Recycling of Beet Sugar Byproducts and Wastes Enhances Sugar Beet Productivity and Salt Redistribution in Saline Soils

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Research Article

Keywords: Filter cake, Molasses, Soil amendments, Soil salinity, Sugar beet, Sugar yield

Posted Date: March 2nd, 2021

DOI: https://doi.org/10.21203/rs.3.rs-256440/v1

Version of Record: A version of this preprint was published at Environmental Science and Pollution Research on April 20th, 2021. See the published version at https://doi.org/10.1007/s11356-021-13860-3.

Abstract

Soil salinity adversely affects the growth, yield, and quality parameters of sugar beet, leading to a reduction in root and sugar yields. Improving the physical and chemical properties of salt-affected soils is essential for sustainable cultivation and sugar beet production. A field experiment was conducted at t the Delta Sugar Company Research Farm, El-Hamool, Kafr El- Sheikh, Egypt to evaluate the response of sugar beet to the application of beet sugar filter cake treated with sulfuric and phosphoric acid-treated, phosphogypsum (PG), desaline, humic acid and molasses under saline soil conditions. The application of treated filter cake enhanced root length, diameter and leaf area. The application of molasses enhanced root length, diameter and leaf area as well. Application of molasses increased sugar content and root yield. The application of either treated filter cake or molasses produced the highest recoverable sugar yield. Linear regression analysis revealed that the root yield, quality index and recoverable sugar yield increased in response to the increased availability of either Ca^{2+} and K content in the soil which increases in response to the application of soil amendments and molasses. The application of treated beet sugar filter cake and molasses increased the calcium, magnesium and potassium availability in the soil. Treated filter cake is a promising organic soil amendment that enhanced the yield by 29%, and yield-related traits of sugar beet by improving the physical and chemical properties of the soil.

Introduction

The increasing production of sugar beet (*Beta vulgaris*, L.) in the tropical and subtropical regions is an important part of the beet sugar industry. Its salt tolerance is the main advantage of sugar beet and makes it a promising sugar crop in these regions (Kaffka &Hembree 2004).It has efficient growth, high sugar production, and completes its lifecycle in a short growing season in the newly reclaimed soils dominating these regions which are mostly characterized as saline soils (Abo-Elwafa et al. 2013, Abo-Elwafa et al. 2006, Abou-Elwafa et al. 2020, Balakrishnan &Selvakumar 2009). In Egypt, salt affected soils represent 9.1 % of the total area and 30 % of the cultivated area (FAO 2005). Sugar beet is one of the most salt-tolerant crops available; however, seed germination and seedling establishment is adversely affected by salt levels in soils.

An increase of EC in the electroconductivity (EC) level of soils above 6 dSm-1 drastically reduces the emergence rate and dry weight of sugar beet seedlings (Kaffka &Hembree 2004). In addition, increasing soil salinity reduces germination rate, seedling length, seedling fresh weight and seedling vigor of all sugar beet varieties under investigation. Furthermore, soil salinity results in osmotic and oxidative stress, ion toxicity, nutritional imbalances, decreased cell division activity, changes in metabolic processes, such as photosynthesis and respiration, and disruption of plant membranes (Hasanuzzaman et al. 2014).

The quality of sugar beet also decreases with increasing the soil salt concentration (Dadkhah 2008, Wu et al. 2003). Sodium uptake by sugar beet increases the presence of impurities in the root juice, thereby reducing the quality. (Draycott &Christenson 2003) report an increase in total soluble solids (TSS) in beet root juice in response to increasing salt concentration. Therefore, improving the physical and chemical properties of salt-affected soils is essential for sustainable cultivation and production of sugar beet in Egypt. Different approaches have been reported for successful, low cost and effective remediation of soil salinity including calcium chemical compounds, sulfur compounds and organic compounds (Cha-um &Kirdmanee 2011, Ding et al. 2020, Jesus et al. 2015). Gypsum application improves the growth of fodder beet in saline soils and improves the physical-chemical properties of the soil (Ahmed et al. 2015). The application of humic acid substances improves the physical-chemical properties of the soil, including aggregation, aeration, permeability, water-holding capacity, and micronutrient availability (Tan 2003). Foliar application of humic acid improved sucrose%, extractable sugar%, purity and root and sugar yields, and reduced sugar loss to molasses in sugar beet (El-Hassanin et al. 2016). Application of sugar beet molasses, the residual syrup from sugar beet processing, to the soil surface also mitigates the adverse effects of soil salinity (El-Tokhy et al. 2019).

Large quantities of sugar beet industrial byproducts are produced from beet sugar factories (for example, in Egypt 170,000 tons of filter cake are annually produced), resulting in environmental pollution. Filter cake, a byproduct from the use of the ground limestone in juice clarification, is an important byproduct that contains organic matter and has a relatively high Cation-exchange capacity (CEC) value (Ippolito et al. 2013). Filter cake is a rich source of phosphorus and organic matter that has a high moisture content and has been widely used as a complete or partial substitute for mineral fertilizers in crop plants including sugar beet (Basha 2011, Ossom &Dlamini 2012, Ossom &Rhykerd 2007, Ossom 2010). Filter cake is utilized as fertilizer in several countries, including Brazil, India, Australia, Cuba, Pakistan, Taiwan, South Africa, and Argentina (Prado et al. 2013). Application of filter cake enriched by rock phosphate, with or without, biofertilizer in organic onion culture resulted in improved plant nutrition, growth, crop production and export quality (Basha 2011). However, the high pH value of Egyptian soils (7.9–8.2; Messiha et al., 2007) excludes filter cake as a fertilizer or soil acidity neutralizer. Therefore, modification of the chemical properties of the filter cake is a prerequisite for its application as a soil amendment or fertilizer in Egypt.

The hypothesis of this study is that because of the high calcium content of beet sugar byproducts (treated filter cake and molasses) they can efficiently improve the chemical and physical properties of the soil and enhance crop productivity. The current study was aimed to; i) convert the filter cake from an unwanted byproduct to a useful soil amendment, ii) evaluate the application of the treated filter cake as a soil amendment, and iii) compare the effect of treated filter cake to other soil amendments on yield, yield-related traits and sugar beet quality under saline soil conditions.

Material And Methods

Plant material and field experiment

A field experiment was conducted at the Delta Sugar Company Research Farm, El-Hamool, Kafr El- Sheikh, Egypt during the 2017/2018 and 2018/2019 growing seasons. Two commercial sugar beet cultivars designated Top and Bleno were used in the first and second growing seasons, respectively. Seeds were sown on October 22 in both growing seasons and plants were harvested on April 15. Seeds were hand sown at 15-20 cm spaces in a 15 m^2 plot that consisted of 5 rows of 5 m in length, with a distance of 60 cm between rows. Recommended rates of N, P and K and all other cultural practices were performed according to locally recommended practices for sugar beet production. In brief, single super phosphate (15.5% P_2O_5) at a rate of 474 kg ha^{-1} was applied during soil bed preparation. Nitrogen was applied in the form of urea (46.5% N) at a rate of 214 kg N ha^{-1} in two equal doses, i.e., the first one after thinning with the second irrigation, and the second one applied with the third irrigation. Potassium sulfate (50% K_2O) at a rate of 119 kg K_2O ha^{-1} was added with the first irrigation. Furrow irrigation was applied. The same treatments were applied to the same plots in both growing seasons.

The main plots were assigned to six soil amendment treatments, i.e., control treatment (without amendments), 2.5 ton ha^{-1} of treated filter cake, 5 ton ha^{-1} of treated filter cake, 2.5 ton ha^{-1} of phosphogypsum (PG), 10 L ha^{-1} of desaline, and 10 L ha^{-1} of humic acid. The sub-plots were assigned to three molasses (a viscous byproduct resulting from refining sugar beets or sugarcane into sugar) treatments, i.e., control treatment (without molasses application), 62.5 L ha^{-1} of molasses and 125 L ha^{-1} of molasses applied to the soil surface before sowing.

Characterization and production of applied soil amendments

The four soil amendments were phosphogypsum (PG) which is a byproduct of the processing of phosphate rock in industries producing phosphate fertilizers such as superphosphate and phosphoric acid; desaline which is a desalination commercial product that contains 5% N, 5% P, 5% K, 5% Ca, 2.5% Mg, 5.5% humic acid, 0.5% salicylic acid, 20% Citric acid and 5% polysaccharides; humic acid and treated filter cake. To convert the filter cake from a deleterious byproduct to a useful soil amendment material, the filter cake was treated with a mixture of 1.5:1 of sulfuric and phosphoric acids (180 ml of sulfuric acid and 120 ml of phosphoric acid) kg^{-1} of filter cake. All four types of soil amendments were applied to the soil surface before sowing. Chemical characterization of raw filter cake, filter cake treated with a mixture of sulfuric and phosphoric acids and molasses are presented in Suppl. Tables 1, 2 and 3.

Phenotypic evaluation

At harvest, three growth and yield-related traits, i.e., leaf area, root length and root diameter were measured as an average of seven selected plants from each plot. A representative root sample from each plot was collected for quality analysis by measuring sucrose%, sodium (Na)%, potassium (K)% and α-amino-N in root juice using the venma, Automation BV AnalyzerIIG-16-12-99, 9716JP/ Groningen/Holland according to the procedure used by Delta Sugar Company, as described by le-Docte (1927) and Brown and lilliland (1964). The results were calculated as mmol 100 g^{-1} beet. Quality index, Sucrose losses%, recoverable sugar% and recoverable sugar yield were calculated using the following equations according to Reinefield et al., (1975):

$$\text{Quality \%} = Pol\% - 0.29 + 0.343\ (K + Na) + 0.0939(\alpha - amino\ N)x100/Pol\%$$

$$\text{Recoverable sugar yield} = \text{Root yield}\ \times Recoverable\ sugar\%$$

Soil analysis

For analysis of the physical and chemical properties of the soil after harvest, composite represented soil samples were collected from the surface layer (0 - 30 cm) of the experimental soil before sowing. After harvest, soil samples were collected from each plot. Soil samples were air-dried, ground and sieved using 2 mm sieves. The soil pH was measured in a 1:2.5 of soil to deionized water suspension using a glass electrode (Jackson 1973). The electrical conductivity (EC) of the soil was determined in a 1:2.5 of soil to water extract using the EC meter (Hesse 1998). Available soil nitrogen was extracted using 2 M potassium chloride and then nitrogen in the extract was measured using micro-kjeldahl method (Burt 2004). Available phosphorus in the soil was extracted using 0.5 M sodium bicarbonate solution at pH 8.5 (Olsen &1916- 1954) and phosphorus was determined using the spectrophotometer set at a wavelength of 550 nm. The ammonium acetate procedure at pH 7.0 was implemented to extract the extractable potassium. Potassium was then measured using flame photometry (Jackson 1973). The organic matter (OM) in the soil was measured using the Walkley–Black method (Jackson 1973). The main physical and chemical soil properties are shown in Suppl. Table 4.

Experimental design and Statistical analysis

Experiments were designed in a four-replicates randomized complete block design (RCBD) in a split-plot design. 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. The SigmaPlot 14 Software (Systat Software, San Jose, CA, USA) was implemented to perform linear regression.

Results

Effect of the application **of beet sugar byproducts as soil amendments** on beet **yield and yield-related traits**

The interaction between soil amendments and molasses exhibited significant effects on root length, diameter, leaf area and root in the first growing season, whereas in the second growing season the significant effects were only observed on leaf area and root yield (Table 1). The highest root length and leaf area values in the first growing season (27.50 cm and 181.75 cm2) were obtained from the application of 2.5 ton ha-1 of treated filter cake and 62.5 L ha-1 of molasses. Similarly, the application of treated filter cake in combination with either molasses resulted in the highest leaf area and root yield in both growing seasons (Table 2).

Table 1
Analysis of variance of evaluated traits in the two growing seasons 2017/2018 and 2018/2019.

Growing season	Source of Variance	Root length	Root diameter	Leaf area	Root yield	Pol	Na	K	α-amino N	QZ	RSY
2017/2018	Soil amendments (SA)	**	**	**	**	**	**	**	**	**	**
	Molasses (M)	NS	**	NS	NS	**	**	**	**	**	**
	SA×M	**	**	**	**	**	**	**	**	**	**
2018/2019	Soil amendments (SA)	*	*	**	**	**	NS	**	*	**	**
	Molasses (M)	NS	NS	**	**	**	**	**	NS	**	**
	SA×M	**	**	**	**	**	**	**	**	**	**

NS, *, ** indicate not significant, significant at P ≥ 0.05, and at P ≥ 0.01, respectively.

Table 2
Effect of soil amendments and molasses application on root length, diameter and leaf area in the 2017/2018 and 2018/2019 growing seasons.

Growing season		2017/2018				2018/2019			
Treatment		Root length (cm)	Root diameter (cm)	Leaf area (cm^2)	Root yield (t ha^{-1})	Root length (cm)	Root diameter (cm)	Leaf area (cm^2)	Root yield (t ha^{-1})
Without filter cake	Control	18.45d	9.27e	124.00de	45.33gh	22.77	12.92	139.50f	54.25g
	Molasses (62.5 L ha^{-1})	20.32cd	10.33cde	157.75abc	50.75efg	23.67	13.3	159.50ef	57.63f
	Molasses (125 L ha^{-1})	20.22cd	9.95de	146.50b-e	48.48fgh	23.8	13.7	168.00def	59.58ef
	Mean	19.67	9.85 b	142.75	48.20	23.42	13.31	155.67	57.15
Treated filter cake (2.5 t ha^{-1})	Control	27.25a	12.02ab	172.75ab	62.58c	25.38	15.2	235.50b	77.63a
	Molasses (62.5 L ha^{-1})	27.50a	11.97ab	181.75a	68.00a	25.2	14.72	244.00ab	71.00b
	Molasses (125 L ha^{-1})	24.68b	11.92ab	150.75bcd	62.75ab	25.3	14.47	253.00a	72.13b
	Mean	26.47	11.97	168.42	65.28	25.29	14.80	230.83	73.66
Treated filter cake (5 t ha^{-1})	Control	27.00a	12.60ab	173.75ab	64.80ab	24.9	13.77	198.50cd	65.63d
	Molasses (62.5 L ha^{-1})	24.77b	11.95ab	156.25abc	62.18ab	25.15	14.32	205.00bc	67.38cd
	Molasses (125 L ha^{-1})	25.27b	12.20ab	158.25abc	63.15ab	25.37	14.65	209.00bc	71.08bc
	Mean	25.68	12.25	152.75	63.33	25.14	14.25	204.17	68.03
Phosphogypsum	Control	21.12c	10.00de	139.50cde	52.25ef	23.8	13.25	166.75def	59.25ef
	Molasses (62.5 L ha^{-1})	18.57d	9.77de	120.25e	43.20h	24.57	13.47	232.25abc	63.75de
	Molasses (125 L ha^{-1})	21.08c	9.90de	141.75cde	48.48fgh	24.67	14.05	238.50b	65.25d
	Mean	20.26	9.89	133.83	47.98	24.35	13.59	212.50	62.57
Desaline	Control	21.10c	11.20bc	140.00cde	54.88de	24.85	14.07	239.25b	66.88d
	Molasses (62.5 L ha^{-1})	23.82b	12.65a	156.50abc	58.38bcd	24.92	14.1	228.25bc	63.63de
	Molasses (125 L ha^{-1})	24.00b	12.20ab	153.25abc	58.38bcd	25.12	14.32	228.75c	67.13cd

Different letters in the same column indicate significant differences between treatments.

Growing season		2017/2018				2018/2019			
	Mean	22.97	10.02	149.92	57.20	24.97	13.17	218.75	65.88
Humic acid	Control	21.15c	10.70cd	142.00cde	56.20cde	23.8	13.3	166.75	59.25ef
	Molasses (62.5 L ha^{-1})	21.90c	12.57ab	152.75abc	58.75bcd	23.87	13.35	171.75def	58.88ef
	Molasses (125 L ha^{-1})	24.65b	12.35ab	163.25abc	61.73abc	24.65	13.9	175.75de	64.88d
	Mean	22.57	11.08	152.67	58.90	24.11	13.52	171.42	61.00
Without molasses		22.68	10.97	148.67	56.43	24.25	13.75	191.04	63.83
Molasses (62.5 L ha-1)		22.82	11.54	154.21	56.85	24.57	13.88	203.46	63.70
Molasses (125 L ha-1)		23.32	11.42	152.29	57.13	24.82	14.18	212.17	66.09
Different letters in the same column indicate significant differences between treatments.									

The application of treated filter cake enhanced root length and diameter as well as leaf area and root yield in both growing seasons (Table 2). The highest values of root length and diameter in both growing seasons (26.47 and 25.68 cm in the first growing season and 25.29 and 25.14 cm in the second one) were obtained from the application of 2.5 and 5 tons ha^{-1} of treated filter cake, respectively. Likewise, the application of 2.5 ton ha^{-1} of treated filter cake resulted in the largest root diameter in both growing seasons (11.97 cm in the first growing season and 14.80 cm in the second one) (Table 2). The largest leaf area (168.42 and 230.83 cm2) was obtained from the application of 2.5 ton ha^{-1} of treated filter cake in the first and second growing seasons, respectively. The highest root yields (65.28 and 73.66 tons ha^{-1} in the first and second growing seasons, respectively) were obtained from the application of 2.5 ton ha^{-1} of treated filter cake (Table 2).

Molasses application enhanced only root diameter in the first growing seasons with the highest root diameter resulted from the application of either 62.5 or 125 L ha^{-1} of molasses. Meanwhile, in the second growing season, the application of molasses affected leaf area and root yield, and the application of molasses at 125 L ha^{-1} produced the highest leaf area and root yield (Table 2).

Effect of treated **filter cake and molasses** on **beet juice quality parameters**

The main factors of sugar beet juice quality are sucrose content (Pol%), Na%, K% and α-amino N% which affect juice quality and thereby the extractable sugar and losses. Soil amendments exhibited highly significant effects on sucrose content, Na%, K% and α-α-amino N% in both growing seasons (Table 1). The highest sugar content (19.91% and 19.38%) in the first and second growing seasons, respectively, resulted from the control treatment. Meanwhile, the application of treated filter cake resulted in the lowest values of sugar content in both growing seasons. Application of soil amendments, treated filter cake, in particular, reduced Na%, K% and α-amino-N in root juice in both growing seasons. The application of 2.5 ton ha^{-1} of treated filter cake produced the lowest values of Na%, K% and α-amino N% in both growing seasons (Table 3).

Table 3
Effect of soil amendments and molasses application on sucrose%, Na%, K% and α-amino N in the 2017/2018 and 2018/2019 growing seasons.

Growing season		**2017/2018**				**2018/2019**			
Treatment		Pol (%)	Na (%)	K (%)	α-amino N (%)	Pol (%)	Na (%)	K (%)	α-amino N (%)
Without filter cake	Control	19.73ab	4.59ab	8.50ab	2.75a	19.47abc	2.01ab	5.18a-d	5.18
	Molasses (62.5 L ha^{-1})	20.09a	4.57ab	8.64a	2.47b	19.50ab	2.16ab	4.98b-e	4.98
	Molasses (125 L ha^{-1})	19.90ab	4.67a	8.51ab	2.48bc	19.16abc	1.76abc	5.23abc	5.98
	Mean	19.91	4.61	8.55	2.57	19.38	1.98	5.13	1.42
Treated filter cake (2.5 t ha^{-1})	Control	18.36e	3.51gh	7.41ghi	1.87ef	18.92bc	2.04ab	5.05a-e	5.05
	Molasses (62.5 L ha^{-1})	18.69cde	3.68fg	7.30hi	2.15d	18.22d	1.84ab	5.37a	5.37
	Molasses (125 L ha^{-1})	18.66cde	3.14i	7.20i	1.77f	18.33d	1.69bc	5.08a-e	5.08
	Mean	18.57	3.14	7.30	1.93	18.49	1.86	5.17	1.40
Treated filter cake (5 t ha^{-1})	Control	18.62de	4.52ab	7.75efg	2.32cd	19.09abc	2.23a	5.23abc	5.23
	Molasses (62.5 L ha^{-1})	18.54de	4.38a-d	8.25bc	2.40bc	18.85bc	1.81abc	4.99b-e	4.99
	Molasses (125 L ha^{-1})	18.97cde	4.09c-f	7.57f-i	1.75f	18.77c	1.87ab	4.85de	4.85
	Mean	18.71	4.23	7.86	2.16	18.91	1.97	5.02	1.34
Phosphogypsum	Control	18.19e	4.08c-f	7.60fgh	2.32cd	19.36abc	1.99ab	5.12a-e	5.12
	Molasses (62.5 L ha^{-1})	19.33bcd	3.99def	7.91def	1.91ef	19.15abc	1.73bc	4.88cde	4.88
	Molasses (125 L ha^{-1})	19.47abc	4.33a-d	7.77efg	1.78f	19.64a	1.41c	5.27ab	5.27
	Mean	18.99	4.13	7.76	2.00	19.02	1.86	5.09	1.44
Desaline	Control	19.46abc	4.22b-e	7.53ghi	2.00e	19.11abc	2.10ab	5.29ab	5.29
	Molasses (62.5 L ha^{-1})	18.86cde	4.46abc	8.54ab	2.57b	19.05abc	1.99ab	5.12a-e	5.12
	Molasses (125 L ha^{-1})	18.91cde	4.06c-f	7.99cde	2.48bc	19.11abc	2.13ab	5.32ab	5.32
	Mean	18.08	4.24	8.02	2.35	19.09	2.07	5.25	1.62
Humic acid	Control	18.61de	3.27hi	7.27hi	2.42bc	19.44abc	2.02ab	5.14a-d	5.14
	Molasses (62.5 L ha^{-1})	19.02cde	4.00def	8.38ab	2.30cd	19.37abc	2.06ab	4.77e	4.77
	Molasses (125 L ha^{-1})	18.94cde	3.80efg	8.20bc	2.25cd	18.89bc	1.76abc	5.10a-e	5.1

Different letters in the same column indicate significant differences between treatments.

Growing season	2017/2018				2018/2019			
Mean	18.85	3.69	7.95	2.32	19.24	1.95	5.11	1.56
Without molasses	18.83	4.03	7.68	2.28	19.03	2.06	5.17	1.49
Molasses (62.5 L ha-1)	19.09	4.18	8.17	2.30	19.22	1.93	5.02	1.41
Molasses (125 L ha-1)	19.14	4.02	7.87	2.09	19.99	1.77	5.14	1.43
Different letters in the same column indicate significant differences between treatments.								

Likewise, molasses application revealed significant effects on all measured juice quality parameters. The highest sucrose content resulted from the application of molasses at the rate of either 25 or 125 L ha^{-1} in both growing seasons (Table 3), indicating the efficiency of beet sugar byproducts as soil amendments in enhancing sucrose accumulation. The application of 125 L ha^{-1} of molasses resulted in the lowest values of measured impurities (Na%, K% and α-amino N%). The interaction between soil amendments applied and molasses treatments significantly affected sucrose content, Na%, K% and α-amino N% in both growing seasons.

The lowest values of Na%, K% and α-amino-N% in both growing seasons were obtained from the application of 2.5 ton ha^{-1} of treated filter cake in combination with 125 L ha^{-1} of molasses (Table 3).

Effect of the **application of treated filter cake and molasses** on **beet quality and sugar yield**

The interaction between soil amendments and molasses application exhibited significant effects on the quality index and recoverable sugar yield in both growing seasons (Table 1). The highest quality index (77.72 and 86.15%) and recoverable sugar yield (9.85 and 12.00 ton ha-1) in the first and second growing seasons, respectively, were produced from the application of 2.5 ton ha-1 of treated filter cake in combination with 125 L ha-1 of molasses (Table 4).

Table 4
Effect of soil amendments and molasses application on quality index (QZ)% and recoverable sugar yield (RSY) in the 2017/2018 and 2018/2019 growing seasons.

Growing season		**2017/2018**		**2018/2019**	
Treatment		QZ (%)	RSY (t ha-1)	QZ (%)	RSY (t ha-1)
Without filter cake	Control	74.32g	6.65i	84.90cde	8.98g
	Molasses (62.5 L ha^{-1})	75.47ef	7.07g	85.25bcd	9.58f
	Molasses (125 L ha^{-1})	74.32g	7.18h	85.70b	9.78f
	Mean	74.71	7.18	85.28	9.42
Treated filter cake (2.5 t ha^{-1})	Control	77.22abc	9.23b	84.73def	11.68b
	Molasses (62.5 L ha^{-1})	77.37ab	9.08bc	84.10g	10.83cd
	Molasses (125 L ha^{-1})	77.72a	9.85a	86.15a	12.00a
	Mean	77.44	9.33	86.66	11.50
Treated filter cake (5 t ha^{-1})	Control	75.52ef	9.10bc	84.20fg	10.55de
	Molasses (62.5 L ha^{-1})	76.10de	8.78d	85.40bc	10.80cd
	Molasses (125 L ha^{-1})	77.10cd	9.23b	85.48bc	11.40b
	Mean	76.24	9.00	85.03	10.93
Phosphogypsum	Control	74.80fg	7.10h	85.12b-e	9.75f
	Molasses (62.5 L ha^{-1})	76.32b-e	6.38j	85.20b	10.53de
	Molasses (125 L ha^{-1})	77.20abc	7.18h	85.25bcs	10.92c
	Mean	76.11	6.68	85.52	10.41
Desaline	Control	75.78ef	8.08f	84.67def	10.84cd
	Molasses (62.5 L ha^{-1})	75.40ef	8.30ef	85.00cde	10.46e
	Molasses (125 L ha^{-1})	75.37ef	8.30ef	84.53efg	10.82cd
	Mean	75.52	8.23	84.73	10.73
Humic acid	Control	77.10a-d	8.05f	85.10b-e	9.78f
	Molasses (62.5 L ha^{-1})	75.73ef	8.45e	85.73b	9.71f
	Molasses (125 L ha^{-1})	76.17cde	8.90cd	85.22bcd	10.33e
	Mean	76.33	8.47	85.35	10.00
Without molasses		75.79	8.03	84.79	10.83
Molasses (62.5 L ha-1)		76.07	8.23	85.28	10.33
Molasses (125 L ha-1)		76.32	8.30	85.22	10.78
Different letters in the same column indicate significant differences between treatments.					

Soil amendments application increased sugar beet quality index (Qz) and recoverable sugar yield (RSY) in both growing seasons (Table 4). The highest value of the quality index (77.44 and 86.66%) and recoverable sugar yield (9.33 and 11.50 ton ha^{-1}) in the first and second growing seasons, respectively, were produced from the application of 2.5 ton ha^{-1} of treated filter. The application of molasses at a rate of 125 L ha^{-1} increased the quality index (76.32 and 85.22%) and recoverable sugar yield (3.32 and 4.32.5 ton ha^{-1}) in the first and second growing seasons, respectively (Table 4).

Effect of beet **sugar byproducts soil amendments** on **soil chemical properties**

The interaction between soil amendments and molasses on soluble cations, anions and some macronutrients in the soil after sugar beet harvest exhibited significant effects (Table 1). The highest Ca2 + content was obtained from the interaction between the application of 5 ton ha-1 of treated filter cake in combination with 62.5 L ha-1. The highest Na + content (46.53 meq L-1) and the lowest Na + content (11.0 meq L-1) were recorded from the application of 5 ton ha-1 of treated filter cake in combination with 62.5 L ha-1 of molasses (Table 5).

Table 5
Effect of soil amendments and molasses application on soluble cations, anions and available N, P and K at the experimental soil after sugar beet harvest over the 2017/2018 and 2018/2019 growing seasons.

Treatment		Ca^{2+}	Mg^{+}	Na^{+}	K^{+}	Cl^{-}	HCO_3^{-}	SO_4^{-2}	N	P	K
		(meq L^{-1})						(ppm)			
Without filter cake	Control	21.12	12.90	44.77	1.13	47.10	4.62	28.19	29.55	3.60	395.85
	Molasses (62.5 L ha^{-1})	23.00	12.40	44.58	1.06	46.90	4.53	29.60	35.40	4.05	377.80
	Molasses (125 L ha^{-1})	24.27	13.61	42.14	1.57	43.96	4.71	32.92	41.30	4.95	403.20
	Mean	22.80	12.97	43.93	1.08	45.98	4.62	30.24	35.42	4.20	410.29
Treated filter cake (2.5 t ha^{-1})	Control	36.51	14.62	24.92	1.26	30.95	6.53	39.84	32.50	8.55	480.70
	Molasses (62.5 L ha^{-1})	36.91	15.33	23.65	1.35	28.13	7.24	41.62	35.40	9.00	480.70
	Molasses (125 L ha^{-1})	37.06	16.77	21.42	1.45	25.99	7.17	43.55	35.40	12.00	458.65
	Mean	36.83	15.57	23.33	1.35	28.36	6.98	41.67	34.44	9.85	473.35
Treated filter cake (5 t ha^{-1})	Control	42.26	15.72	15.79	1.07	21.27	9.50	44.06	29.55	13.80	459.45
	Molasses (62.5 L ha^{-1})	46.07	13.73	15.27	1.12	20.67	10.11	45.40	35.40	13.35	482.50
	Molasses (125 L ha^{-1})	42.91	18.42	14.47	1.15	21.29	9.77	45.89	35.40	12.90	452.50
	Mean	43.74	15.96	15.18	1.11	21.08	9.79	45.12	33.45	13.35	464.82
Phosphogypsum	Control	34.20	17.55	22.25	1.52	28.15	4.71	42.65	29.55	9.90	448.20
	Molasses (62.5 L ha^{-1})	35.14	14.66	23.56	1.15	28.75	4.52	41.24	29.55	11.25	464.95
	Molasses (125 L ha^{-1})	35.09	14.53	22.73	1.26	28.50	4.77	40.04	32.50	13.35	438.30
	Mean	34.81	15.58	22.85	1.30	28.52	4.66	41.36	30.53	11.50	450.48
Desaline	Control	27.38	13.95	37.70	1.00	39.04	4.52	36.47	26.55	6.30	389.95
	Molasses (62.5 L ha^{-1})	28.98	13.16	37.02	1.26	38.44	4.61	40.66	29.55	3.45	465.85
	Molasses (125 L ha^{-1})	28.10	14.23	35.50	1.41	41.83	4.69	32.73	29.55	11.40	428.15
	Mean	28.15	13.78	36.74	1.22	39.77	4.60	36.62	28.46	6.74	427.98
Humic acid	Control	28.33	13.37	35.38	1.13	40.58	4.53	33.12	29.55	4.95	400.30
	Molasses (62.5 L ha^{-1})	24.43	13.24	40.00	1.10	39.04	4.62	35.11	32.50	5.25	417.60
	Molasses (125 L ha^{-1})	23.30	13.37	40.68	1.16	39.95	4.71	33.85	32.50	6.75	405.35
	Mean	25.36	13.33	38.69	1.13	39.86	4.62	34.01	31.52	5.56	407.75

Treatment	Ca^{2+}	Mg^{+}	Na^{+}	K^{+}	Cl^{-}	HCO^{-}_{3}	$SO_4{}^{-}{}_{2}$	N	P	K
Without filter cake	31.64	14.69	30.13	1.18	33.68	5.74	37.39	29.54	7.85	412.88
Molasses (62.5 L ha^{-1})	32.42	13.75	30.68	1.17	33.66	5.94	38.94	23.97	7.73	448.24
Molasses (125 L ha^{-1})	31.78	15.16	29.49	1.33	33.59	5.54	38.16	34.44	10.23	431.03

The application of soil amendments decreased the available N. However, the application of treated filter cake increased the available P and K. The application of molasses increased the available N, P and K in the soil after sugar beet harvest. All applied soil amendments significantly influenced the contents of calcium (Ca^{2+}), magnesium (Mg^{+}), potassium (K^{+}), bicarbonate ($HCO_3{}^{2-}$) and sulfate ($SO^{-}{}_{4}$) ions compared to the control treatment. Application of treated filter cake at the rate of either 2.5 or 5 ton ha^{-1} exhibited the highest impact on increasing the average contents of Ca^{2+}, Mg^{+}, K^{+}, $HCO_3{}^{2-}$ and $SO^{-}{}_{4}$ and reducing the average contents of Na^{+} and Cl^{-} (Table 5). The application of molasses did not exhibit any clear effect on the content of these elements or nutrients (Table 5).

Juice quality parameters, root and sugar yields correlation to soil amendments application

Linear regression analysis between either Ca^{2+} and K content in the soil, that are enriched in the applied soil amendments, and root yield, sucrose content, quality index and recoverable sugar yield across the two growing seasons fitted to the linear equation. The general linear model regression revealed positive correlations between Ca^{2+} and K and either revealed root yield, sucrose content, quality index and recoverable sugar yield with a coefficient of determination (R^2) ranged between 0.302–0.758 (Figs. 1 and 2). These results indicate that root yield, quality index and recoverable sugar yield were increased in response to the increase of either Ca^{2+} and K content in the soil which is increased in response to the application of soil amendments and molasses. While sucrose content was reduced as either Ca^{2+} and K content in the soil was increased.

Discussion

The application of treated filter cake and/or molasses enhanced root length and diameter, leaf area and root yield in both growing seasons. The action of treated filter cake in enhancing root length and diameter, leaf area and root yield could be attributed to its high calcium content that dramatically improves soil physical and chemical properties and hence enhances sugar beet growth (Abejehu 2015, Moda et al. 2015, Prado et al. 2013). Furthermore, the linear relationship between soil Ca^{2+} content and average root yield (Fig. 1) indicates that Ca^{2+} plays a crucial role in enhancing the growth and development of sugar beet. The effect of molasses on yield and yield-related traits could be the result of polysaccharides in molasses that enhance plant growth and soil microorganisms which release some plant regulators that increase the plant growth and yield (Honma et al., 2012).

The application of soil amendments increased sugar content, and the highest values resulted from molasses application at the rate of 125 L ha^{-1}. This may be due to the presence of high calcium content in the treated filter cake which is antagonized with sodium ions and enhance soil aggregation which improves soil properties, plant growth and yield (Miller &Smith 2010). This was emphasized by the positive linear regression detected between soil Ca^{2+} content and sucrose content. Besides, sugar percentage is decreased in response to increasing root yield by the dilution effect (Shaheen et al. 2017). Furthermore, the high sugar content produced from the control treatment could be ascribed to that the partitioning of photoassimilates was in favor of increasing sugar content in the control treatment where root yield had been reduced (Hosseini et al. 2019, Koch et al. 2019, Lemoine et al. 2013, Sowiński 1999). Furthermore, the reduction in Na, K and α-amino-N contents in root juice in response to the application of soil amendments, in particular treated filter cake, might be due to that the presence of an excess of Ca^{2+} ions that led to a reduction in the absorption of Na^{+} and K^{+} and therefore affected membrane permeability to control sodium absorption (Wakeel 2013). This is obvious from the linear regression relationships between Ca^{2+} and both Na and K content in the roots. Na and K contents in the roots were decreased in response to increasing Ca^{2+} content in the soil (Fig. 3). Soil amendments can cause contradictory effects on elements mobilization and phytoavailability depending on the type of elements and amendments (Shaheen et al. 2017).

Soil amendments application, in particular treated filter cake as well as molasses, enhanced beet roots quality and recoverable sugar yield (RSY). These results might be due to the high root yields produced from the application of treated filter cake. The high content of calcium in the applied amendments affects the bioavailability and immobilization of Na and K by reducing soil pH and increasing the availability of exchangeable soil Ca via the antagonistic actions. The antagonistic actions have multiple effects on improving the soil physical and chemical properties, maintaining soil quality and enhancing plant growth and consequently yield (Bhuiyan et al. 2015, David 2007, Hasanuzzaman et al. 2014). The positive linear regression between Ca^{2+} content in the soil and the averages of quality index and recoverable sugar yield (Fig. 1) and Na and K contents in the roots support this hypothesis.

Analysis of the chemical composition of the experimental soil after harvest revealed that all the applied soil amendments increased calcium, magnesium and potassium contents in the soil compared to the control treatment. These results indicate that soil amendments can cause antagonistic effects on the element mobilization and phytoavailability depending on the type of element and amendment. The impact of the application (1%) of several low-cost amendments and environmental wastes on the mobilization, immobilization availability and uptake of some nutrients in the long-term sewage effluent irrigated sandy soils. The increased contents of Ca^{2+} and Mg^{2+} in the experimental soil in response to the application of treated filter cake is due to the high content of both elements in the filter cake. However, the reduction in Na^{+} and Cl^{-} contents is due to the increase in Ca^{2+}, $HCO^{2-}{}_{3}$ and $SO^{-}{}_{4}$ contents. Likewise, the high P content observed in the soil after harvest is due to high P content in the filter cake, whereas the high soil content of K could be due to the high K content in the applied molasses (Hussain et al. 2013, Kemi Idowu &Adote Aduayi 2007, Miller &Smith 2010, Momayezi et al. 2010).

In conclusion, the current study represents treated beet sugar filter cake as an efficient soil amendment that has great potential for use in conservation agriculture. Treated filter cake can be applied as a soil amendment and substitute for inorganic phosphorus and potassium fertilizers. Treated filter cake is a promising organic soil amendment that greatly enhances sugar beet yield and yield-related traits through improving the physical and chemical properties of the soil. Furthermore, the application of treated beet sugar filter cake as a soil amendment can improve sugar beet quality through improving juice quality by reducing impurities content that retard sugar extraction.

Declarations

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 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 gratefully acknowledge the staff of the Delta Sugar Company Research Farm, Kafr El-Sheikh, Egypt for excellent technical assistance. The authors deeply thanks Dr. Imad Eujayl, USDA-ARS- NWISRL, Kimberly, ID, USA, for his critical revision and language editing.

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Figures

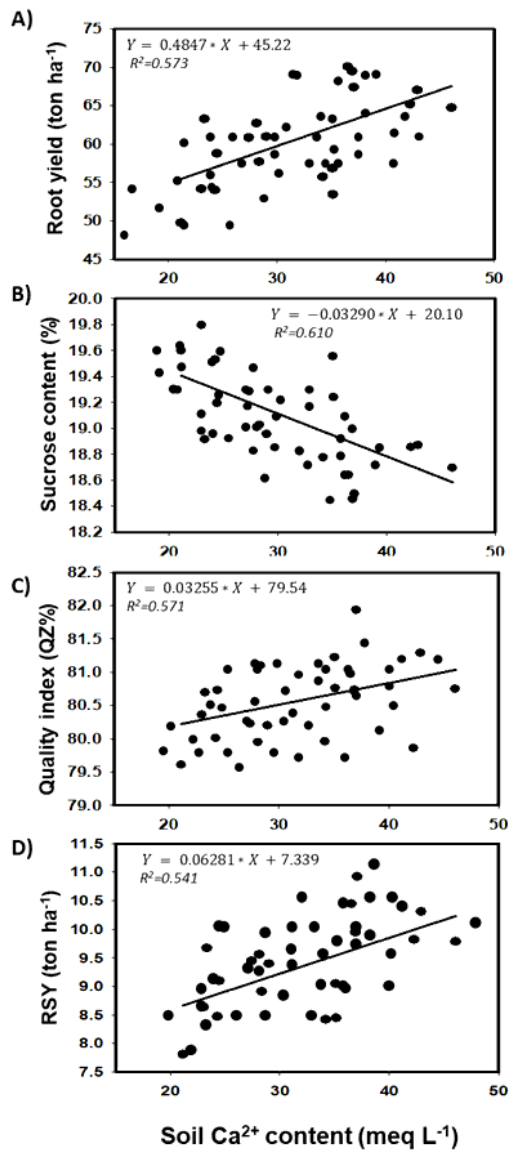

Figure 1

Response of root yield (A), sucrose content (B), quality index (C) and recoverable sugar yield (RSY; D) to soil Ca2+ content fitted by the linear-linear model under the 2017/2018 and 2018/2019 growing seasons.

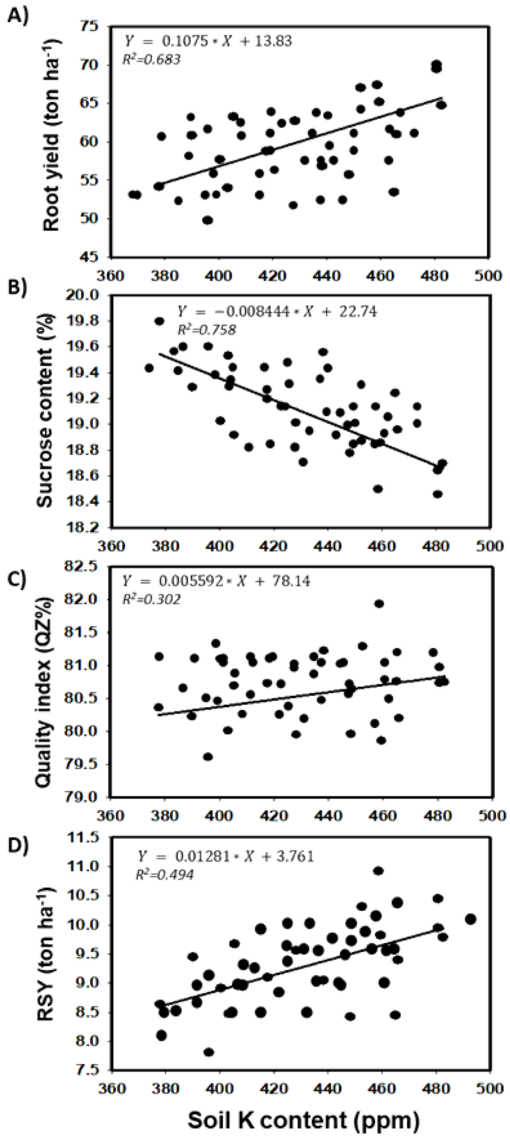

Figure 2

Regression analysis between root yield (A), sucrose content (B), quality index (C) and recoverable sugar yield (RSY; D), and soil K content fitted by the linear-linear model under the 2017/2018 and 2018/2019 growing seasons.

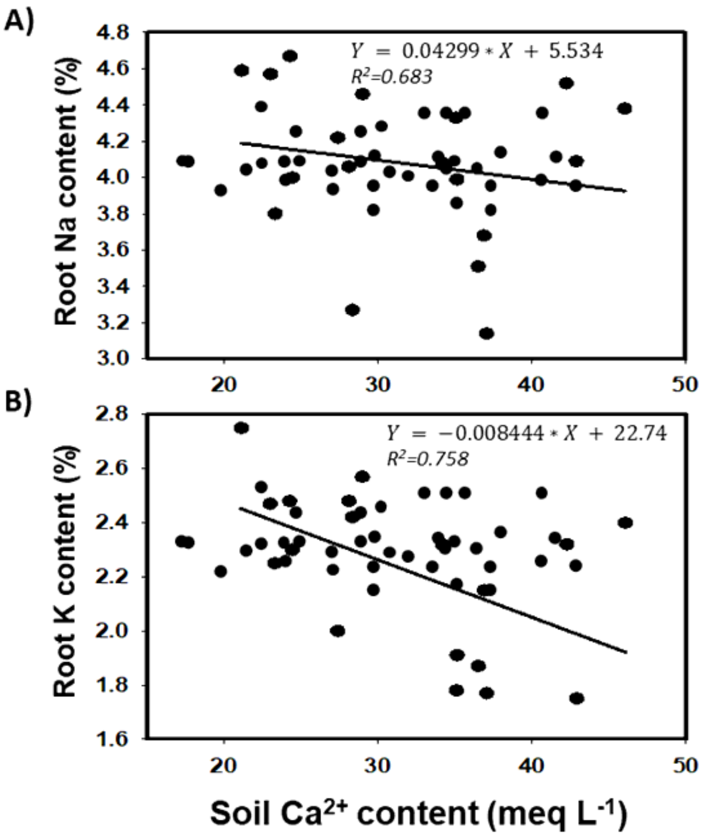

Figure 3

Response of root Na content (A) and root K content (B) to soil Ca2+ content fitted by the linear-linear model under the 2017/2018 and 2018/2019 growing seasons.

Supplementary Files

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- Suppl.Table1.docx
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