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PHYSIOCHEMICAL AND PHYSIOLOGICAL QUALITIES OF SOYBEAN SEED YIELD AS A RESPONSE TO DIFFERENT IRRIGATION PRACTICES IN EGYPT

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Abstract

The aim of the paper is the analysis of the response of soybean seed yield and its component including (plant height, number of pods/plant, and 100-seed weight), water productivity and quality properties (physiochemical including protein and fats content and physiological including germination ratio, length of seedling shoots and roots, seedling dry weight, and seed vigor index) to seven irrigation practices were evaluated in a field experiment based on a randomized complete block design; the irrigation practices including sprinkler and drip system at full irrigation with 100% ETc (S100 and D100) and deficit irrigation with 80 and 60% ETc (S80, D80, S60, D60) and compared to furrow irrigation (F). Findings revealed that, S100 and D100 improved seed yield by 10.8 and 16.8% compared to F treatment. The highest yield components and water productivity was achieved by D100 treatment with values of 113 cm plant height, 115 pods/plant, 14.4 g weight of 100 seeds and 0.62 kg/m^{3}respectively. With the irrigation regime, protein content had a positive correlation while fat content had a negative correlation; the highest protein content was 28.75 and 28.20% achieved by S100 and D100, while the highest fats content was 22.91 and 22.63% achieved by D60 and S60. There is a positive correlation between the physiological properties and the irrigation regime; the highest physiological properties were germination ratio 98.3 and 96.7%, root length 8.7 and 7.33 mm, shoot length 1.98 and 1.87 mm, seedling dry weight 0.69 and 0.67 g and seed vigor index 117.9 and 110.8 achieved by D100 and S100.

Key words**:** *irrigation practice, deficit irrigation, soybean quality*

INTRODUCTION

Egypt as one of the countries located in arid to the semiarid zone is presently suffering a water scarcity as a result of current climatic changes, posing a danger to sustainable agricultural production and water productivity; as a result, the impact of water scarcity on agriculture has become more serious under the climatic changes [4]. It becomes increasingly difficult to continue using the current low-efficiency irrigation methods, and it is important to investigate relevant factors affecting productivity, such as careful planning and management of irrigation strategies, innovative irrigation techniques that required for sustainable use of water in irrigated agricultural systems [16].

The soybean has a significant impact on the global food supply and is one of the major sources of vegetable oil, providing more than 30% of global oil production. Also, it is a rich in dietary fiber, phospholipids, minerals, and vitamins [13]. The cultivated area in Egypt in 2021 was 20,600 ha, producing approximately 62,580 tons [17]. Soybean crop is highly sensitive to water shortage at various growth stages, so it is must be watered during important growth stages such as flowering, pod initiation, and seed filling [29]. Water deficit can reduce germination percentage and healthy plant growth, and development of seeds which significantly decreased seed yield, especially during the pod set and seed filling stage [28]. Application of water stress to soybeans upon critical growth stages is detrimental to protein contents[1]; yield and its components [25]; relative water content, chlorophyll content, and growth traits [14]. Irrigation water is considered the main environmental factor in arid and semi-arid climates, being responsible for several metabolic processes related to plant growth and development; also, it is an essential element that impacts physical and chemical processes that affect the yield and quality of soybean seeds [32]. Response of soybean to five irrigation regime (100, 75, 50, 25, and 0 %) as a percentage of evaporation by a Class A pan was estimated, the maximum production was achieved with full irrigation (100%); while under water scarcity conditions soybean can be irrigated as much as 75% of the evaporation pan as an option [9], the same effect obtained by [3] in sandy soil. Three irrigation regimes (100, 90 and 80%) of irrigation requirement in Kafr El-Sheikh Governorate, Egypt for a furrow-irrigated soybean crop were investigated, irrigation regime had a significant effect on yield and yield components; 100% treatment was the superior and achieved the highest values, no significant differences between the 100% and 90% irrigation regimes [22]. Irrigation system has a vital role in determining the yield and nutritional quality of the soybean seeds [6, 30].

Seedling vigor indicates seedling weight or height, and is an essential indication of seed quality, determining the probability of quick and uniform plant emergence under a range of different field circumstances [27]. The recent researches still have only focused on saving significant amounts of irrigation water, improving water use and developing high performance irrigation programs for growing high quality crops that utilize less water, whereas, research on the effects of agricultural practices on seed composition is limited. Therefore, the present experiment was carried out by keeping this in view, aimed to study and evaluate the effect of different irrigation practices on soybean yield and its components, and seeds quality (physicochemical and physiological properties).

MATERIALS AND METHODS

Experimental layout

A field experiment was carried out during the summer season of 2022 at Rice Mechanization Center (RMC), Meet El-Deyba, Kafr El-Sheikh Governorate, Egypt, which is located at 31° 6′N latitude, 30° 50′E longitude, and an elevation of about 6 meters above sea level. The experimental field was prepared according to traditional land preparation and the furrows were raised at a distance of 70 cm. Giza 111 soybean variety was manually planted in May and harvested in October. All agronomic practices were done in accordance with agricultural recommendations for soybean. The soil mechanical analysis of the experimental field was performed in Soils, Water and Environmental Res. Institute Lab., Kafr El-Sheikh, Agricultural research center, Egypt (Table 1). The meteorological data of the research site is presented in Table 2.

Table 1. Mechanical analysis of the experimental soil

Soil depth, cm	Particle size distribution			Texture	FC, %	PWP ,%
	Clay, %	Sand, %	Silt, %			
0-15	55.40	32.24	12.36	Clay	45.16	21.33
15-30	53.02	32.85	14.13	Clay	43.02	21.20
30-45	54.26	29.16	16.58	Clay	41.00	21.07
45-60	54.00	28.64	17.36	Clay	39.13	19.77

FC: Field capacity, PWP: Permanent wilting point
Source: Own calculation.

Table 2. Average monthly meteorological data for the research site

Month	T_{mini},°C	$T_{max..}$,°C	$T_{avg.}$,°C	RH, %	WS, m/sec
May	15.7	33.0	24.4	50.5	2.8
Jun.	19.3	37.3	28.3	40.3	3.0
Jul.	21.8	39.5	30.7	43.0	2.8
Aug.	22.5	39.6	31.1	45.6	2.7
Sept.	22.4	38.9	30.7	49.2	2.7

Source: Central Laboratory for Agricultural Climate (CLAC), Agricultural Research center, Egypt.

Irrigation system components

The main components of the irrigation systems as shown in Fig. 1 were a centrifugal pump (30 m^3/h nominal discharge and 3 inch inlet and outlet diameters) driven by a 3.75kW internal combustion engine, a control unit consisting of (control valves, pressure gauges, and flow-meter), main line, lateral lines and emitters. The main line was made of HDPE with an outer diameter of 75 mm. In the sprinkler (S) system; the laterals were made of PVC with an outer diameter of 32 mm connected to the main line by control valves. In the drip (D) system; sub main line made of HDPE with an outer diameter of 55 mm was installed to transfer the irrigation water from the main line to the laterals via a manifold with an outer diameter of 32 mm. Polyester screen filter, 120 mesh with a diameter of 32 mm were installed to prevent clogging of sprinklers and drip tapes. An angle impact sprinkler made of plastic with a mail inner diameter of ½ inch, single nozzle with a diameter of 4 mm, trajectory angle of 27°C, throw diameter of 18 m, and discharge rate of 750 L/h at 125 kPa operating pressure were installed on the laterals at a distance of 9 m in a square layout and overlapping 50% of the throw diameter. Radial gross and net precipitation rates were 2.9 and 2.45 mm/h. Lateral drip tapes made of PE with an inner diameter of 16 mm, length of 30 m, spacing between emitters of 10 cm, and a discharge rate of 1,400L/h/100 m of length at 60 kPa operating pressure. Distribution uniformity along the drip line was classified excellent and the manufacturer's coefficient of variation was less than 0.05.

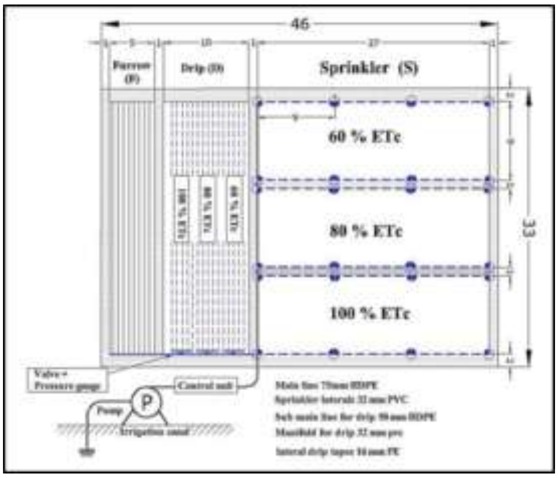

Fig. 1. Irrigation system components and treatments distribution
Source: Own design.

Experimental Treatments

Three irrigation regimes as a percentage of crop evapotranspiration (100%, 80% and 60% ETc) for the two irrigation systems (sprinkler, S and drip, D) were investigated and compared with furrow irrigation method.
The seven experimental irrigation treatments could be explained as follows:
S100: sprinkler system at full irrigation 100% ETc; S80: sprinkler system at deficit irrigation with 80% ETc; S60: sprinkler system at deficit irrigation with 60% ETc; D100: drip system at full irrigation 100% ETc; D80: drip system at deficit irrigation with80% ETc; D60: drip system at deficit irrigation with 60% ETc and F: furrow irrigation (traditional method).

Irrigation water requirements

Using the CROPWAT 8 software program, water requirements for the soybean crop was calculated based on Penman-Monteith formula [5]as follows:

$$ETc = ETo * K_c \quad (1)$$

where:
ETc: Crop evapotranspiration (mm/day);
ETo: Reference evapotranspiration (mm/day) and;
K_c: The soybean crop's coefficient values.

In furrow treatment, irrigation was suspended when irrigation water reached the field's low end. For all treatments, surface irrigation was applied for two events (pre-planting and subsequent irrigation), and then irrigation practices were applied.
Table 3 shows the mean values of total applied irrigation water for various treatments (m^3/ha).

Table 3. Total applied irrigation water for different treatments under study

Treatment	Applied water, m^3/ha	Treatment	Applied water, m^3/ha
S100	6,826	D80	4,976
S80	5,741	D60	4,083
S60	4,657	F	7,729
D100	5,869		

Source: original values calculated based on the experimental data obtained.

Furrow treatment consumed the highest irrigation water compared to other treatment; surface irrigation is known to have a low efficiency of 40 to 60%, meaning that nearly half of the applied water is lost due to drainage and/or deep percolation.

Full treatments (S100 and D100) saved approximately 11.7 and 24.1% respectively of the irrigation water compared to furrow treatment.

Experimental measurements

To realize the main objective of this study many measurements including soybean yield and its components, soybean water productivity, and soybean seeds quality (physiochemical and physiological properties) were taken into consideration and recorded as following:

Soybean seed yield

The soybean seed yield was calculated by completely harvesting and threshing the experimental plot for each treatment. The collected seeds per plot were weighted and then adjusted to 13% moisture content and converted to kg/ha basis.

Yield components

Random samples of 20 plants from each experimental plot treatment were taken from different locations per central rows for measuring yield components of soybean plants including plant height; cm, number of pods/plant, and 100-seed weight; g.

Water productivity (WP, kg/m^3)

The water productivity explains how each irrigation treatment converts water into a seed yield. It was computed as the ratio of the harvested seed yield (kg/ha) to the total applied irrigation water for each treatment under study according to [26].

$$WP = \frac{Harvested\ seed\ yield, kg/ha.}{Total\ applied\ irrigation\ water, m^3/ha.} \qquad (2)$$

Soybean seed quality

Physiochemical properties

Three samples (25 seeds each) of dried mature soybean seeds from each treatment were prepared for chemical analysis in the Food Technology Research Institute. Protein and fats content; % was determined in the laboratory using the methodology of laboratory protocol.

Physiological properties

Germination ratio (G, %): three replications were carried out with 50 seeds each study treatments (from the produced soybean seeds under different irrigation treatments) which were uniformly distributed on two sheets of paper towel and covered by an additional one. The paper sheets were moistened at the rate of 2.5 times the weight of dry paper and placed in 12 cm diameter Petri dishes. They were kept in paper rolls in the seed germinator at 20ºC of RMC laboratory. Evaluations consisted of counting the number of normal seedlings produced from germinating seeds per day from the fourth day of cultivation until the eighth day. Good seeds have more than 80% germination rate [21]. The obtained results were expressed in percentage of normal seedlings according to the following equation [31].

$$G, \% = \frac{No.of\ germinated\ seeds}{No.of\ sample\ seeds} \times 100 \qquad (3)$$

Length of Seedling shoots and roots: itwas a measurement of the number of plant tissues with supportive functions (roots) compared to the amount of plant tissue with growth functions (shoots).It was performed from the germinated normal seedlings obtained in the germination test on the 8th day after the beginning of the test. The shoot and root lengths of the normal seedlings were measured, using a graduated ruler in mm/seedling [21].

Seedling dry weight (SDW, g/10 seedling): it was conducted with the germinated normal seedlings obtained in the length of Seedling shoots and roots test; these parts (shoots and roots) were cut and separated from the rest of the seed (reserve tissue) and placed in paper bags and dried in an oven at 65°C for 72 hours (or until stabilization of weight) according to [21].

Seed vigor index (V): it is considered an important index of seed quality that determines the potential for rapid and uniform emergence of the seedlings and then grown plants. It was calculated from the results of seed germination ratio and seedling dry weight using the formula as described by [2].

$$V= (G, \%) \times (SDW, g/10\ seedlings) ....(4)$$

Statistical analysis

The treatments were laid out in a randomized complete block design. Analysis of variance (ANOVA) was performed using Co-Stat program for windows. The means for different treatments were compared at a significance level of 5%.

RESULTS AND DISCUSSIONS

Soybean seed yield

The obtained results of soybean seed yield under different treatment cleared that the response of soybean seed yield was varied from treatment to other and there is a significant difference between treatments on soybean seed yield at probability of 0.05 (Fig. 2). In comparison to a seed yield of 3,107 kg/ha for furrow irrigation, the seed yield ranged from 3,443 to 2,224 kg ha^{-1} under sprinkler irrigation treatments and from 3,629 to 2,398 kg ha^{-1} under drip irrigation treatments. Full irrigation treatments S100 and D100 increased seed yield by 10.8 and 16.8 % compared to F treatment, while deficit treatments did not improve seed yield compared to F treatment. Application of deficit irrigation with 60% ETc (S60 and D60) reduced seed yield compared with full irrigation by 35.4 and 33.9% under sprinkler and drip irrigation systems respectively. In general, any water stress imposed on soybean plants results in a significant decrease in seed yield compared to the full irrigation water, given that it is a summer crop where the high temperature exceeded 39°C in July and August (Table 2) caused high transpiration rates, which exposes the plants to severe water stress under deficit irrigation. The highest three seed yield values were 3,629, 3,443, and 3,107 kg ha^{-1} which obtained at D100, S100, and F treatments respectively, while the lowest values were 2,398 and 2,224 kg ha^{-1} which obtained at D60 and S60 treatments respectively. In the same concern, [12] referred to the influence of climate conditions on the management of irrigation water. The highest soybean seed yield obtained at full irrigation [19, 22]. The drip system was superior to the sprinkler system in grain yield under different irrigation regimes; the same result obtained by [24, 29].

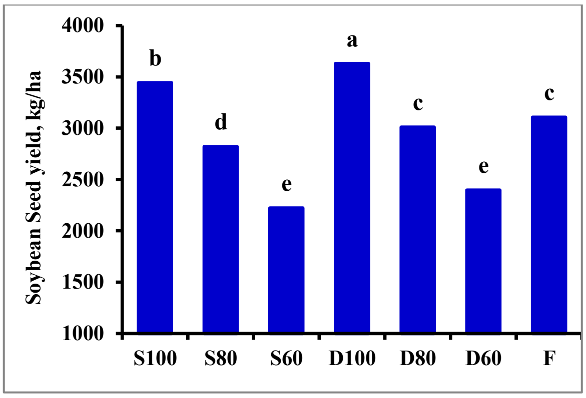

Fig. 2. Soybean seed yield for different treatments
*The same letters indicated not significantly different at 0.05 level.
Source: Own calculation based on experimental data.

Soybean yield components

The obtained results of yield components including plant height; cm, number of pods/plant, and 100-seed weight, g is recorded in Table 4. The results revealed that there is a significant difference between treatments on soybean yield components at probability of 0.05. As the amount of irrigation water reduced, the yield components decreased, that is, the full irrigation treatments (S100 and D100) surpassed the deficit in the yield components; bearing in mind that there is no significant difference between the S100 and D100 treatments in plant height and between S100 and F treatment in number of pods/plant and 100 seeds weight. Drip treatments surpassed corresponding sprinkler treatments. Water stress has a comparable influence on soybean yield components as [25, 9] revealed that subjecting soybean plants to water stress by increasing irrigation intervals or decreasing applied water during the growth stages has a detrimental impact on yield components. The same effect of water stress on the number pods per plant and the weight of 100 seeds observed by [11], but that effect on plant height fluctuated from one cultivar to another. Water deficit stress slowed the plant's height;

this restraint is related closely to the level, duration, and frequency of the irrigation deficit [12]. The highest yield component was achieved by D100 treatments with values of 113 cm plant height, 115 pods/plant, and 14.4 g weight of 100 seeds, reflecting an increase of 6.6, 10.6, and 10.5% respectively compared to F treatment.

Table 4. Soybean seeds yield components (plant height; cm, number of pods/plant, and 100-seed weight, g) for different treatments

Treatments	Plant height, cm	Number of pods /plant	100 seeds weight, g
S100	111 ab	106 b	13.1 b
S80	106 c	88 d	12.37 c
S60	100 e	77 e	11.03 d
D100	113 a	115 a	14.4 a
D80	109 b	97 c	12.4 c
D60	103 d	85 d	12.2 c
F	106 c	104 bc	13.03 b

The same letters in a column indicated not significantly different at 0.05 level
Source: Own calculation based on experimental data.

Water productivity

Water productivity for different treatments is showed in Fig. 3. The results revealed that there is a significant difference in water productivity between the different treatments; the water productivity was significantly influenced by three irrigation systems; deficit irrigation had a significant effect on water productivity in the drip irrigation system whereas this effect did not occur in the sprinkler irrigation system. Compared to sprinkler and surface treatments, drip irrigation improved water productivity since a higher crop was produced with less water. D100 treatment had the highest water productivity with a value of 0.62 kg/m^3, considering that there was no significant difference between it and the D80 treatment, Whereas the F treatment had the lowest water productivity with a value of 0.4 kg/m^3. The findings indicated that the irrigation technique that increases the soybean yield provides the highest water productivity. According to the results obtained, an optimal supply of irrigation water was necessary to produce the highest yield. The results are consistent with the findings reported by [23] that stated increasing water stress decreases water productivity. Improving water productivity under full irrigation recorded by many researchers where the seed yield improved [8]. On the other hand, many researchers stated an increase in water productivity underwater stress [10, 20]. These differences attributed to the soybean cultivars as well as the environmental conditions in which the experiments were carried out [9].

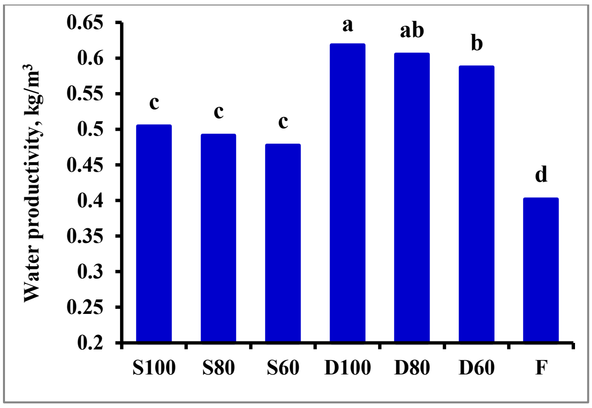

Fig. 3. Water productivity for different treatments
*The same letters indicated not significantly different at 0.05 level
Source: Own calculation based on experimental data.

Soybean seed quality

Physiochemical properties

The obtained results of physiochemical properties including seed protein and fats content for different treatments is listed in Table 5. It could be cleared that there is a significant difference between treatments on protein and fats content at probability of 0.05, there is a positive correlation for protein content and a negative correlation for fat content with the irrigation regime. The significant differences were found in protein and fat content of soybean seeds might be due to the differences in the water amount of irrigation treatments which affecting the growth rate of soybean crop plants. The highest effect on protein content was achieved by S100 and D100 treatments with values of 28.75 and 28.20% respectively, taking into consideration that there was no significant difference between the two treatments; followed by furrow treatment which surpassed deficit treatments in protein content. The lowest effect on protein content was obtained by D60 treatment with a value of 24.55%. The highest effect on fats content was achieved by D60 and S60 treatments with values of 22.91 and 22.63% respectively, taking into consideration that there was no significant difference between the two treatments; followed by D80 treatment with a value of 22.35% which had no significant difference between it and S60 treatment. The lowest effect on fats content was obtained by S100 and D100 treatments with values of 19.65 and 20.49% respectively. Our results were in agreement with the interior results of [32]. Fats content increased as water deficit increased this mean the higher fats content obtained at low soil moisture content. So the relationship between protein content and oil content was negatively correlated. In the same manner an inverse relationship between soybean protein and oil content was found by [27] where as a 1% increase in seed protein content resulted in a 1.5% reduction in oil content.

Table 5. Soybean seeds protein and fats content for different treatments

Treatment	Protein, %	Fats,%
S100	28.75 a	19.65 f
S80	26.15 c	21.65 c
S60	25.25 d	22.63 ab
D100	28.20 a	20.49 e
D80	25.80 cd	22.35 b
D60	24.55 e	22.91 a
F	27.25 b	21.21 d

The same letters in a column indicated not significantly different at 0.05 level
Source: Own calculation based on experimental data.

Physiological properties

Germination ratio: regarding the physiological property of the germination ratio, a significant difference between treatments was found at a probability of 0.05 level. There is a positive correlation between the germination ratio and the irrigation regime, which means that decreasing the applied water during the growing phases decreased the germination ratio of the recovered seeds Fig. 4. D100 and S100 treatments had the most significant effect, with values of 98.3 and 96.7%, respectively, followed by F treatment with a value of 95.8%, considering that there was no statistical difference between D100 and S100 treatments or between S100 and F treatments. The germination ratio was reduced by about 10.2 and 17.3%, respectively, for drip and sprinkler treatments, when the water regime was reduced from 100 to 60% ETc. Our results correspond with the prior findings of [19] through which they reflect that deficit irrigation reduced germination compared to full irrigation. Water deficit stress leads to a decreased accumulation of seed reserves and thereby reduces the germination rate [32]. All treatments provided an appropriate germination rate, not less than 80% according to [21].

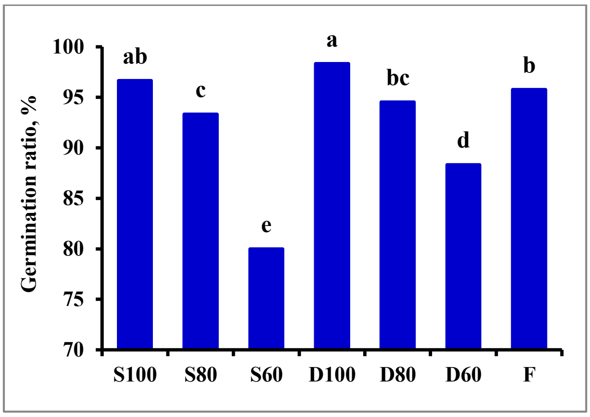

Fig. 4. Soybean seed germination ratio for different treatments
*The same letters indicated not significantly different at 0.05 level
Source: Own calculation based on experimental data.

*Length of Seedling shoots and roots:*the obtained results showed a significant difference in length of seedling shoots and roots between different treatments Fig. 5. Deficit irrigation decreased length of seedling shoots and roots compared to full and furrow irrigation. The highest effect obtained by D100 and S100 treatments with root length of 8.7 and 7.33 mm and shoot length of 1.98 and 1.87 mm respectively; bearing in mind there is no significant difference in root length between S100 and F treatments. The lowest effect obtained by S60 and D60 treatments with root length of 3.58 and 4.66 mm and shoot length of 1.46 and 1.49 mm respectively; taking into account there is no significant difference in shoot length between the two treatments. These results aligned with those published by [7] who observed the negative effect of water stress on shoot length. The length of seedling shoots and roots was negatively impacted when the seedlings came from seeds exposed to water stress [19].

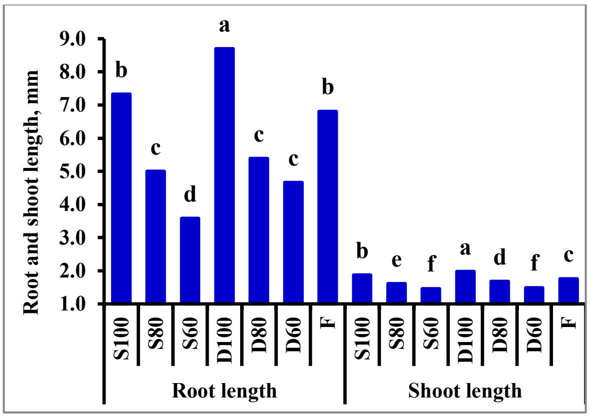

Fig. 5. Length of soybean seedling shoots and roots for different treatments
*The same letters for the same property indicated not significantly different at 0.05 level (ANOVA analysis)
Source: Own calculation based on experimental data.

Seedling dry weight: The soybean seedling dry weight as one of the physiological properties for produced soybean seeds under different irrigation treatments was determined and the obtained results were presented in Fig. 6.

These results indicated a significant difference in soybean seedling dry weight between different treatments at the probability of 0.05, there is a positive correlation between soybean seedling dry weight and the irrigation regime, as the increase in the water regime increased the seedling dry weight. Full irrigation (D100, S100, and F) treatments achieved the highest seedling dry weight with values of 0.69, 0.67, and 0.65 g, considering there was no significant difference between D100 and S100 treatments or between S100 and F treatments. Decreasing the water regime under drip irrigation from 100 to 60% ETc results in a decrement percentage of 23.2% in seedling dry weight compared with 32.8 % decrease under sprinkler irrigation. The lowest seedling dry weight was 0.45 g which obtained by S60 treatment. Similar findings were obtained by [15, 18] in which, water deficit stress is encourage leaf senescence and shortens the duration and weight of seed filling, mainly by restricting photosynthesis and nutrient supply to growing seeds. Water deficit stress causes reductions in seedling dry weight, because of the reduction in shoot and root length [7].

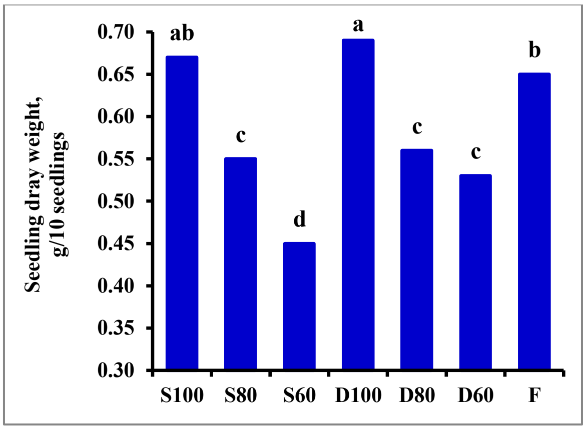

Fig. 6. Soybean seedling dry weight under different irrigation treatments
*The same letters indicated not significantly different at 0.05 level.
Source: Own calculation based on experimental data.

Seed vigor index: The obtained results of seed vigor index referred to significant difference between different treatments at the probability of 0.05 level Fig. 7. There is a positive correlation between vigor index and the irrigation regime, where vigor index increased as the water regime increased.

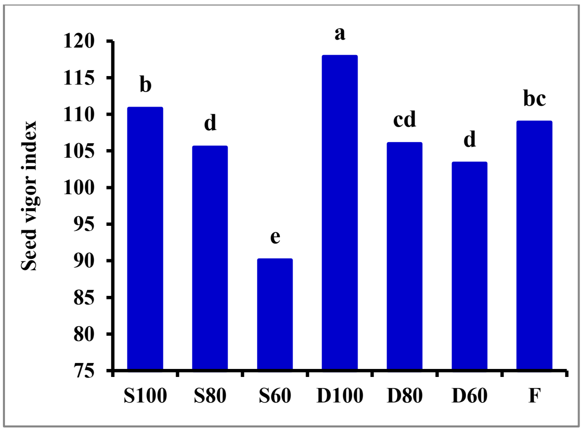

Fig. 7. Soybean seedling dry weight under different irrigation treatments
*The same letters for the same property indicated not significantly different at 0.05 level
Source: Own calculation based on experimental data.

Since the vigor index is related to the germination ratio and the seedling dry weight, the effect of various treatments on the vigor index follows the same pattern. The highest effect obtained by full irrigation treatments (D100, S100, and F) with values of 117.9, 110.8, and 108.9 respectively, considering there was no significant difference betweenS100 and F treatments. Deficit treatments tended to decrease vigor index, decreasing the water regime from 100 to 60% ETc decreased vigor index by about 12.4 and 18.7 % under drip and sprinkler treatments respectively. The lowest effect obtained by S60 treatment with a value of 90.1. The obtained results were harmonious with the preceding results of [33] in which drought stress increased the percentage of small and medium seeds which had lower germination and vigor than large seeds.

CONCLUSIONS

Considering the results obtained, it is feasible to conclude that a gradual increase in the water regime was accompanied by an increase in soybean yield and its components, water productivity, protein content, and physiological properties, whereas fats decreased. Drip irrigation with the full regime had the highest results, followed by sprinkler irrigation with the full regime and then furrow irrigation. Deficit irrigation reduced soybean yield and quality properties. Drip and sprinkler irrigation systems with the full regime are the most appropriate and efficient practices for improving soybean yield and quality.

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