), WR = Total volume of applied water (m^3/ ha)

2.6. Crop Response Factor
The crop response factor (Ky) which expresses the relationship between relative evapotranspiration reduction (1 – ETa /ETm) and relative yield reduction (1 –Ya⁄Ym) was postulated for red cabbage according to the following formula [19].

$$\left(1 - \frac{Ya}{Y_{max}}\right) = k_y \left(1 - \frac{ET_a}{ET_{max}}\right) \tag{7}$$

Y_a = Actual fresh weight or yield, Ym maximum fresh weight, ETa = Actual evapotranspiration, ETm = Maximum evapotranspiration, Ky= crop yield response factor that depends on the type of crop, irrigation method, ETc.

2.7. Total Fresh Fruit Yield (ton/ha^{-1})
The crop was harvested when it reached horticultural maturity on December 10, 2022. On this date, red cabbage heads were picked from all the plants in each replicate of each treatment combination and weighed with a sensitive balance having a precession of 100 mg. The results were then expressed as t/ha^{-1}.

3. Results and Discussion

3.1. Response of Fresh Fruit Yield to Level of Irrigation

To determine the response of red cabbage fresh fruit yield to levels of irrigation under different treatment combinations, a linear relationship was established between these two variables, and the results were displayed in Fig. 1. As can be noticed in Fig. 1, there is a steady increase in fruit yield with an increase in the level of irrigation with saline water over the entire range of applied water. In contrast, the fresh fruit yield tended to increase up to a full irrigation level, beyond which there is a slight drop in fresh fruit yield at the over-irrigation level (1.2 FI). Unlike the fresh water, the saline water offered a stronger, sounder linear relationship (R2 = 0.90). One plausible explanation for this phenomenon is a decrease in salinity stress with an increase in the applied water's depth. Applicationof irrigation levels beyond full irrigation may cause excessive nutrient leaching and create unfavourable soil physical conditions. [20] reported that over-irrigation had negative off-side effects such as the leaching of nutrients and enhancement of pest infestation.

Although the fresh yield tended to decrease with a decrease in the level of applied water, the ANOVA test revealed that no significant difference in fresh yield was found under different levels of applied water with fresh water. On the contrary, the fresh yield under 0.5 IF differed significantly at (P(0.01) from the fresh yield under all the remaining levels of applied water with saline water.

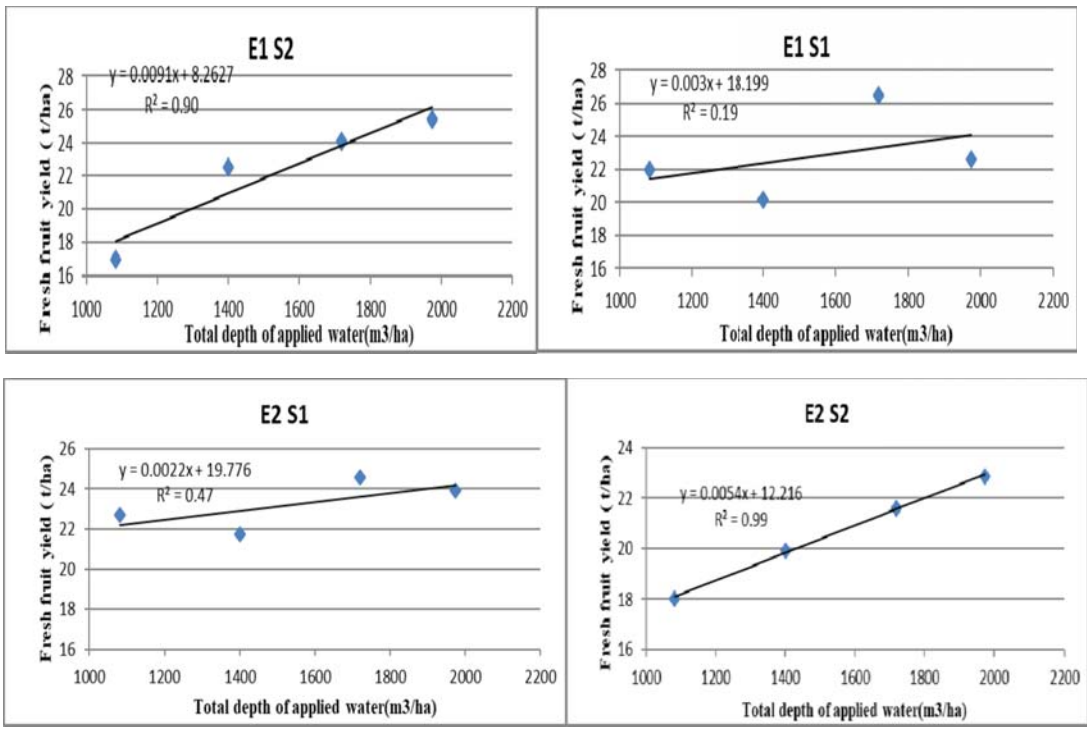

Figure 1. Plot of red cabbage fresh fruit versus depth of applied water.

3.2. Field Water Use Efficiency

Data about the Field Water Use Efficiency of red cabbage is shown in Table 1 and Fig. 2. It is evident from Fig. 2 that the Water Use Efficiency varied from a minimum of 11.48 kg m^3 (114.8 kg/ha.mm) under 1.2 FI S1E1 to a maximum of 20.96 kg m^3 (209.6 kg/ha.mm) under 0.5 FI S1E2. This is in confirmation of the findings of [21], who observed that the highest water use efficiency in terms of marketability was achieved when irrigation led to a 30% depletion of the available soil moisture. [22] have obtained a higher water use efficiency for Chinese cabbage (42.1–47.3 kg m3) in the stress range of 13–17 kappa.

As can be observed in Fig. 2, there is a steady increase in Water Use Efficiency with an increase in the level of deficit irrigation for both fresh and saline water under the GR type of emitter used during this study. This parameter offered a nearly similar trend under turbo emitters, with some simple deviations from an increasing trend. These results are in line with the finding of [23], who observed that the GR type outperformed the turbo type. The GR type offered a higher value for design emission uniformity and a smaller value for the coefficient of manufacture variation. Reducing the level of applied water by a factor of 0.5 of IF resulted in a red cabbage water use efficiency increase of 31.82%and 12.33% under the combined effects of E1S1 and E1S2, respectively, compared with those under full irrigation. This level of applied water also led to higher percentages of increases in water use efficiency under the combined effects of E2S1 and E2S2, respectively, compared with those under fullirrigation. These results indicate that the GR emitter offered higher performance compared to the turboemitter.

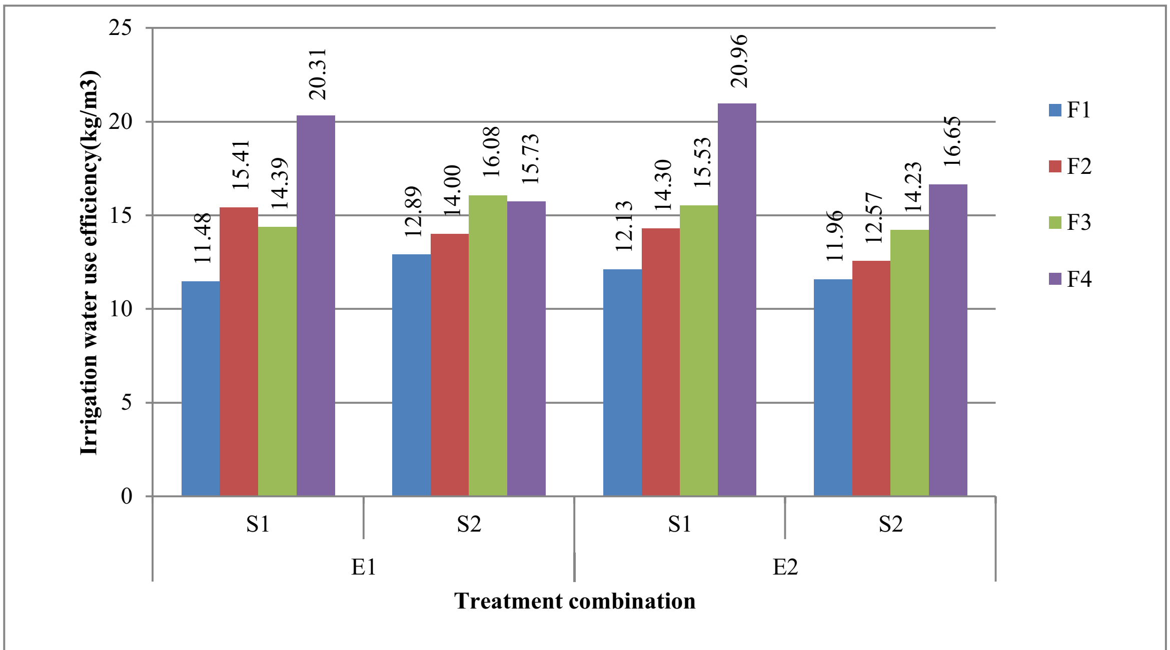

Figure 2. Water use efficiency for red cabbage as affected by the interactions between type of emitter, water quality and deficit irrigation level.

On the other hand, the results indicate that deficit irrigation performed better under fresh water compared to saline water. In other words, it can be elucidated that the water use efficiency of fresh water was superior to that of saline water. They may be attributed to the deleterious effects of water salinity. The data presented in Table 1 revealed that the increase in the area of cultivation with saved water can compensate for yield reductions resulting from deficit irrigation. For 50% FI, extra yields of 13.25 and 12.04 t/ha can be produced when fresh and saline water is used under the GR emitter type, respectively. The corresponding additional yields under Turbo emitter with freshwater and salinewater were 12.29 and 9.01 t/ha, respectively. Overall, the freshwater outperformed the saline water in compensating for the reduction in yield due to deficit irrigation.

Although there is a steady increase in water use efficiency with an increase in the level of deficit irrigation for both fresh and saline water under both GR and turbo emitters, the water use efficiency only under 0.5 IF with freshwater differs significantly from those under other levels of deficit irrigation.

Table 1. Additional cultivated area and additional yield that contained under the interactive effect of emitter type, water quality, and deficit irrigation level.

Type of emitter	Water quality	Deficit level	fresh fruit yield (t/h)	Volume of applied water(m3)	Water use efficiency (kg m^{-3})	Irrigation water saved (%)	Yield reduction (%)	An additional area that can be cultivated (ha)	Additional yield (t/ha) under 100% FI
E1	S1	100%FI	26.50	1719.17	15.41^{ab}	0	0.00	0	0.00
E1	S1	75%FI	20.16	1400.42	14.39 ^{b}	25	23.94	0.25	6.63
E1	S1	50%FI	21.97	1081.67	20.31 ^{a}	50	17.09	0.5	13.25
E1	S2	100%FI	24.08	1719.17	14.00 ^{b}	0	0.00	0	0.00
E1	S2	75%FI	22.52	1400.42	16.08 ^{ab}	25	6.49	0.25	6.02
E1	S2	50%FI	17.01	1081.67	15.73 ^{ab}	50	29.36	0.5	12.04
E2	S1	100%FI	24.58	1719.17	14.30 ^{b}	0	0.00	0	0.00
E2	S1	75%FI	21.75	1400.42	15.53 ^{ab}	25	11.50	0.25	6.15
E2	S1	50%FI	22.68	1081.67	20.96 ^{a}	50	7.75	0.5	12.29
E2	S2	100%FI	21.60	1719.17	12.57 ^{b}	0	0.00	0	0.00
E2	S2	75%FI	19.93	1400.42	14.23 ^{b}	25	7.73	0.25	4.98
E2	S2	50%FI	18.01	1081.67	16.65 ^{ab}	50	16.60	0.5	9.01

3.3. Crop Response Factor

It is obvious from Table 2 that Ky values increased parallel to the increase in water amount from 50% IF to 75% with fresh water under both GR and Turbo emitters. With fresh water, Ky increased from 0.46 to 1.29 under E1 and from 0.21 to 0.62 under E2 as the deficit level dropped from 50% to 75%. Unlike fresh water, saline water exhibited the opposite trend.

Table 2. The relative yield drop and relative crop evapotranspiration deficit under different treatment combinations.

Treatment combination	Relative yield decrease (1-Ya/Ym)	relative crop evapotranspiration deficit(1-ETa/ETm)	Crop response factor (Ky)	Relative yield (1-Ya/Ym), (%)
E1S1 100%FI	0.00	0.00	0.00	100.00
E1S175%FI	0.24	0.19	1.29	76.06
E1S1 50%FI	0.17	0.37	0.46	82.91
E1S2 100%FI	0.00	0.00	0.00	100.00
E1S275%FI	0.06	0.19	0.35	93.53
E1S250%FI	0.29	0.37	0.79	70.66
E2S1 100%FI	0.00	0.00	0.00	100.00
E2S175%FI	0.12	0.19	0.62	88.49
E2S1 50%FI	0.08	0.37	0.21	92.24
E2S2 100%FI	0.00	0.00	0.00	100.00
E2S275%FI	0.08	0.19	0.42	92.26
E2S250%FI	0.17	0.37	0.45	83.39

To find out the overall sensitivity of red cabbage to deficit irrigation in terms of crop response factor under different combination treatments, a linear relationship was built between the relative decrease in red cabbage yield and the relative decrease in evapotranspiration with a zero Y-intercept (Fig. 3). The slope of the linear relationship represents the red cabbage response factor under different treatment combinations. As can be seen in Fig. 4, the seasonal ky-values under the GR emitter were 0.627 and 0.703 for fresh and saline water, respectively. The corresponding values were 0.292 and 0.566 for fresh and saline water with the turbo emitter. With no exception, all the Ky values were less than unity, indicating that a unit water deficit resulted in a less than one-unit reduction in fresh yield [19].

This implies that the red cabbage tolerated water stress and produced a satisfactory fresh yield. These results are in line with the findings of [24], who obtained values in the range of 0.96-0.97, and [25], who obtained a value of 0.95 for cabbage. Conversely, some researchers found values higher than unity; [26] obtained a Ky value of 1.19, and [13] obtained a value of 1.036. One plausible explanation for mismatching is the fact that a host of factors such as climatic conditions, type of cultivar, planting time, and planting density govern the crop yield and efficient use of water and have a substantial effecton the variability of this parameter [27]. Overall, the obtained results revealed that the red cabbage tolerated water stress and produced a satisfactory fresh yield. It is also apparent from the results thatthe GR emitter yielded a lower value for this parameter compared to those under the Turbo emitter, signifying that the former type offered better performance. As the Ky-values with fresh water were lower compared to those under saline water for the same type of emitter, this confirms that the crop offered a higher tolerance under fresh water.

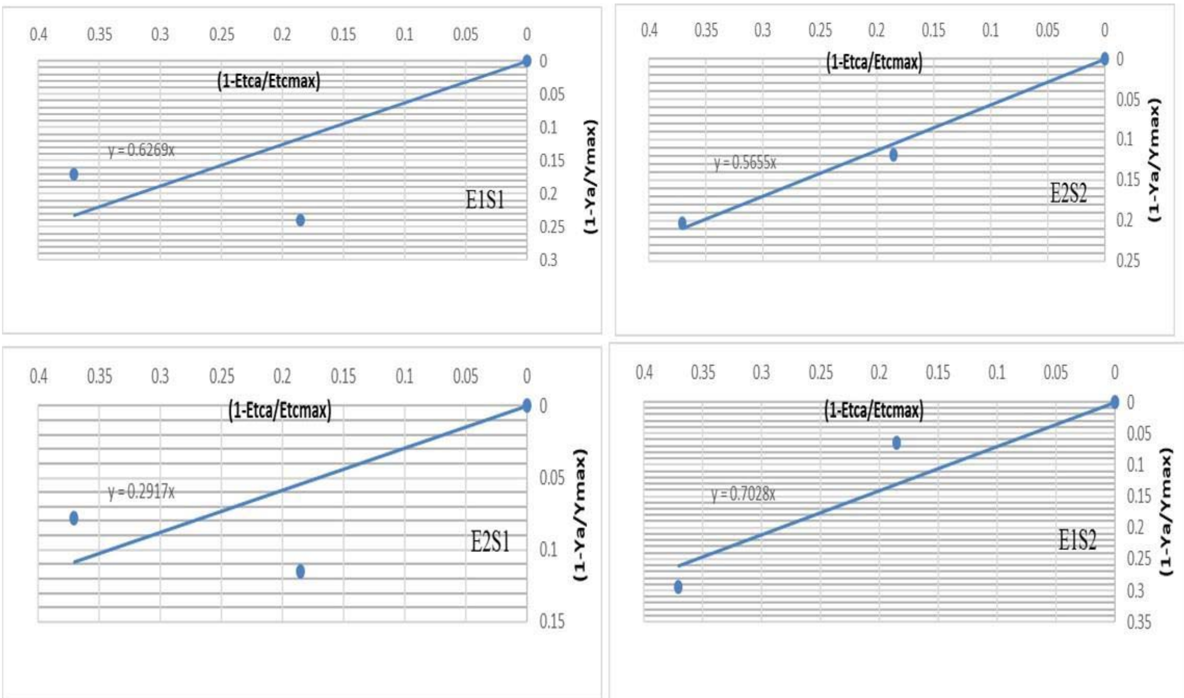

Figure 3. Crop response factor for red cabbage under different treatment combinations.

It is expected that the efficiency of the use of saline water will reduce when the cultivation of the crop is repeated during the next years due to salt accumulation if the leaching requirement is not considered. So further research is proposed before making the proper recommendation about using saline water under the study area's climatic conditions.

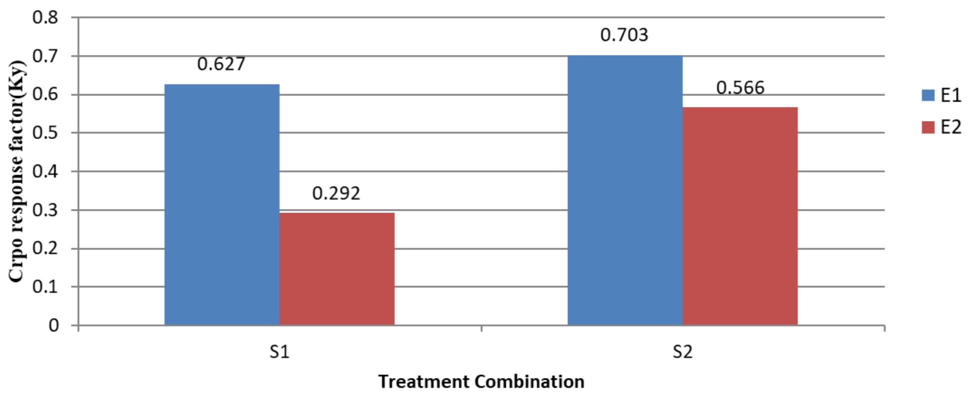

Fig.4. Red cabbage response factor as affected by quality of water and emitter type

Figure 4. Red cabbage response factor as affected by quality of water and emitter type.

Conclusions

The current study indicated that red cabbage can tolerate water stress and produce a satisfactory fresh yield under deficit irrigation. The highest water efficiency was achieved under the combined effect of fresh water and GR emitters when the level of applied water at full irrigation was reduced by a factor of 0.5.

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