Assessing the Agronomical and Environmental Impacts of the Application of Green Waste-derived Compost on Sugar Beet Under Deficit Irrigation Conditions

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Research Article

Keywords: Sugar beet, Compost, Drip irrigation, Sprinkler irrigation, Drought

Posted Date: November 10th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-1061371/v1>

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Abstract

In the light of global warming and climate changes, as well as the rapid expansion in sugar beet production in the arid and semi-arid regions, improving sugar beet productivity under deficit irrigation is of great importance. Green waste-derived compost (GWC) is a valuable soil amendment for improving soil organic matter, decreasing waste products and potential pollutants.

The application of 14 ton ha⁻¹ of GWC resulted in the highest root and recoverable sugar yields especially under the well-irrigated conditions under drip irrigation. Although, the impurities% in the beet root juice was increased under deficit irrigation conditions, sugar beet root biofortification and juice quality were significantly improved under drip irrigation in response to the application of 14 ton ha⁻¹ of GWC by increasing sucrose content, QZ% and RS%. The application of GWC under drip irrigation enhanced water use efficiency for root yield (WUE_{RY}) and recoverable sugar yield (WUE_{RSY}), in particular under drip irrigation. The soil chemical and physical properties were significantly improved in response to the application of GWC. The results indicate that the application of GWC is essential for the sustainable sugar beet production and efficient irrigation water use in sandy soils.

Keywords: Sugar beet; Compost; Drip irrigation; Sprinkler irrigation; Drought

Introduction

Production of sugar beet (*Beta vulgaris*, L.) in the arid and semi-arid regions to replace or supplement cane sugar production (Abou-Elwafa et al. 2020; Alotaibi et al. 2021). The main advantages of sugar beet cultivation as a promising sugar crop in these areas is its ability to effectively grow and produce a high sugar content and yield in a short growing period. Besides, in addition to its ability to efficiently grow in the newly reclaimed soils which are common in these areas, sugar beet has a lower irrigation requirement (Abou-Elwafa et al. 2013; Abou-Elwafa et al. 2020; Balakrishnan and Selvakumar 2009).

Drought stress is the most devastated abiotic stress that causes great crop losses worldwide. In the light of global warming and climate changes, where some geographical regions are expected to face frequent severe drought conditions, the development of agronomical practices to improve crop productivity by enabling plants to cope with deficit irrigation conditions is considered as an efficient and cost-effective strategy to overcome drought stress in low-value cropping systems (Abou-Elwafa 2016; Abou-Elwafa and Shehzad 2021; Simova-Stoilova et al. 2016). Therefore, significant efforts have been carried out to minimize the impacts of drought stress on the potential yield and quality of sugar beet (Abou-Elwafa et al. 2020). The occurrence of drought stress early in the growing season exhibits adverse effects on root growth and development of sugar beet. Meanwhile, when drought stress occurred during the late growth stages, the leaf area and number of leaves, and thereby the photosynthetic capacity would be reduced. Furthermore, drought could adversely affect soil microorganisms leading to enhancing the susceptibility of crop plants to drought stress. Microorganisms could promote plant resistance to drought stress through several independent mechanisms, e.g., producing i) the production of polysaccharides that enhances soil structure and water-holding capacity, ii) the production of indoleacetic acid (IAA), deaminase and proline that induce drought tolerance in crop plants, iii) enhancing water circulation through fungal mycelia, and iv) adverse impacts on microbial community structure and abundance, and thereby reducing nutrient availability (Milošević et al. 2012; Nguyen et al. 2018). Furthermore, drought stress would increase the concentrations of Na, K and α -amino-N, which adversely affect sugar recovery from the roots (Putnik-Delić et al. 2013).

Green waste-derived compost (GWC) is a concept for waste recycling and utilization that has been recently become an essential approach for relieving urban green waste and improving urban

polluted soil (Bai et al. 2010; Jones et al. 2009; Vargas-Hernández et al. 2018). The reduction in the soil organic matter due to intensive cropping systems, and the increase in the water pollution caused by the elevated concentration of animal production has made the application of green waste-derived compost (GWC) a valuable approach for improving the soil organic matter while decreasing waste products and potential pollutants (Peigné and Girardin 2004). GWC is known to have a high water-holding capacity and can supply water to plants over time, and thereby increases the water retention of GWC amended soils (Kranz et al. 2020). The application of GWC increases water availability to the plants and relieves the suppressant effect of irrigation deficit on plant productivity (Nguyen et al. 2012).

Environmentally, a major advantage of the application of GWC for soil amendment and improvement beside its higher organic matter content is that it is a low pollutant and costs (Aziablé and Kolédzi 2018; Sánchez-Monedero et al. 2019). Furthermore, when mixed with the soil, GWC releases a large number of microorganisms into the soil and hence increases the soil microbes. These microbes would have a significant impact on the decomposition of organic matter, and the accumulation and bioavailability of soil nutrients leading to an increase in the agricultural productivity to ensure food security to a great extent (Ayilara et al. 2020; Tong et al. 2018). Additionally, the application of GWC in the field has been proven to reduce nitrogen losses, which is essential for sustainable agriculture (Ullah et al. 2020). Moreover, GWC application helps in protecting the underground water from becoming polluted.

The present study aims to i) evaluate the impact of green waste-derived compost (GWC) application on yield and quality of sugar beet under different irrigation systems in sandy soils, and ii) evaluate the effect of GWC application on water-use efficiency and drought tolerance of sugar beet in sandy soils.

Materials and Methods

Plant materials and experiments

A field experiment was conducted at the Nobaria Sugar Industry and Refining Company, El-Beheira, Egypt (L 30,38 4" N, 30o, 13.35, 9" E 28 m asl) during the 2017/2018 and 2018/2019 growing seasons. A commercial sugar beet variety designated Gazelle was used in both growing seasons. Seeds were sown on September 23 and 27 and plants were harvested on April 10 and 13, in the first and second growing seasons, respectively. Seeds were hand sown at 15 cm spaces in a

15 m² plot consists of 5 rows of 5 m in length, with 60 cm between rows. the green waste-derived compost (GWC) was applied as a soil amendment in two doses, i.e., 0 and 14 t ha⁻¹. The chemical analysis of the applied GWC is shown in Suppl. Table 1. Three levels of 60, 80 and 100% of the soil field capacity of either drip and sprinkler irrigation systems were applied. The application of N, P and K and other cultural practices were carried out according to the locally recommended practices for sugar beet production. In brief, super phosphate (15.5% P₂O₅) was applied during soil bed preparation at a rate of 475 kg ha⁻¹. Nitrogen was applied at a rate of 250 kg ha⁻¹ in the form of urea (46.5% N) in two equal doses, i.e., the first one after thinning (4-6 leaves-old plant), and the second one applied 4 weeks later. Potassium sulphate (50% K₂O) was applied 4 weeks after sowing at a rate of 120 kg ha⁻¹.

A tri-replicate split-split plot design arranged in a randomized complete block design (RCBD) was used. The main plots were assigned to the two applied irrigation systems, i.e., drip and sprinkler irrigation. The deficit irrigation treatments allocated to the sup-plot, whereas the sub-sub-plots were assigned to the application of GWC as a soil amendment.

Characterization of experimental soil and irrigation water

Composite representative samples were collected from the surface layer (0-30 cm) of the experimental soil for analyzing the physical and chemical properties before sowing. After harvest, soil samples were collected from each plot and chemically analyzed. After air-drying, soil samples were ground and sieved using 2 mm sieves. The soil pH was estimated in a 1:2.5 of soil to deionized water suspension using a glass electrode (Jackson 1973). A 1:2.5 of soil to water extract was implemented to measure the soil electrical conductivity (EC) using the EC meter (Hesse 1998). Available nitrogen in the soil was extracted using 2 M potassium chloride and micro-kjeldahl method was employed to was determined then nitrogen in the extract (Burt 2004). A 0.5 M sodium bicarbonate solution was used to extract the available soil phosphorus at pH 8.5 and then the spectrophotometer set at a wavelength of. 400 mμ was employed to measure phosphorus (Olsen 1954). Extraction of the available soil potassium was performed according to the ammonium acetate procedure at pH 7.0. Potassium was then measured using flame photometry (Jackson 1973). Estimation of the organic matter (OM) in the soil was performed using the Walkley–Black method (Jackson 1973). The main physical and chemical soil properties are shown in Suppl. Table 2.

Irrigation water used in the experiment was pumped from a well. The chemical analysis of the irrigation water was performed according to the (AOAC 1970) (Suppl. Table 3). Irrigation was performed by drip and sprinkler irrigation systems. The distance between the drippers was 20 cm. Sprinkler irrigation was applied with 4 m and 5 m sprinkler spacing. Irrigation was applied based on measuring the soil field capacity using the undisturbed method essentially described by (Ali 2010). Well-irrigated treatment was irrigated when the soil moisture reached 40% of the field capacity, meanwhile the drought-stressed treatments were irrigated when the soil moisture reached 24 and 30% of the soil field capacity (60 and 75% of the well-irrigated treatment).

Phenotypic evaluation

At harvest, roots from the three guarded rows of each plot were employed to determine root yield, and a representative root sample was used for analysis of juice quality at the Nobaria Sugar Industry and Refining Company laboratory. Sucrose%, Na%, K%, α -amino-N and quality index (QZ) were measured. Impurities and recoverable sugar (RS)% were calculated according to (Reinefield et al. 1974) as follow:

$$\text{Impurities\%} = [0.343 (K + Na) + 0.094 \alpha - \text{amino N} + 0.29]$$

$$\text{Sugar recovery\%} = Pol - 0.29 - 0.343(K + Na) - 0.094(\alpha - \text{amino N})$$

Recoverable sugar yield (RSY) in tons per hectare was also estimated.

Crop water use parameters

Several water parameters were determined including:

i) Reference Evapotranspiration (ET_o): was calculated according to the Penman-Monteith method was used in CROPWAT model (Smith 1992) using the available meteorological data from Wadi El-Natrun meteorological station (Suppl. Table 4) according to the following formula:

$$ET_o = \frac{0.408\Delta(R_n - G) + \gamma \frac{900}{T + 273} u_2 (e_s - e_a)}{\Delta + \gamma(1 + 0.34u_2)}$$

where ET_o = reference evapotranspiration rate (mm d⁻¹), T = average air temperature (°C), and u₂ = wind speed (m s⁻¹) at 2 m above soil surface, R_n= net radiation (MJ m⁻² d⁻¹) G= soil heat flux

(MJ m⁻² d⁻¹), Δ= slope of vapor pressure and temperature curve (kPa °C⁻¹), γ = psychrometric constant (kPa °C⁻¹), and es - ea= vapor pressure deficit (kPa).

ii) The amount of irrigation water was calculated using the following equation (Vermeirn and Gopling 1984):

$$AIW = \frac{ET_o \times KcI}{Ea (1 - LR)}$$

where: ETo = Reference evapotranspiration, Kc = crop coefficient (for sugar beet crop as reported by FAO, Allen et al. 1998), I= irrigation intervals (days), Ea= irrigation efficiency of the drip and sprinkler irrigation systems, and LR = leaching requirements.

The irrigation time for drip irrigation system was estimated in advance by measuring the actual emitter discharges according to the following equation:

$$t = \frac{AIW \times A}{q} \text{ (Ismail 2002)}$$

where t = irrigation time (h), A = wetted area (cm²), and q = emitter discharge (L h⁻¹).

The irrigation time for sprinkler irrigation system was estimated according to the following equation:

$$t = \frac{AIW}{AR} \text{ (Holzapfel et al. 2009)}$$

where AR= application rate (mm h⁻¹)

$$AR = \frac{1000 \times Q}{L_l \times L_s} \text{ (Holzapfel et al. 2009)}$$

where Q = sprinkler discharge (m³ h⁻¹), L_l = distance between lateral (m) L_s = distance between sprinkler (m).

iii) Water use efficiency (WUE) was calculated using the following formula according to (Jensen 1980):

$$WUE = \frac{\text{Crop yield (kg ha}^{-1}\text{)}}{\text{Applied irrigation water (m}^3\text{ ha}^{-1}\text{)}}$$

Statistical analysis

The Proc Mixed model in the SAS 130 package version 9.2 was implemented to carry out the

analysis of variance (ANOVA) and Fisher's least significant difference (LSD) of significantly differed treatments. The linear regression analysis was performed using the SigmaPlot 14 Software (Systat Software, San Jose, CA, USA).

Results

Effect of GWC application and irrigation systems on beet yields under deficit irrigation conditions

The application of the green waste-derived compost (GWC), irrigation systems and deficit irrigation conditions exhibited highly significant effects on water use efficiency (WUE), root and recoverable sugar yields (Table 1). The highest root and recoverable sugar yields (56.50, 9.81 and 55.77, 9.17 ton ha⁻¹, in the first and second growing seasons, respectively) resulted from the application of 14 ton ha⁻¹ of GWC in the two growing seasons (Table 1). Deficit irrigation significantly reduced both root and sugar yields, and the highest values were produced from the 100% irrigation treatment in both growing seasons (Table 1). Moreover, the employment of drip irrigation has significantly improved root and recoverable sugar yields in both growing seasons (Table 1).

The interactions between GWC application, irrigation systems and deficit irrigation treatments exhibited significant and highly significant effects on root and recoverable sugar yields (Table 1). The application of GWC at the rate of 14 ton ha⁻¹ under drip irrigation exhibited the highest root and recoverable sugar yields under the 100% irrigation treatment in both growing seasons (Table 1).

Effect of GWC application and irrigation systems on beet root juice quality under deficit irrigation conditions

The application of GWC exhibited significant effects on beet root juice quality parameters, i.e., sucrose content, quality index (QZ%), recoverable sugar (RS)% and impurities% in the two growing seasons. The application of 14 ton ha⁻¹ of GWC significantly improved beet root biofortification and juice quality by increasing sucrose content, QZ% and RS%. However, the impurities% in the beet root juice was significantly increased in response to the application of GWC in both growing seasons (Table 2). Irrigation systems significantly affect sucrose content, QZ, RS and impurities in the two growing seasons. The QZ and RS were significantly increased

under drip irrigation system, whereas the impurities were reduced in response to the employment of drip irrigation (Table 2). All quality parameters including, sucrose, QZ, RS and impurities differed significantly in response to deficit irrigation in the two growing seasons. The juice quality and impurity parameters, i.e., sucrose%, RS%, QZ% and impurities, were increased in the beet root juice in response to deficit irrigation leading to an overall considerable improvement in the juice quality and root biofortification.

The interaction between GWC application, irrigation systems and water deficit treatments revealed significant effects on all measured quality traits in both growing seasons (Table 2). The highest values of sucrose, QZ and RS (20.76 and 20.51%, 87.20 and 86.60%, and 17.99 and 16.97%, in the first and second growing seasons, respectively) resulted from the application of 14 ton ha⁻¹ of GWC under drip irrigation conditions in combination with the 60% irrigation deficit treatment (Table 2). Meanwhile, the lowest impurity values (2.30 and 2.43, in the first and second growing seasons, respectively) resulted from the employment of sprinkler irrigation without GWC application under the well-irrigated treatment (100% irrigation treatment).

Effect of GWC application and irrigation systems on WUE under deficit irrigation conditions

Water use efficiency calculated for either root yield (WUE_{RY}) or recoverable sugar yield (WUE_{RSY}) were significantly influenced by the application of the green waste-derived compost (GWC), irrigation systems and deficit irrigation conditions (Table 3). The highest WUE_{RY} and WUE_{RSY} values resulted from the application of 14 ton ha⁻¹ of GWC in the two growing seasons (Table 3). WUE was significantly promoted in response to deficit irrigation, and the highest WUE_{RY} and WUE_{RSY} values were produced under the 60% deficit irrigation treatment in both growing seasons (Table 3). Furthermore, the employment of drip irrigation has significantly enhanced both WUE_{RY} and WUE_{RSY} in both growing seasons (Table 3).

WUE_{RY} and WUE_{RSY} were significantly affected by the interactions between GWC application, irrigation systems and deficit irrigation treatments in both growing seasons (Table 3). The highest WUE_{RY} and WUE_{RSY} values (12.72 and 2.27, and 12.91 and 2.18, in the first and second growing seasons, respectively) resulted from the application of 14 ton ha⁻¹ of GWC under drip irrigation conditions in combination with the 60% deficit irrigation treatment (Table 3).

Effect of GWC application on soil chemical properties

The application of GWC significantly increased the available N, P and K in the soil. Similarly, GWC application significantly influenced the contents of calcium (Ca^{2+}), magnesium (Mg^{+}), sodium (Na^{+}), potassium (K^{+}), chlorine (Cl^{-}), bicarbonate (HCO_3^{2-}) and sulfate (SO_4^{-}) ions compared to the control treatment (Table 5).

The interaction between GWC application, irrigation systems and water deficit treatments exhibited significant effects on soluble cations, anions and some macronutrients in the soil after sugar beet harvest (Table 1). The highest values of all soluble cations and anions in the soil after sugar beet harvest were obtained from the application of GWC under drip irrigation conditions in combination with the 60% irrigation deficit treatment (Table 4).

Correlation and regression analyses between GWC application and root quality parameters

Root yields revealed positive highly significant positive correlations with the recoverable sugar yields (RSY). Moreover, sucrose content exhibited highly significant positive correlations with the quality index and the recoverable sugar percentage (RS%). Meanwhile, the correlation between impurity% and quality index (QZ) was highly significant negative (Table 5). Linear regression analysis between the recoverable impurities% and either RS% and RSY revealed negative under either the control treatment or the application of GWC across the two growing seasons fitted to the linear equation. The general linear model regression exhibited negative correlations between impurities% and either RS% or RSY, with a coefficient of determination (R^2) ranged from 0.301-0.836 (Figure 1). However, these negative correlations were more sharp and strong under GWC application as indicated by the R^2 values (Figure 1).

Discussion

In the light of climate changes, global warming, steady population growth, diminishing sugarcane cultivated area and irrigation shortage, promoting sugar beet cultivation in arid and semi-arid regions is the only possible solution to overcome the gap between sugar production and consumption in Egypt (Abo-Elwafa et al. 2006; Aljabri et al. 2021). This necessitates to seek the application of agronomical practices that would improve sugar beet productivity to cope with deficit irrigation conditions. The current study was conducted to evaluate the impact of the application of green waste-derived compost (GWC) on the performance and yielding ability of sugar beet under irrigation deficit conditions.

In the present study, the application of GWC significantly increased sugar content and RS% as well as impurity% which in turn reduced the root juice quality index (QZ). The higher sucrose contents observed in response to the GWC application could be attributed to the elevated plant growth caused by GWC application which led to an increase in the photosynthetic capacities of the plants and the accumulation of more sucrose in the roots (Anli et al. 2020; Pedroza-Sandoval et al. 2017; Rady et al. 2016). Besides, it has been reported that GWC could accelerate the synthesis of photosynthetic pigments not only by supplying essential nutrients but also by changing the physical and chemical properties of the growth media, and hence reducing nutrients leaching and increasing plants water-use efficiency (Elhindi 2012). Meanwhile, the reduction in the RS% as a result of the application of GWC could be attributed to the increase in the impurity levels. The increased impurity and the reduced QZ levels in response to the application of GWC might be due to that the improved metal solubility, mobility and bioavailability in the soils which in the presence of low Ca^{2+} content promotes the absorption of Na^+ , K^+ and α -amino nitrogen and therefore affected membrane permeability to control sodium absorption (Wakeel 2013). This is obvious from the strong negative linear regressions between impurities percentage in the root juice and the recoverable sugar percentage and recoverable sugar yield observed under the application of GWC (Figure 1) support this hypothesis. Besides, soil amendment materials would exhibit contradictory impacts on the mobilization and phytoavailability of elements depending on the type of the applied soil amendment and the element (Shaheen et al. 2017). The application of GWC promoted root yield in both growing seasons, which might be due to that GWC dramatically improves the soil physical and chemical properties and enhances the nutrients solubility and phytoavailability in the soil and thereby promotes sugar beet growth and yield (Businelli et al. 2009; Smolinska 2015). The significant increase in the recoverable sugar yield resulted from the application of GWC is likely due to the high root yields produced from the application.

The significant improvement in the sugar beet water-use efficiency calculated for either root yield (WUE_{RY}) or recoverable sugar yield (WUE_{RSY}) in response to the application of GWC, in particular under irrigation deficit conditions suggest that GWC application has enhanced the water-holding capacity of the soil, and thereby promoted the ability of the plants to face irrigation deficit and to use the applied water more efficiently. The soil water-holding capacity is the most determinant factor for water-use efficiency (WUE) in agriculture. The application of

GWC is a powerful approach to improve soil organic matter, which has been evidently proven to be the key responsible factor for water-holding capacity (Martínez-Blanco et al. 2013; Sayara et al. 2020). In large granules soil such as sandy soils, compost serves as a sponge that holds water, therefore, application of compost to sandy soils is considered an ideal promising natural fertilizing approach to overcome the adverse consequences of climate change and water shortage, in particular in arid and semi-arid regions (Adugna 2016; Garcia et al. 2017; Skuras and Psaltopoulos 2012). The drastically elevated contents of soluble cations, anions and some macronutrients in the soil after harvest in response to the application of GWC is consistent with the role of compost application in the soil in increasing metal availability by the formation of soluble metal-organic complexes, and hence increasing the plant uptake efficiency (Businelli et al. 2009; Rady et al. 2016; Smolinska 2015; Zheljazkov and Warman 2004).

In conclusion, the current study root yield was increased in response to the application of green waste-derived compost (GWC), which could be ascribed to the great improvement in the physical and chemical properties of the soil, and nutrients mobilization and uptake. The improved metal solubility, mobility and bioavailability in the soil caused by the application of GWC further enhanced sugar content, RS% and impurity%, however, the root juice quality index (QZ) was reduced. The improved water-holding capacity of the soil in response to the application of GWC has increased water-use efficiency, in particular under irrigation deficit conditions.

Ethics approval and consent to participate

Not applicable.

Consent to Participate

Not applicable.

Funding

Not applicable.

Authors' contributions

SFA conceived the study, analyzed the data, and wrote the manuscript. FMI performed the experiment and collected the data. MA, SA, RNA and JC helped in data analysis and presentation. All authors read and approved the final version of the manuscript.

Availability of data and material

All data are included within the manuscript and its supplementary material.

Competing interests

The authors declare that there is no conflict of interest.

Acknowledgments

The authors are thankful to Taif University Research Supporting Project number (TURSP-2020/315), Taif University, Taif, Saudi Arabia, for providing the financial support and research facilities.

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Table 1. Effect of the application of green waste-derived compost (GWC) and water deficit on root (RY) and recoverable sugar (RSY) yields under three levels of drip (D) and sprinkler (S) irrigation systems in a sandy soil in 2017/2018 and 2018/2019 growing seasons.

Growing season	Water deficit	Irrigation system	RY (t ha ⁻¹)			RSY (t ha ⁻¹)		
			GWC-0	GWC-14	Mean	GWC-0	GWC-14	Mean
2017/2018	60%	S	47.58	49.66	48.62	8.07	8.59	8.33
		D	48.33	50.55	49.44	8.25	9.04	8.65
	80%	S	53.66	58.33	56.00	8.89	9.92	9.41
		D	54.98	59.35	57.17	9.35	10.33	9.84
	100%	S	55.88	59.75	57.82	9.45	10.21	9.83
		D	58.67	61.35	60.01	10.09	10.77	10.43
	Mean		53.18	56.50	54.84	9.02	9.81	9.42
	LSD _{0.05}		2.60	2.71	2.15	0.54	0.41	0.50
2018/2019	60%	S	47.63	48.96	48.30	7.70	8.00	7.85
		D	48.87	51.33	50.10	8.04	8.66	8.35
	80%	S	52.36	54.77	53.57	8.24	8.75	8.50
		D	53.74	55.67	54.71	8.86	9.35	9.11
	100%	S	57.98	61.22	59.60	9.29	9.92	9.61
		D	59.73	62.66	61.20	9.62	10.36	9.99
	Mean		53.39	55.77	54.58	8.63	9.17	8.90
	LSD _{0.05}		0.38	1.89	2.30	0.63	0.46	0.51

464 **Table 2.** Effect the application of green waste-derived compost (GWC) application and water deficit on quality of the sugar beet
 465 variety Gazelle under three levels of drip (D) and sprinkler (S) irrigation systems in a sandy soil in 2017/2018 and 2018/2019 growing
 466 seasons.

Growing season	Water deficit	Irrigation system	Sucrose (%)			Impurities (%)			QZ (%)			RS (%)		
			GWC-0	GWC-14	Mean	GWC-0	GWC-14	Mean	GWC-0	GWC-14	Mean	GWC-0	GWC-14	Mean
2017/2018	60%	S	19.87	20.03	19.95	2.69	2.84	2.77	84.50	82.20	83.35	16.97	17.29	17.13
		D	20.31	20.76	20.54	2.52	2.72	2.62	85.40	83.60	84.50	17.07	17.99	17.53
	80%	S	20.17	20.36	20.27	2.49	2.72	2.61	84.90	84.30	84.60	16.55	17.01	16.78
		D	20.05	20.37	20.21	2.41	2.56	2.49	85.15	84.60	84.88	17.00	17.41	17.21
	100%	S	20.03	20.14	20.29	2.48	2.66	2.57	85.20	84.10	84.65	16.91	17.09	17.00
		D	20.03	20.48	20.26	2.30	2.53	2.42	85.10	84.80	84.95	17.20	17.46	17.33
	Mean		20.16	20.57	20.37	2.49	2.74	2.62	85.04	83.93	84.49	16.95	17.38	17.17
	LSD _{0.05}		0.21	0.24	0.22	0.10	0.10	0.11	0.49	0.58	0.47	0.24	0.32	0.27
2018/2019	60%	S	19.62	20.07	19.85	2.78	2.91	2.85	84.30	83.60	83.95	16.17	16.34	16.26
		D	19.82	20.51	20.17	2.61	2.77	2.69	86.60	83.70	85.15	16.46	16.97	16.72
	80%	S	19.13	19.65	19.39	2.67	2.79	2.73	84.50	82.60	83.55	15.73	15.98	15.86
		D	19.31	20.09	19.70	2.45	2.67	2.56	85.20	82.80	84.00	16.48	16.30	16.39
	100%	S	19.21	19.71	19.46	2.55	2.74	2.65	84.20	82.70	83.45	16.03	16.20	16.12
		D	19.58	19.77	19.68	2.43	2.56	2.50	85.10	83.10	84.10	16.11	16.54	16.33
	Mean		19.45	19.93	19.69	2.58	2.74	2.66	84.98	83.08	84.03	16.16	16.46	16.31
	LSD _{0.05}		0.31	0.40	0.31	0.08	0.13	0.10	0.51	0.62	0.60	0.22	0.25	0.31

Table 3. Effect of green waste-derived compost (GWC) on water use efficiency (WUE) for root yield (RY) and recoverable sugar yield (RSY) of sugar beet under three levels of drip (D) and sprinkler (S) irrigation systems in a sandy soil in 2017/2018 and 2018/2019 growing seasons.

Growing season	Water deficit	Irrigation system	WUE _{RY} (kg m ⁻³)			WUE _{RSY} (kg m ⁻³)		
			GWC-0	GWC-14	Mean	GWC-0	GWC-14	Mean
2017/2018	60%	S	9.53	9.94	9.74	1.62	1.72	1.67
		D	12.16	12.72	12.44	2.08	2.27	2.18
	80%	S	8.42	9.15	8.79	1.39	1.56	1.48
		D	10.82	11.68	11.25	1.84	2.03	1.94
	100%	S	7.21	7.71	7.46	1.22	1.32	1.27
		D	9.48	9.91	9.70	1.63	1.74	1.69
	Mean		9.60	10.19	9.89	1.63	1.77	1.70
	LSD _{0.05}		0.19	0.18	0.19	0.06	0.09	0.08
2018/2019	60%	S	9.54	9.80	9.67	1.54	1.69	1.62
		D	12.29	12.91	12.60	2.02	2.18	2.10
	80%	S	8.22	8.59	8.41	1.29	1.38	1.34
		D	10.57	10.95	10.76	1.73	1.85	1.79
	100%	S	7.48	7.90	7.69	1.20	1.29	1.25
		D	9.65	10.12	9.89	1.55	1.68	1.62
	Mean			9.63	10.05	9.84	1.56	1.68
	LSD _{0.05}		0.24	0.24	0.20	0.22	0.08	0.11

473 **Figure legends**

474 **Figure 1.** Response of recoverable sugar percentages (RS%) and recoverable sugar yield (RSY)
475 to the root impurities in the beet root juice under the control treatment (A and B: without GWC
476 application) and the application of GWC (C and D) fitted by the linear-linear model over the
477 2017/2018 and 2018/2019 growing seasons.

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Figures

Figure 1

Response of recoverable sugar percentages (RS%) and recoverable sugar yield (RSY) to the root impurities in the beet root juice under the control treatment (A and B: without GWC application) and the application of GWC (C and D) fitted by the linear-linear model over the 2017/2018 and 2018/2019 growing seasons.

Supplementary Files

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