Egyptian Sugar Journal (2022), 19 : 71 - 81
https:// doi.org/ 10.21608 / esugj.2023.181138.1028

RESEARCH ARTICLE

Effect of water deficit irrigation and bio-fertilizers on growth, yield and quality of sugar beet

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Received: 15 January 2023\ Revised: 22 January 2023\ Accepted: 24 January 2023\ Published online: 25 January 2023

Abstract

The beet sugar industry in the tropical and subtropical regions is growing as an important component of sugar production. A field experiment was conducted at Shandaweel Agricultural Research Station, Sohag Governorate, Egypt in the 2019/2020 and 2020/2021 growing seasons to study the effects of the application of bio-fertilizers, i.e., control, vinasses, yeast extract and a mixture of yeast extract and vinasses, on the growth, yield and quality of four sugar beet varieties under water deficit conditions. The analysis of variance (ANOVA) revealed significant effects of Drought stress, bio-fertilizers, varieties and their interactions on chlorophyl contents, root length and diameter, Root yield (RY), Pol %, Recoverable sugar (RS) %, Quality index (Qz) % and Recoverable sugar yield (RSY). Except for Pol% and RS%, drought stress led to a significant reduction in all studied traits. The application of a mixture of vinasses and yeast extract resulted in the highest values of all studied traits. The highest values of most of the studied traits were produced from the monogerm variety Poseidon when treated with a mixture of vinasses and yeast extract under either the optimum irrigation and drought-stressed conditions in both growing seasons. Meanwhile, the lowest values of most of the studied traits were produced from the Lilly variety under either the optimum irrigation and drought-stressed conditions without the application of any bio-fertilizers (the control treatment) in both growing seasons. The results of the present study are of great importance for the sustainable production of sugar beet in Egypt.

Key words: Beta vulgaris; Drought stress; Vinasses; Yeast extract; Bio-fertilization.

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Introduction

Sugar beet (*Beta vulgaris*, L.) has acquired more importance and has become the first source of sugar in Egypt. The total sugar beet cultivated area in Egypt exceeds 600,000 feddan, producing about 20 million Mt of sugar beets with an average sucrose content of about 18% (www.fao.org 2020; Abou-Elwafa et al. 2020). The beet sugar industry in the tropical and subtropical regions, which are mostly developing countries, including Egypt, is growing as an important component of sugar production (Balakrishnan and Selvakumar 2009; Abo-Elwafa et al. 2013). Recent studies indicated that by the year 2030, one-third of the population in developing countries will be exposed to absolute water scarcity, in the sense that they will not have sufficient water resources to meet their agricultural, industrial and environmental demands. With the reduction of water resources, in agriculture, the application of suitable irrigation methods has become a necessity for the protection of water resources and the reduction in contamination of chemicals in groundwater. The most difficult point, in agriculture, is to obtain more yields with less water, which may be possible to increase the water use efficiency of the plant. Ibrahim et al. (2002) showed that the highest values of sugar beet root yield (34.95 and 30.20 t/fed) and sugar yield (5.00 and 3.18 t/ fed) were obtained under drought period of 6 weeks before harvesting in the first and second seasons, respectively in clay soil. Withholding irrigation 40 days before harvest reduces root yield compared to 10, 20 and 30 days before harvest, but increases total and white sugar content (Sohrabi and Heidari 2008). However, the implemented irrigation systems had no significant influence on root yield, sugar content, extractable sugar content, white sugar yield and α-amino N and molasses sugar (Jahedi et al. 2012). Yield and quality traits were significantly affected by deficit irrigation. Root and recoverable sugar yields were significantly reduced in response to deficit irrigation. Sucrose content, quality index (QZ)% and sugar recovery (RS%) were significantly increased in response to deficit irrigation (Abou-Elwafa et al. 2020). Ibrahim (2017) studied three irrigation intervals irrigation every 25, 35 and 45 days found that the highest values of all studied characters resulted from 45 days, while the maximum percentages of TSS, sucrose and purity resulted from 25 days in both seasons. Moreover, delayed irrigation causes significant decreases in sugar beet plant growth parameters (root diameter, root weight, and root yield), while increasing root length compared to the optimal irrigated treatment (Abu-Ellail and El-Mansoub 2020). Abu-Ellail et al. (2021) revealed that elongated irrigation intervals (4 weeks) led to a marked decrease in root diameter, root weight and root yield, while increasing root length, sucrose%, extractable sugar%, and sugar yield in both growing seasons. Chlorophyll a and b and carotenoids were significantly decreased in response to delayed irrigation, while antioxidant enzymes were increased under stress conditions. Furthermore, reducing water supply by up to 30% reduces sucrose %, extractable sugar %, quality index (QZ)%, root and sugar yields (Yassin et al. (2022).

Organic farming strategy is growing rapidly all over the world to conserve human health and the environment, which became at risk because of the use of pesticides and chemical fertilizers. The dangerous effect is because the repeated use of chemical fertilizers destroys soil biota. Foliar application of yeast extract on sugar beet plants caused significant increase in top, root and sugar yields, as well as gave the highest values of sucrose% and purity% (Shahin et al. 2004). The application of algae extract has significantly promoted sucrose content, Na content, quality index%, root yield, recoverable sugar%, recoverable sugar yield and sugar loss yield, and reduced K%, α-amino-N% and sugar loss%. (Galal et al. 2022). Shalaby and El-Nady (2008) concluded that yeast treatment foliar spraying and soil inoculation using concentration of 5 g/l as a biocontrol against fusarium infection of sugar beet plants. Significant differences in root length and diameter (cm), pol%, and sugar recovery% of sugar beet as well as root and recoverable sugar yields (ton/fed) of sugar beet were found between the studied soil application of yeast treatments (zero, 2.0 and 4.0 kg/fed) (Ferweez et al. 2011). Aly et al. (2014) indicated that using yeast extract at the rate of 5 g/liter as a soil application and a foliar spraying on sugar beet plants increased root yield components and root and gross sugar yields/fed in both seasons. Furthermore, the time of yeast extract addition exhibited a significant effect on the vegetative characters, quality properties of beet roots (sugar recovery (%), quality index (%), sugar loss (%), polarization (%), K, Na and α-N) and root and recoverable sugar yields/fed. (Ferweez and Abd El-Monem 2018). Besides, delaying spraying sugar beet plants with yeast extract and boron from 75 up to 90 days from sowing resulted in gradual and significant increases and recorded the highest values of root and top, purity and sucrose percentages, root and sugar yields/fad. The best results of yield components, root juice quality parameters and yields were resulted from foliar spraying sugar beet plants with yeast extract at the rate of 6 g/liter in both seasons (Sarhan et al. 2020).

The addition of 50 m3 vinasses/ha would substitute 55% of N, 72% of P2O5 and 100% of K2O that has to be applied using mineral fertilization to produce a great sugar and cane yields (Rodríguez 2000). The application of vinasses in agriculture added a substantial amount of nutrients, improved the quality of degraded soil, as well as increased crop yields (Vadivel et al. 2014). The application of diluted vinasses (20%) with 25% of the mineral potassium fertilizer required for sandy soil has added substantial amount nutrients, especially K and organic matter, which improved soil chemical properties, nutritional status and crop yield (Osman et al. 2016). Moreover, the foliar application of vinasses at the rate of 4% (v/v) resulted in the lowest values of quality index, recoverable sugar% and recoverable sugar yield (Abofard et al. 2021). The present investigation was carried out to; i) evaluate sugar beet varieties for heat drought stress tolerance in a sub-tropical region in southern Egypt, and ii) study the response of sugar beet varieties to bio fertilizers.

Materials and methods

Plant material and field experiments

The current experiment took place in Shandaweel Agricultural Research Station, Sohag Governorate, Egypt, (lat 24.54o N and long 32.94o E) over two growing seasons 2019/2020 and 2020/2021. The filed experiments were carried out in a randomized complete blocks design (RCBD) using a split-split plot arrangement with three replications in both growing seasons. Two irrigation treatments (optimum irrigation and drought-stressed irrigation) were allocated in the main plots. The four sugar beet varieties, i.e., the monogerm seed varieties Poseidon and Nancy, and the multigerm seed varieties Gazelle and Lilly, were randomly distributed in the sub-plots. Four bio-fertilizer treatments comprise yeast extract and vinasses, i.e., control (without any application), vinasse at 5%, yeast at 5% and vinasse at 5% with yeast at 5%, were allocated to the sub-sub plots. The experimental unit area was 10.5 m2 (1/400 feddan including 5 rows of 0.6 m apart and 3.5 m in length).

At soil preparation, 30 kg of P2O5 in the form of calcium super-phosphate (15% P2O5) was applied. Plants were thinned at the fourth leaf stage (30 days after sowing) to one plant per hill. Nitrogen fertilization was applied in form of urea (46% N) at the rate of 80 kg/fed at two equal doses, the first one after thinning and before irrigation, and the second one month later. Potassium fertilizer in the form of potassium sulfate (48% K2O) was applied as a side-dressing in two equal doses, the first half after thinning (35 days after sowing) and the second half before the third irrigation (70 days after sowing). All agronomical practices were performed as locally recommended for sugar beet cultivation and production.

Soil analysis of the experimental sites

Composite represented soil (0-30 cm) samples were randomly collected from the experimental sites before sowing and after harvest and prepared for both physical and chemical analysis. Samples were air dried, ground and finally were sieved using 2 mm sieves to determine the physical and chemical properties. Mechanical analysis was determined according to the international pipette method (Piper 1950). Soil pH was measured in (1: 2.5) soil: water suspension using HannapH-meter (Jackson 1967). Total soluble salts were determined by measuring the electrical conductivity (ECe) by the electrical conductivity meter (EC meter model consort 410) in saturation extract of soil in dS m-1, United States Salinity Laboratory staff (Richards 1954). Total carbonates were determined using Collins calcimeter (Dexter et al. 1967). Organic matter was determined by Walkley and Blacks method (Hesse 1974). The basic physical and chemical properties of the experimental soils are presented in Table 1.

Table 1. Basic physical and chemical properties of the experimental soil sites in the 2019/2020 and 2020/2021 growing seasons.

		2019/2020	2020/2021
Mechanical analysis	Fine sand	21%	37%
	Coarse	1.46%	1.14%
	Silt	42%	32%
	Clay	35.54%	29.86
Soil texture		Clay loam	Clay loam
	Organic matter (%)	1.16	1.17
	NAvailable(ppm)	25.20	26.32
	$CaCO_3$%	1.37	1.48
	Soluble ions (meq /100g soil (1:5)		
Chemical analysis	CO_3^-	----	----
	$H\,CO_3^-$	0.26	0.33
	Cl^-	0.79	0.90
	$SO_4^=$	1.00	1.15
	Ca^{++}	0.50	0.55
	Mg^{++}	0.24	0.34
	Na^+	1.17	1.33
	K^+	0.14	0.16
	EC, ds/m (1:5)	0.25	0.26
	pH (1:1)	7.3	7.2

Phenotypic evaluation

Photosynthetic pigments (chlorophyll a and b meter) were determined. The SPAD-502 (Konica Minolta Sensing, Inc., Japan) was used to measure leaf chlorophyll readings (SPAD) on attached leaves in the fresh leaves of sugar beet plant at 90 and 120 days after sowing (Minolta, 1989). At harvest (195 days after sowing), plants from the three middle rows of each plot were harvested and cleaned, and roots were weighted to estimate root yield in ton per feddan (4200 m2). Five plants were randomly harvested from the guarded ridges of each plot to determine root length (cm) and diameter (cm). Root samples were then used to measure and calculate the following quality and yield characteristics:

Sucrose percentage (Pol %) was determined using the saccharometer according to the procedure outlined by Le Docte (1927).

Quality index (Qz%), was calculated according to the following formula:

Quality %=Pol%-0.29+0.343 (K+Na)+0.0939(α-amino N)x100/Pol%

Recoverable sugar (RS%), was calculated according to the following formula:

Sugar recovery% =Pol-0.29-0.343(K+Na)-0.094(α-amino N)

Recoverable sugar yield (RSY; ton fed-1).

Statistical analysis

The Proc Mixed of SAS 130 package version 9.2 was used to perform analysis of variance (ANOVA) and Fisher's least significant difference (LSD) of significantly differed treatments.

Results and discussion

Effect of drought stress on growth, yield and quality of sugar beet varieties

Most of the measured and calculated growth, yield and quality traits exhibited significant differences between the two irrigation treatments (Table 2), with superiority was scored for the optimum irrigation treatment in all studied traits in both growing seasons (Tables 3 and 4). However, root length was markedly affected by the studied irrigation regimes only in the first growing season (Table 2). These results may be due to the fact that water is an essential factor for the turgidity of leaf cells, the lengthening of stalk cells as well as photosynthesis process. Indeed, water is the most important food quantitatively for plants. These findings are in agreement with those reported by Sohrabi and Heidari (2008), Abu-Ellail and El-Mansoub (2020) and Yassin et al. (2022). However, it is worth mentioning that the increase in the final output,i.e., recoverable sugar yield can be ascribed to the increase in root yield and recoverable sugar %, which are the main components of the expected recoverable sugar yield. The results showed that quality index (Qz) % was insignificantly influenced by the applied irrigation regimes in both growing seasons, while root length, Pol% and recoverable sugar % were insignificantly affected by the two irrigation regimes in the second growing season (Table 2).

Table 2. Analysis of variance for drought stress, bio-fertilizers, varieties and their interactions on evaluated traits in the 2019/2020 and 2020/2021 growing seasons.

	Chl. at 90 days (Chl. 90)	Chl. at 120 days (Chl. 120)	Root length (RL; cm)	Root diameter (RD; cm)	Root yield (t fed^{-1})	Pol (%)	Recoverable sugar (RS%)	Quality Index (Qz%)	Recoverable sugar yield (RSY; t fed^{-1})
				2019/2020					
Replications (R)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Drought (D)	**	**	**	**	**	**	**	NS	**
Varieties (V)	**	**	**	**	**	**	**	**	**
D × V	**	**	*	**	**	**	**	NS	**
Bio-fertilizers (B)	**	**	**	**	**	**	**	**	**
D × B	*	NS	*	*	NS	**	**	NS	**
V × B	**	**	*	**	NS	**	**	*	**
D × V × B	*	*	**	**	*	**	**	*	**
				2020/2021					
Replications (R)	NS	NS	NS	NS	NS	NS	NS	NS	NS
Drought (D)	**	**	NS	**	**	NS	NS	NS	**
Varieties (V)	**	**	**	**	**	**	**	**	**
D × V	**	NS	**	**	**	NS	NS	NS	**
Bio-fertilizers (B)	**	**	**	**	**	**	**	**	**
D × B	**	**	*	NS	NS	*	NS	NS	NS
V × B	*	**	**	*	NS	**	**	NS	**
D × V × B	**	**	**	NS	NS	**	**	NS	**

*, ** and NS denote significant, highly significant and non-significant effects, respectively.

Data in Table 2 indicated that the evaluated sugar beet varieties differed significantly in their growth, yield and quality traits in both growing seasons. The results showed a marked superiority of the monogerm Poseidon sugar beet variety over the other varieties in all studied traits (Tables 3 and 4). On the contrary, except for quality traits, the Lilly variety recorded the lowest mean values of the studied traits. Concerning the obtained yields, the Poseidon variety exceeded the Nancy, Gazelle and Lilly varieties by 0.77, 5.16 and 8.13%, and 0.97, 5.13 and 7.94% in root yield in the first and second growing seasons, respectively (Table 4). Likewise, the Poseidon variety exceeded the Nancy, Gazelle and Lilly varieties by 4.39, 12.08 and 17.23%, and 2.26, 12.73 and 14.21% in recoverable sugar yield in the first and second growing seasons, respectively (Table 4). These findings are in agreement with those reported by El-Sayed et al. (2018), Alice et al (2019), El-Mansuob et al. (2020) and Yassin et al. (2021).The monogerm sugar beet variety Poseidon produced the highest values of most studied traits when growing under either the optimum irrigation or drought-stressed (60% of IWR) conditions in both growing seasons (Tables 3 and 4). The superiority of a specific sugar beet variety in particular of traits under specific agricultural conditions could be attributed to its genetic make-up which enables it to respond differently to the changed environmental conditions, available nutrients and light interception, and thus affects its photosynthetic capacity and partitioning of photoassimilates. These results are in agreement with previously reported findings (Abu-Ellail et al. 2020; Galal et al. 2022). Meanwhile, the multigerm sugar beet Lilly grown under either the optimum irrigation or drought-stressed conditions produced the lowest values of most studied traits in both growing seasons (Tables 3 and 4).

Table 3. Effect of drought stress on sugar beet growth traits in the 2019/2020 and 2020/2021 growing seasons.

		2019/2020				2020/2021			
		Chl. 90	Chl. 120	RL (cm)	RD (cm)	Chl. 90	Chl. 120	RL (cm)	RD (cm)
Optimum irrigation	Poseidon	53.71	59.34	28.08	9.28	54.95	62.71	29.68	9.29
	Nancy	49.99	57.11	27.83	8.47	52.42	59.36	29.75	8.91
	Gazelle	46.38	47.51	27.18	8.53	51.46	51.53	28.43	9.01
	Lilly	44.21	44.98	26.93	8.33	49.86	48.69	27.75	8.39
	Mean	48.57	52.24	27.51	8.65	52.17	55.57	28.90	8.90
Deficit irrigation	Poseidon	48.58	57.41	29.96	8.94	48.12	58.72	31.88	9.14
	Nancy	50.01	54.21	29.98	8.13	49.43	55.95	30.94	8.70
	Gazelle	44.13	46.18	28.17	7.93	46.36	47.79	28.39	8.58
	Lilly	42.69	44.35	28.10	8.14	47.81	45.35	29.09	8.31
	Mean	46.35	50.54	29.05	8.29	47.93	51.95	30.08	8.68
$LSD_{0.05}$		**1.06**	**0.71**	**0.55**	**0.15**	**1.04**	**NS**	**0.77**	**0.08**
Poseidon		51.14	58.38	29.02	9.11	51.53	60.71	30.77	9.14
Nancy		50.00	55.66	28.91	8.30	50.93	57.65	30.35	8.70
Gazelle		45.25	46.85	27.68	8.23	48.91	49.66	28.41	8.58
Lilly		43.45	44.67	27.52	8.24	48.84	47.02	28.42	8.31
$LSD_{0.05}$		**0.75**	**0.50**	**0.39**	**0.11**	**0.73**	**0.45**	**0.54**	**0.06**

Table 4. Effect of drought stress on the yield and quality of sugar beet in the 2019/2020 and 2020/2021 growing seasons.

		2019/2020					2020/2021				
		RY (t fed^{-1})	Pol (%)	RS%	Qz%	RSY (t fed^{-1})	RY (t fed^{-1})	Pol (%)	RS%	Qz%	RSY (t fed^{-1})
Optimum irrigation	Poseidon	30.85	17.02	14.12	83.68	4.36	32.02	17.04	14.14	83.62	4.54
	Nancy	31.42	16.93	14.07	84.64	4.44	32.58	16.76	13.98	82.84	4.56
	Gazelle	29.17	16.38	13.48	84.10	3.93	30.34	15.93	13.09	81.53	3.97
	Lilly	28.69	16.36	13.41	83.13	3.84	29.76	16.39	13.61	82.94	4.05
	Mean	30.03	16.67	13.77	83.89	4.14	31.18	16.53	13.71	82.73	4.28
Deficit irrigation	Poseidon	28.51	16.67	15.02	84.51	4.29	29.77	17.20	14.44	83.86	4.30
	Nancy	27.47	16.88	14.04	84.53	3.86	28.61	17.01	14.24	83.94	4.08
	Gazelle	27.15	16.61	13.71	84.01	3.72	28.33	15.96	13.31	82.23	3.77
	Lilly	26.19	16.33	13.32	82.56	3.49	27.38	16.35	13.49	82.28	3.70
	Mean	27.33	16.62	14.02	83.90	3.84	28.52	16.63	13.87	83.08	3.96
$LSD_{0.05}$		**0.06**	**0.18**	**0.19**	**NS**	**0.07**	**0.26**	**NS**	**NS**	**NS**	**0.09**
Poseidon		29.68	17.46	14.57	84.09	4.33	30.90	17.12	14.29	83.74	4.42
Nancy		29.45	16.91	14.06	84.58	4.14	30.60	16.89	14.11	83.89	4.32
Gazelle		28.16	16.50	13.59	84.05	3.83	29.33	15.94	13.20	81.88	3.87
Lilly		27.39	16.34	13.37	85.85	3.67	28.57	16.37	13.55	82.61	3.87
$LSD_{0.05}$		**0.20**	**0.13**	**0.14**	**0.62**	**0.05**	**0.19**	**0.16**	**0.12**	**0.50**	**0.06**

Effect of bio-fertilizers on the growth, yield and quality of sugar beet varieties

The analysis of variance (ANOVA) results revealed significant and highly significant effects of bio-fertilizer treatments (vinasses, yeast and vinasses + yeast) on all studied traits either in one or both growing seasons (Table 2). Our results revealed that application of bio-fertilizer, i.e., vinasses, yeast and vinasses + yeast induced the formation of photosynthetic pigments (chlorophyll), and consequently significantly increased root length, diameter, root yield, pol%, RS%, Qz% and RSY in both growing seasons (Tables 5 and 6).

The promoting effect of bio-fertilizers (vinasses and yeast) could be due to the biologically active substance produced by these bio-fertilizers such as auxins, gibberellins, cytokinins, amino acids and vitamins. These results are in accordance with those obtained by Shalaby and El-Nady (2008), Ferweez et al. (2011), Sarhan et al. (2020) and Abofard et al. (2021).

Table 5. Effect of bio-fertilizers on the growth, yield and quality traits of sugar beet varieties in the 2019/2020 and 2020/2021 growing seasons.

		Chl. 90	Chl. 120	RL (cm)	RD (cm)	RY (t fed^{-1})	Pol (%)	RS%	Qz%	RSY (t fed^{-1})
2019/2020	Control	43.79	46.32	25.95	8.15	27.36	16.14	13.10	82.68	3.59
	Vinasse	46.69	51.45	28.09	8.52	28.49	16.76	13.93	84.56	3.97
	Yeast	48.70	52.91	29.06	8.54	29.26	17.03	14.17	84.33	4.15
	Vinasse + Yeast	50.56	54.87	30.03	8.68	29.56	17.27	14.38	84.02	4.25
	$LSD_{0.05}$	0.78	0.19	0.36	0.08	0.21	0.15	0.15	0.54	0.05
2020/2021	Control	46.40	47.19	27.32	8.35	28.49	15.93	12.95	81.18	3.69
	Vinasse	48.77	53.41	29.20	8.58	29.61	16.65	13.92	83.84	4.12
	Yeast	51.01	56.00	30.58	8.78	30.43	16.96	14.20	83.75	4.32
	Vinasse + Yeast	54.02	58.45	30.84	9.03	30.86	16.77	14.08	83.35	4.35
	$LSD_{0.05}$	0.71	0.79	0.49	0.07	0.23	0.12	0.16	0.56	0.06

Except for Qz% in the second growing season and root yield in both growing seasons, the interaction between sugar beet varieties and bio-fertilizers exhibited significant and highly significant effects on all traits in both growing seasons (Table 2). The Poseidon sugar beet variety produced the highest values of chlorophyll a and b at 90 and 120 days, RL and RD, Pol%, RS% and RSY when sprayed with a mixture of Vinasses and Yeast extract (Table 6).

Table 6. Effect of the interaction between varieties and bio-fertilizers on growth, yield and quality traits of sugar beet in the 2019/2020 and 2020/2021 growing seasons.

		Chl. 90	Chl. 120	RL (cm)	RD (cm)	RY (t fed^{-1})	Pol (%)	RS%	Qz%	RSY (t fed^{-1})
				2019/2020						
Poseidon	Control	45.65	49.98	26.93	8.55	28.13	15.91	12.92	81.95	3.64
	Vinasse	51.17	59.85	28.98	9.30	29.45	17.96	15.13	85.22	4.44
	Yeast	52.45	60.35	29.58	9.27	30.47	18.09	15.24	84.85	4.64
	Vinasse + Yeast	55.30	63.32	30.58	9.33	30.67	17.87	14.98	84.35	4.59
Nancy	Control	45.42	48.73	26.75	8.05	28.20	16.52	13.44	83.15	3.79
	Vinasse	48.77	56.13	28.72	8.33	29.12	16.52	13.78	85.23	4.02
	Yeast	52.35	58.27	29.55	8.28	30.11	17.04	14.34	85.37	4.31
	Vinasse + Yeast	53.47	59.50	30.62	8.53	30.35	17.54	14.65	84.58	4.45
Gazelle	Control	42.48	44.03	25.33	7.95	26.71	16.37	13.45	83.83	3.59
	Vinasse	44.07	45.68	26.95	8.35	28.20	16.33	13.41	84.00	3.78
	Yeast	46.02	48.10	28.43	8.27	28.71	16.62	13.67	84.28	3.92
	Vinasse + Yeast	48.45	49.57	29.98	8.35	29.04	16.67	13.84	84.10	4.02
Lilly	Control	41.63	42.53	24.77	8.03	26.41	15.73	12.59	81.77	3.32
	Vinasse	42.75	44.12	27.70	8.08	27.23	16.24	13.39	83.77	3.64
	Yeast	44.00	44.92	28.68	8.35	27.76	16.37	13.44	82.82	3.73
	Vinasse + Yeast	45.42	47.10	28.92	8.48	28.17	17.01	14.04	83.03	3.96
	$LSD_{0.05}$	1.55	0.97	0.73	0.16	NS	0.30	0.31	1.08	0.11
				2020/2021						
Poseidon	Control	47.85	50.32	29.00	8.75	29.34	16.53	13.39	81.57	3.93
	Vinasse	49.58	61.55	30.58	9.02	30.61	16.90	14.15	84.12	4.33
	Yeast	51.50	64.62	31.17	9.23	31.62	17.59	14.80	84.67	4.68
	Vinasse + Yeast	57.20	66.37	32.33	9.55	32.02	17.45	14.81	84.60	4.75
Nancy	Control	47.12	49.52	27.17	8.38	29.33	16.22	13.27	82.75	3.89
	Vinasse	49.77	58.65	29.77	8.57	30.23	17.01	14.30	84.27	4.32
	Yeast	52.20	60.38	31.55	8.85	31.28	17.58	14.75	84.55	4.61
	Vinasse + Yeast	54.62	62.07	32.90	9.00	31.54	16.74	14.13	84.00	4.45
Gazelle	Control	45.23	45.30	27.38	8.17	27.75	15.32	12.37	79.38	3.43
	Vinasse	47.73	47.37	28.33	8.53	29.35	16.03	13.23	82.97	3.88
	Yeast	50.25	52.17	29.77	8.72	29.83	16.32	13.72	82.77	4.09
	Vinasse + Yeast	52.42	53.82	28.15	8.92	30.38	16.10	13.49	82.42	4.10
Lilly	Control	45.42	43.63	25.73	8.08	27.54	15.64	12.77	81.02	3.52
	Vinasse	48.00	46.08	28.13	8.20	28.24	16.67	14.02	84.00	3.96
	Yeast	50.08	46.82	29.83	8.32	28.98	16.37	13.51	83.03	3.91
	Vinasse + Yeast	51.84	51.55	29.98	8.63	29.51	16.80	13.89	82.38	4.10
	$LSD_{0.05}$	**1.41**	**1.57**	**0.98**	**0.13**	**NS**	**0.25**	**0.32**	**NS**	**0.12**

Effect of the interaction between drought stress and bio-fertilizers

Data in Table 2 showed significant interactions between drought stress treatments and bio-fertilizers on all studied traits in the 2019/2020 growing season. The application of Vinasses +Yeast under either the optimum irrigation and drought-stressed conditions revealed the highest values of chlorophyll a and b at 90 and 120 days, RL, RD, RY, Pol%, RS% and RSY. Meanwhile, the lowest values of all studied traits were obtained from the control treatment (without the application of any bio-fertilizers) under either the optimum irrigation and drought-stressed conditions (Table 7). Similar results were obtained in the second growing season, 2, except that there were no significant effects on the root diameter, root yield and recoverable sugar %.

Table 7. Effect of the interaction between drought stress and bio-fertilizer treatments on the growth, yield and quality of sugar beet traits in the 2019/2020 and 2020/2021 growing seasons.

		Chl. 90	Chl. 120	RL (cm)	RD (cm)	RY (t fed^{-1})	Pol (%)	RS%	Qz%	RSY (t fed^{-1})
					2019/2020					
Optimum irrigation	Control	44.18	47.28	25.33	8.28	28.74	16.16	13.14	82.72	3.78
	Vinasse	47.78	52.14	27.50	8.67	29.86	16.59	13.73	84.84	4.10
	Yeast	50.07	53.83	28.01	8.74	30.61	16.76	13.90	84.04	4.26
	Vinasse + Yeast	52.26	55.69	29.18	8.92	30.82	17.16	14.31	84.31	4.41
Deficit irrigation	Control	43.40	45.36	26.56	8.01	25.98	16.10	13.06	82.63	3.39
	Vinasse	45.59	50.75	28.68	8.37	27.13	16.94	14.13	84.63	3.84
	Yeast	47.34	51.99	30.12	8.34	27.91	17.30	14.45	84.62	4.04
	Vinasse + Yeast	49.06	54.05	30.87	8.43	28.30	17.38	14.45	83.73	4.03
	$LSD_{0.05}$	**1.10**	**0.69**	**0.52**	**0.11**	**0.30**	**0.21**	**0.22**	**NS**	**0.08**
					2020/2021					
Optimum irrigation	Control	47.63	48.36	26.63	8.53	29.85	15.89	12.86	81.01	3.84
	Vinasse	50.58	54.77	28.44	8.78	31.03	16.53	13.79	83.71	4.28
	Yeast	53.72	57.80	29.80	9.02	31.79	16.86	14.05	83.61	4.47
	Vinasse + Yeast	56.77	61.37	30.73	9.28	32.03	16.84	14.11	83.61	4.52
Deficit irrigation	Control	45.18	46.02	28.02	8.17	27.13	15.96	13.04	81.35	3.54
	Vinasse	46.97	52.06	29.97	8.38	28.20	16.77	14.05	83.97	3.96
	Yeast	48.30	54.19	31.36	8.54	29.07	17.07	14.34	83.90	4.17
	Vinasse + Yeast	51.27	55.53	30.96	8.78	29.70	16.71	14.04	83.09	4.17
	$LSD_{0.05}$	**1.00**	**1.11**	**0.69**	**NS**	**NS**	**0.17**	**NS**	**NS**	**0.07**

The interaction among drought stress, sugar beet varieties and bio-fertilizer

The interaction of drought stress, varieties and bio-fertilizer treatments revealed significant and highly significant effects on all studied traits in both growing seasons (Table 2). The monogerm variety Poseidon achieved the highest values of most of the studied traits when treated with a mixture of vinasses and yeast extract under either the optimum irrigation and drought-stressed conditions in both growing seasons (Tables 8 and 9). Meanwhile, the lowest values of most of the studied traits were produced from the Lilly variety under either the optimum irrigation and drought-stressed conditions without the application of any bio-fertilizers (the control treatment) in both growing seasons (Tables 8 and 9).

Table 8. Effect of the second-order interactions among the three studied factors on growth, yield and quality traits of sugar beet in the 2019/2020 growing season.

			Chl. 90	Chl. 120	RL (cm)	RD (cm)	RY (t fed^{-1})	Pol (%)	RS%	Qz%	RSY (t fed^{-1})
Optimum irrigation	Poseidon	Control	47.10	51.67	26.00	8.60	29.22	16.16	13.44	82.57	3.90
		Vinasse	55.13	60.27	28.67	9.40	30.67	17.14	14.22	83.97	4.36
		Yeast	57.20	61.17	27.67	9.50	31.54	17.62	14.72	84.13	4.64
		Vinasse + Yeast	57.40	64.27	30.00	9.63	31.98	17.15	14.19	84.03	4.54
	Nancy	Control	44.20	50.37	26.33	8.03	30.25	16.67	13.54	83.30	4.10
		Vinasse	47.93	57.93	27.67	8.27	31.23	16.70	13.96	85.63	4.36
		Yeast	52.70	59.97	28.00	8.53	32.23	16.62	13.90	84.80	4.48
		Vinasse + Yeast	55.13	60.17	29.33	9.03	31.97	17.75	14.88	84.83	4.76
	Gazelle	Control	43.03	44.20	25.00	8.40	28.13	16.25	13.24	83.23	3.73
		Vinasse	44.80	45.83	26.57	8.80	29.08	16.32	13.43	84.67	3.91
		Yeast	48.00	49.37	28.03	8.50	29.60	16.42	13.48	84.10	3.99
		Vinasse + Yeast	49.70	50.63	29.13	8.40	29.88	16.53	13.77	84.40	4.11
	Lilly	Control	42.40	42.90	24.00	8.10	27.37	15.58	12.42	81.77	3.40
		Vinasse	43.27	44.53	27.10	8.20	28.47	16.20	13.32	83.67	3.79
		Yeast	44.37	44.80	28.33	8.43	29.08	16.38	13.50	83.13	3.93
		Vinasse + Yeast	46.80	47.70	27.27	8.60	29.43	17.22	14.40	83.97	4.24
Deficit irrigation	Poseidon	Control	44.20	48.30	27.87	8.50	27.03	15.67	12.49	81.33	3.38
		Vinasse	47.20	59.43	29.30	9.20	28.23	18.78	16.06	86.47	4.52
		Yeast	49.70	59.53	31.50	9.03	29.39	18.55	15.77	85.57	4.64
		Vinasse + Yeast	53.20	62.37	31.17	9.03	29.37	18.60	15.78	84.67	4.63
	Nancy	Control	46.63	47.10	27.17	8.07	26.16	16.38	13.34	83.00	3.49
		Vinasse	49.60	54.33	29.77	8.40	27.00	16.33	13.61	84.83	3.67
		Yeast	52.00	56.57	31.10	8.03	27.99	17.47	14.79	85.93	4.14
		Vinasse + Yeast	51.80	58.83	31.90	8.03	28.73	17.33	14.42	84.33	4.15
	Gazelle	Control	41.93	43.87	25.67	7.50	25.28	16.48	13.66	84.43	3.45
		Vinasse	43.33	45.53	27.33	7.90	27.31	16.35	13.39	83.33	3.66
		Yeast	44.03	46.83	28.83	8.03	27.81	16.82	13.86	84.47	3.86
		Vinasse + Yeast	47.20	48.50	30.83	8.30	28.20	16.80	13.92	83.80	3.93
	Lilly	Control	40.85	42.17	25.53	7.97	25.45	15.88	12.76	81.77	3.25
		Vinasse	42.23	43.70	28.30	7.97	25.96	16.28	13.47	83.87	3.50
		Yeast	43.63	45.03	29.03	8.27	26.45	16.35	13.38	82.50	3.54
		Vinasse + Yeast	44.03	46.50	29.57	8.37	26.91	16.80	13.68	82.10	3.68
		$LSD_{0.05}$	**2.20**	**1.38**	**1.03**	**0.23**	**0.61**	**0.43**	**0.44**	**1.53**	**0.16**

Table 9. Effect of the second-order interactions among the three studied factors on growth, yield and quality traits of sugar beet in the 202/2021 growing season

			Chl. 90	Chl. 120	RL (cm)	RD (cm)	RY (t fed^{-1})	Pol (%)	RS%	Qz%	RSY (t fed^{-1})
Optimum irrigation	Poseidon	Control	49.07	52.60	28.00	8.90	30.35	16.26	13.06	81.53	3.96
		Vinasse	51.63	63.40	29.17	9.20	31.87	16.46	13.69	84.03	4.36
		Yeast	57.17	66.37	30.00	9.37	32.72	17.62	14.74	84.57	4.82
		Vinasse + Yeast	61.93	68.48	31.50	9.70	33.16	17.80	15.06	84.33	5.00
	Nancy	Control	48.37	50.90	27.00	8.50	31.40	16.27	13.31	82.97	4.18
		Vinasse	51.43	60.33	29.00	8.73	32.33	16.79	14.10	84.33	4.56
		Yeast	53.80	61.87	30.67	9.10	33.44	17.40	14.58	84.43	4.88
		Vinasse + Yeast	56.07	64.33	32.33	9.30	33.14	16.60	13.93	83.63	4.62
	Gazelle	Control	46.97	45.83	26.97	8.57	29.14	15.06	12.01	78.40	3.50
		Vinasse	50.00	47.63	27.83	8.97	30.20	16.31	13.46	82.47	4.06
		Yeast	53.03	55.30	29.03	9.17	30.75	16.32	13.56	82.50	4.17
		Vinasse + Yeast	55.83	57.37	29.87	9.33	31.24	16.03	13.32	82.77	4.16
	Lilly	Control	46.10	44.10	24.53	8.13	28.52	15.98	13.06	81.13	3.73
		Vinasse	49.23	47.70	27.77	8.23	29.69	16.57	13.93	84.00	4.14
		Yeast	50.87	47.67	29.50	8.43	30.26	16.09	13.30	82.93	4.02
		Vinasse + Yeast	53.23	55.30	29.20	8.77	30.57	16.92	14.14	83.70	4.32
Deficit irrigation	Poseidon	Control	46.63	48.03	30.00	8.60	28.33	16.80	13.72	81.60	3.89
		Vinasse	47.53	59.70	32.00	8.83	29.35	17.35	14.61	84.20	4.29
		Yeast	45.83	62.87	32.33	9.10	30.53	17.55	14.86	84.77	4.54
		Vinasse + Yeast	52.47	64.27	33.17	9.40	30.88	17.10	14.56	84.87	4.50
	Nancy	Control	45.87	48.13	27.33	8.27	27.25	16.17	13.23	82.53	3.60
		Vinasse	48.10	56.97	30.53	8.40	28.13	17.23	14.49	84.20	4.08
		Yeast	50.60	58.90	32.43	8.60	29.13	17.75	14.92	84.67	4.34
		Vinasse + Yeast	53.17	59.80	33.47	8.70	29.94	16.88	14.32	84.37	4.29
	Gazelle	Control	43.50	44.77	27.80	7.77	26.37	15.58	12.72	80.37	3.36
		Vinasse	45.47	47.10	28.83	8.10	28.50	15.75	12.99	83.47	3.70
		Yeast	47.47	49.03	30.50	8.27	28.91	16.32	13.88	83.03	4.01
		Vinasse + Yeast	49.00	50.27	26.43	8.50	29.52	16.18	13.65	82.07	4.03
	Lilly	Control	44.73	43.17	26.93	8.03	26.57	15.30	12.48	80.90	3.32
		Vinasse	46.77	44.47	28.50	8.17	26.79	16.77	14.12	84.00	3.78
		Yeast	49.30	45.97	30.17	8.20	27.70	16.65	13.72	83.13	3.80
		Vinasse + Yeast	50.45	47.80	30.77	8.50	28.45	16.18	13.64	81.07	3.88
		$LSD_{0.05}$	**1.99**	**2.22**	**1.39**	**0.18**	**NS**	**0.35**	**0.45**	**NS**	**0.16**

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