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Effects of Sugar Beet Residual and Vinasse on Soil Properties and Wheat Productivity under Calcareous Soil Conditions

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ABSTRACT

Vinasse and sugar beet residual are economically valued by-products of the sugar industry that can be used as soil amendment and plant biostimulator for crop production because of their high organic matter content and essential nutrients. A field experiment was conducted at El-Nubaria Agricultural Research Station, Egypt, during two successive winter seasons (2022-2023 and 2023-2024) to evaluate the sugar beet residual and vinasse applications effectiveness on the soil organic matter, nutrient availability, as well as wheat productivity under the low-productivity calcareous soil conditions. A split-plot design was used; sugar beet residual as soil application at (B0) 0 ton/fed, (B1) 3 ton/fed, and (B2) 6 ton/fed were applied to the main plots. The sub-main plots were assigned to four concentrations of diluted vinasse, control (V0), 10% vinasse (V1), 20% vinasse (V2), and 30% vinasse (V3), that were sprayed three times at 45, 60 and 90 days from sowing. The results revealed that a significant positive effect of treatments either individually or together outperformed the control (untreated plots). B2 treatment significantly augmented the soil organic matter by 25% that induced both of wheat biological and grain yield by 58 and 90% respectively over the control treatments. The combined treatment (B2V3) resulted in an increase in plant height (122 cm), number of spikes/m^2 (738.67), grain yield (3.40 ton/fed), biological yield (14.18 ton/fed), and weight of 1000 grains (65.08 g). The highest content of N, P, K , Fe, Mn, Zn and protein in wheat grain were also observed for B2V3 treatment.

Keywords: Calcareous Soil, Sugar Beet Residual, Vinasse, Wheat.

INTRODUCTION

Egypt's desert soils, primarily calcareous, have unique physical and chemical properties due to their high calcium carbonate content with a pH of more than 7 and lack of organic matter, besides the low content of N and P micronutrients that limit plant growth and are negatively impacting the agro-ecosystem. Proper calcareous soil fertility management is required to improve the crop yield and quality towards sustainable crop production. (Bolan *et al*., 2023).

Sugar beet production volume in Egypt during 2010 to 2021 increased from 7.84 to 14.83 million metric ton (Statista, 2024), which consequently led to an increase the residual and waste amounts associated with each step in sugar manufacturing from sugar beet. Recycling organic waste, which negatively impacts the environment, is a promising technology in various farming systems (Seleem *et al*., 2022). Sugar industrial unavoidable wastes such as sugar beet residual and vinasse pose environmental concerns if not recycled, and meanwhile low-cost soil conditioners are needed to improve the water retention and fertility of soil (Kheir and Kamara, 2019).

The sugar beet residual is the unavoidable discharged suspended solids resulting from the sugar beet washing process after separation into a water layer and a tare layer that is later collected in basins to be sundried. This residual is mainly the adherent fertile soil with rootlets networked on the surface of sugar beet root; therefore, they are rich in organic matter content, besides notable amounts of macro and micro plant nutrients (Zengin *et al*., 2003). The percentage of sugar beet residual depends on the soil type and the harvest technique. This percentage differs from 12% when a polder-share lifter machinery is combined with a lifting rotor under relatively dry conditions and 68% under relatively wet conditions. However, using forked shares machinery under relatively dry conditions that were the preferred led to 25% of the sugar beet residuals and 134% under relatively moist conditions (Vermeulen, 2001). Ruysschaert *et al*., 2005 stated that soil losses due to crop harvesting (SLCH) occurs during the harvest of underground crops such as sugar beet, potato, and carrot, where significant amounts of the fertile soil adhering to the pulled crops may be removed from the field forming a type of soil erosion. SLCH is a concern in countries with high production of root and tuber crops that affect their local economies. SLCH may be the cause of increasing the soil loss rate yearly by 1.13 and 0.54 t ha^{-1} In the Netherlands and Ireland respectively. Other affected countries are Greece, Italy and France (Panagos *et al*., 2019)

Vinasse is a liquid by-product produced from molasses fermentation into alcohol. Vinasse is characterized by an acidic pH from 3.5 to 5 and a high chemical oxygen demand up to 140 g/L that represents a high organic load, with a dark brown color due to melanoidins content. In addition to nutrients such as N, P, and K up to 4.2, 3.0, and 17.5 g L^{-1}, respectively (Hoarau *et al*., 2018). Extracting sugar from sugar beet passes through molasses that naturally originate betaines at concentrations up to 8% based on dry solids. Consequently, vinasse, as a by-product of the molasses fermentation into ethanol, is also an important source of natural betaines (Vukusic *et al*., 2019). Betaine is one of the compatible solutes that increase plant tolerance to various stress factors such as

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drought, salinity, and nutrient imbalances through various mechanisms, including cellular osmotic adjustment, detoxification of reactive oxygen species, and protecting plant membrane integrity and stabilizing important proteins such as enzymes (Ashraf and Foolad, 2007).

Wheat (*Triticum aestivum* L.) is the most important grain crop in Egypt, but its production is below average due to the harsh climate conditions (El-Sabagh, 2021). Egypt planted 1.425 million hectares of wheat and produced 9.279 million ton, with an average yield of 6.51 ton ha^{-1} (FAO, 2016). Wheat grains are rich sources of protein (6-21%), fats (1.5-2.0%), cellulose (2.0-2.5%), minerals (1.8%), and vitamins (Malav *et al*., 2017). Globally, Egypt is the largest wheat importer and consumes a large amount of bread that provides, on average, about 40% of the protein and 37% of the calories. Scientists mainly try to decrease the large gap between wheat production and consumption. Wheat production could be increased by applying proper management, including breeding high-yielding varieties and applying agronomic practices that sustain soil fertility (Abdelmageed *et al*., 2019). Sugar beet residual and vinasse may enhance wheat productivity under calcareous soil conditions by improving soil properties and providing plant hormones like abscisic acid and indole-3-acetic acid, which affect growth and yield (Zamarreño *et al*., 2022).

To our knowledge, no investigation was previously published to study the utilization of sugar beet residual from the first cycle of wash from sugar factories in agricultural practices after taking the proper precautions.

The purpose of this study was to increase wheat crop productivity in low-quality calcareous soil by using economic vinasse and sugar beet residual treatments either individually or combined.

MATERIALS AND METHODS

Site location and Experimental Design

A field experiment was conducted on the El-Nubaria Agricultural Research Station in Egypt, located at 30° 54' 48" N Latitude and 29° 51' 50.634" E Longitude. The study aimed to evaluate the effects of sugar beet residual and vinasse application on organic matter, nutrient availability, and wheat productivity in calcareous soil conditions during the 2022/2023 and 2023/2024 winter growing seasons. A composite soil sample (0 to 30 cm depth) was obtained from the experimental sites prior to planting, and its physical and chemical properties were analyzed (Page *et al*., 1982; Dewis and Freitas, 1970), as detailed in Table (1).

The experimental design consisted of a split-plot with three replicates, which included 36 plots (each plot area was 10.5 m^2).The main plot treatments were sugar beet residual to the soil: B0 (zero ton/fed, control), B1 (3 ton/fed), and B2 (6 ton/fed), while the sub-main plots consisted of the foliar vinasse treatments as a diluted solution (v/v) as follows: V0 (0%, control), V1 (10%), V2 (20%), V3 (30%). Vinasse foliar treatments were sprayed at 45, 60 and 90 days after sowing. Table 2 displays the physicochemical properties of sugar beet residual and vinasse (Cottenee *et al.*, 1982). The vinasse used in the study was provided by the integrated industries and sugar company, EL-Hawamdia, while the sugar beet residual was obtained from the El-Nubaria Sugar Refining Company in EL-Beheira, Egypt. The residual consists of the discharged precipitated solids from the initial sugar beet washing process, primarily a mixture of fertile soil adhered to the rootlets network on the sugar beet root surface. This residual was sun-dried and left to be phytosanitary for four months during the summer season with regular stirring before utilizing in the experiment.

Table 1. Physicochemical characteristics of the studied soils

Soil characteristics	Values	Soil characteristics	Values
Particle size distribution (%)		**Chemical analyses**	
Sand (%)	50	O.M (%)	0.7
Silt (%)	20	$CaCO_3$ (%)	22.9
Clay (%)	30	pH (1:2.5 soil) suspension)	7.76
Texture class	Sandy clay loam	ECe dS m^{-1}	1.94
SP (%)	42		
Soluble ions ($cmol_c$ .kg^{-1})			
Ca^{++}	6.50	Available nutrients ($mgkg^{-1}$)	
Mg^{++}	4.50	N	27.6
Na^+	0.36	P	7.6
K^+	8.0	K	161
CO_3^{--}	-	Fe	3.47
HCO_3^-	1.0	Mn	0.82
Cl^-	11.5	Zn	0.28
SO_4^{--}	6.86		

Table 2. Physico-chemical properties of sugar beet residual and vinasse

Property	sugar beet residual	Vinasse
Bulk density (g m^{-3})	0.94	1.2
Moisture contents (%)	14	ND
Total Solids (%)	ND	56
pH (1:10)	7.66	4.43
EC (1:10 dS m^{-1})	1.01	26.3
Total nitrogen (%)	0.77	2.4
Organic carbon (%)	22.26	73.02
Organic matter (%)	12.94	42.45
Ash (%)	77.74	26.98
C/N ratio	16.9	17.7
Total phosphorus (%)	0.33	0.41
Total potassium (%)	0.51	6.9

ND: not determined, all analyses based on dry weight except for bulk density and moisture content

Wheat (*Triticum aestivum* L.), cultivar (Misr 3) was obtained from the Field Crops Institute, Agricultural Research Station and sown on the 17^{th} of November during the winter seasons of 2022–2023 and 2023–2024. Nitrogen fertilizer in the form of ammonium sulfate (20.5% N) was applied at a rate of 480 kg fed^{-1}, phosphorus fertilizer as superphosphate (15.5% P_2O_5) was applied at a rate of 150 kg fed^{-1}, and potassium fertilizer as potassium sulfate (48% K_2O) was applied at a rate of 50 kg fed^{-1}. These applications, along with all other agricultural practices (such as fertilization, irrigation, weed and disease control, etc.) were carried out in accordance with the guidelines provided by the Ministry of Agriculture and Land Reclamation in Egypt for wheat cultivation.

Measurements of agronomic parameter

The wheat plants were harvested 150 days from planting. The plant height (cm) was measured by the mean of ten random plants selected from each plot. Grain yield (ton/fed) and yield components (1000 grain weight (gm), number of spikes/m^2, biological yield (ton/fed) were recorded for both cultivation seasons.

Relative increase of some parameters was calculated using the following equation:

$$\textbf{Relative increase \%} = \frac{\text{Treatment effect on a parameter} - \text{Control effect on the same parameter}}{\text{Control effect on the same parameter}} \times 100$$

Soil and plant analysis

Soil samples were collected at a depth of 0–30 cm for each treatment after the harvest. The samples were dried then crushed and sieved to remove soil particles > 2 mm. Chemical analyses were performed as follows: Organic carbon was determined by the modified Walkely-Black method (Nelson and Sommers, 1996). The available soil nitrogen was extracted using a 1% K_2SO_4 solution and measured by distillation in a macro Kjeldahl apparatus with MgO and Devarda alloy (Bremner and Mulvaney, 1982). The available soil phosphorus was extracted with 0.5 N $NaHCO_3$ at pH 8.5 and measured colorimetrically using stannous chloride at a wavelength of 660, as described by Olsen (1954). The Soil available potassium was extracted with 1 N ammonium acetate (NH_4OAc) solution at pH 7.0 and measured using a flame photometer (Black *et al*., 1965). The available Fe, Zn, and Mn were determined by extracting the soil with DTPA solution (Lindsay and Norvell ,1978).

A 0.5 g oven-dried plant samples (straw and grains) were digested with 10 ml of concentrated H_2SO_4 and $HClO_4$ (1:1 ratio) until clear (Chapman and Pratt, 1961). Nitrogen was estimated using Micro-Kjeldhl, and protein (%) was calculated using factor 5.75. Phosphorus was determined colorimetrically, and potassium was measured using a flame photometer. The iron, zinc, and manganese contents were measured by Inductively Coupled Plasma Spectrometry (ICP) (Model Ultima 2 JY Plasma- Jobin Yvon).

Statistical analysis

The CoStat software package (Ver. 6.311) was used to statistically analyze the data using analysis of variance (ANOVA). The comparison of the means of the data from the two seasons was done using the least significant difference ($P \leq 0.05$) as described by Snedecor and Cochran (1990).

RESULTS AND DISCUSSION

Results

The effect of sugar beet residual and vinasse on the yield and its components

Data presented in Table (3) showed the yield of wheat and its components resulting from sugar beet residual and vinasse treatments under calcareous soil with 22.9% $CaCO_3$. The ANOVA test was performed for two growing seasons, winter 2022/2023 and 2023/2024, and revealed that studied treatments at $P \leq 0.05$ significantly increased the mean performance of important morphological traits of plant growth. Increasing the sugar beet residual as soil application rate from zero to 6 ton fed^{-1} resulted in a significant increase in plant height, biological yield, grain yield, number of spikes, and weight of 1000 grains by 10.7, 58, 90.5, 113.5, and 11.8%, respectively, for the rate of 6 ton fed^{-1} compared with the control (B0). Furthermore, foliar application of vinasse at the highest rate of 30% caused an increase in plant height, biological yield, grain yield, number of spikes, and weight of 1000 grains by 6.1, 21.8, 33.3, 40.8, and 7.9%, respectively, over the control (V0) treatment. For clear illustration of the relative increase in parameters affected by treatments, just the single treatments and two of the interaction treatments were plotted in figures (Fig.1). The interaction between sugar beet residual and vinasse showed a significant effect on the plant height, biological yield, grain yield, and the number of spikes, except for the weight of 1000. The highest values of the aforementioned parameters were obtained from B2V3, followed by B1V3 in both seasons (Fig. 1).

Table 3. The effect of sugar beet residual and vinasse on plant height, yield and yield components of wheat grown in calcareous soil (combined analysis of two seasons)

Sugar beet residual	Vinasse	Plant height (cm)	Biological yield (ton/fed)	Yield of grains (ton/fed)	number of spikes/m^2	weight of 1000 grains
B0	V0	110^{i}	8.07^{j}	1.30^{j}	322.00^{i}	48.57^{e}
	V1	111^{i}	9.24^{i}	1.70^{i}	394.67^{h}	50.43^{de}
	V2	113^{h}	11.20^{h}	2.42^{h}	440.67^{g}	51.50^{cde}
	V3	115^{g}	11.80g^{h}	2.55g^{h}	465.33^{g}	52.10^{bde}
B1	V0	115^{g}	12.12f^{g}	2.75^{fg}	522.67^{f}	52.97^{bcd}
	V1	119^{f}	12.74^{ef}	3.00^{ef}	624.00^{e}	53.07^{bcd}
	V2	120^{e}	13.39^{ed}	3.26^{de}	657.33^{e}	53.13^{bcd}
	V3	122^{cd}	13.74^{d}	3.46^{d}	705.33^{d}	54.00^{bcd}
B2	V0	121de	14.72^{c}	3.58^{b}	729.33^{cd}	54.57^{bcd}
	V1	122^{c}	15.73^{b}	3.70^{b}	764.00^{c}	54.97^{b}
	V2	125^{b}	16.28^{b}	3.85^{b}	928.00^{b}	55.70^{b}
	V3	128^{a}	17.01^{a}	4.19^{a}	1045.33^{a}	62.13^{a}
Means of Sugar beet residual	B0	112C	10.08c	2.01c	405.97C	50.65b
	B1	119B	13.00B	3.12B	627.33B	53.29B
	B2	124A	15.93A	3.83A	866.67A	56.48A
Means of Vinasse	V0	115^{D}	11.64^{D}	2.55^{D}	524.67^{D}	52.03^{B}
	V1	117^{C}	12.57^{C}	2.82^{C}	594.22^{C}	52.82^{B}
	V2	120^{B}	13.62^{B}	3.18^{B}	675.33^{B}	53.44^{A}
	V3	122^{A}	14.18^{A}	3.40^{A}	738.67^{A}	56.08^{A}
LSD $_{0.05}$ of Sugar beet residual (B)		0.6	0.48	0.33	22.4	2.41
LSD $_{0.05}$ of vinasse (V)		0.8	0.40	0.17	23.3	2.39
LSD-interaction (Bx V)		1.3	0.70	0.29	40.4	NS

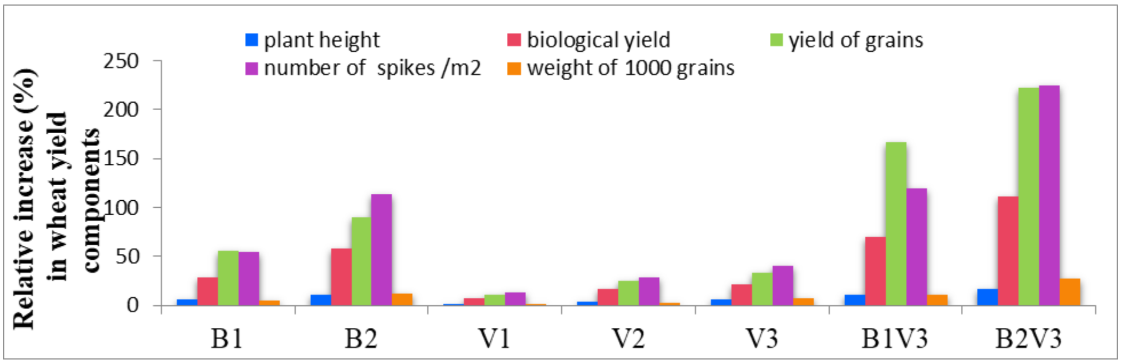

Fig. 1. The relative increase in wheat yield components affected by of sugar beet residual and vinasse treatments

The effect of sugar beet residual and vinasse on the nutrients content in straw

The effect of sugar beet residual and vinasse on the nutrient content of wheat straw is presented in Table (4). The obtained results revealed that sugar beet residual induced a higher nutrient content of N, P, K, Fe, Mn, and Zn in the straw of wheat grown in calcareous soil. A significant increase in the nutrient content of wheat straw can be observed in the order B0 < B2 < B3. In addition, vinasse treatment increased significantly (at $P \leq 0.05$ obtained from ANOVA on combined analysis of two growing seasons) the levels of N, P, K, Fe, Mn, and Zn in wheat straw. At the same time, the highest rate of vinasse (V3) with 30% achieved a significant increment of 14.7, 59.7, 45.8, 169, 39.9, and 48.5%, respectively, relative to the control (V0). The interaction effect of sugar beet residual and vinasse had a significant effect on the concentrations of macro- and micronutrients in wheat straw. The combined treatment (B2V3) in most cases gave a higher value of nutrient content, followed by B1V3 (Table 4 and Fig. 2). The data indicated that the application of both sugar beet residual and vinasse at higher rates was more effective than that of a single type, resulting in a percentage of average concentration that followed the trend: Fe > P > K > Zn > N > Mn in wheat straw.

Table 4. Effects of sugar beet residual and vinasse on straw nutrients content of wheat grown in calcareous soil (combined analysis of two seasons)

Sugar beet residual	Vinasse	Nutrients content					
		N%	P%	K%	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})
B0	V0	0.513^{c}	0.750^{f}	1.61^{k}	291.00^{k}	53.10^{e}	12.04^{f}
	V1	0.540^{bc}	0.080^{ef}	1.84^{j}	301.00^{j}	57.33^{d}	15.50^{e}
	V2	0.610^{abc}	0.087^{ef}	1.97^{h}	507.67^{h}	58.17^{d}	17.42^{d}
	V3	0.580^{abc}	0.102^{def}	2.08^{g}	544.00^{g}	67.1^{b}	23.08^{b}
B1	V0	0.560^{abc}	0.116^{def}	1.90^{i}	486.00^{i}	51.17^{e}	16.42^{de}
	V1	0.600^{abc}	0.142^{def}	2.09^{g}	654.50^{e}	57.17^{d}	17.67^{d}
	V2	0.640^{abc}	0.152^{cdef}	2.40^{e}	766.75^{c}	56.52^{bc}	19.92^{c}
	V3	0.660^{abc}	0.181^{bde}	2.6^{d}	1451.17^{b}	75.33^{a}	23.63b
B2	V0	0.680^{abc}	0.197^{bcd}	2.28^{f}	544.08^{g}	51.50^{e}	20.33^{c}
	V1	0.743^{abc}	0.240^{abc}	2.88^{c}	563.17^{f}	63.00^{c}	20.75^{c}
	V2	0.757^{ab}	0.274^{ab}	3.27^{b}	734.08^{d}	65.10^{bc}	23.42^{b}
	V3	0.780^{a}	0.335^{a}	3.61^{a}	1559.17^{a}	75.50^{a}	25.75^{a}
Means of Sugar beet residual	B0	0.560C	0.086C	1.87C	410.92C	58.93C	17.01C
	B1	0.615B	0.148B	2.26B	839.69B	62.22B	19.41B
	B2	0.740A	0.261A	3.01A	850.13A	63.78A	22.57A
Means of Vinasse	V0	0.584^{C}	0.129^{D}	1.9^{D}	440.47^{D}	51.92^{D}	16.27^{A}
	V1	0.628^{B}	0.154^{C}	2.2^{C}	506.22^{C}	59.14^{C}	17.97^{C}
	V2	0.668^{A}	0.171^{B}	2.55^{B}	669.50^{B}	62.82^{B}	20.25^{B}
	V3	0.670^{A}	0.206^{A}	2.77^{A}	1184.78^{A}	72.64^{A}	24.16^{A}
LSD $_{0.05}$ of Sugar beet residual (B)		0.019	0.004	0.042	5.71	1.99	0.941
LSD $_{0.05}$ of vinasse (V)		0.699	0.004	0.036	5.09	2.29	0.797
LSD-interaction (Bx V)		NS	0.103	0.062	8.82	3.97	1.38

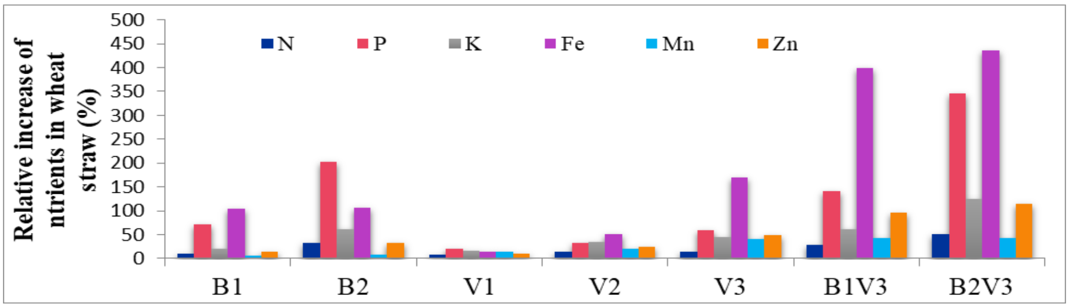

Fig. 2. The relative increase in wheat straw content of macro- and micronutrients affected by of sugar beet residual and vinasse treatments

The effect of sugar beet residual and vinasse on the protein and nutrient content in grains

Table (5) showed the macro- and micronutrients in wheat grain as a result of sugar beet residual (at two rates of 3 and 6 ton fed^{-1}) and vinasse (at three rates of 10, 20, and 30%) treatments. Increasing the application rate of sugar beet residual up to 6 ton fed^{-1} in calcareous soil significantly increased the grain content of protein up to14.5% and the nutrients N, P, K, Fe, Mn, and Zn up to 2.52, 0.80, 0.72, 431.58, 90.63, and 83.91 mg kg^{-1}, respectively at $P \leq 0.05$ obtained from ANOVA carried on combined analysis of two growing seasons (Fig.3). At the same time, the average percentage of protein significantly increased up to 14.11%, and the average concentrations of N, P, K, Fe, Mn, and Zn in wheat grains treated with the highest rate of vinasse (30%) resulted in significant increases up to , 2.45, 0.78, 0.72, 488.47, 84.42, and 82.56 mg kg^{-1}, respectively. Concerning the impact of the interaction between sugar beet residual and vinasse on protein and macro- and micronutrients in wheat grains except Mn, the statistical analysis showed that highly significant increments were achieved by applying B2V3.

Table 5. Effects of sugar beet residual and vinasse on the protein and nutrients content of wheat grains (combined analysis of two seasons)

Sugar beet residual	Vinasse	Protein %	Nutrients content					
			N %	P %	K %	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})
B0	V0	11.27^{i}	1.96^{i}	0.380^{j}	0.460^{i}	304.92i	52.42^{h}	47.75^{i}
	V1	11.56^{hi}	2.01^{hi}	0.433i	0.533^{h}	334.42g	60.33^{g}	52.67^{h}
	V2	11.85^{gh}	2.06^{gh}	0.540^{gh}	0.56^{gh}	339.58g	66.42^{f}	57.50^{g}
	V3	12.08^{g}	2.10^{g}	0.570^{fg}	0.566^{fg}	462.25c	69.42^{ef}	64.92^{e}
B1	V0	12.54^{f}	2.18^{f}	0.517^{h}	0.576^{efg}	317.67^{h}	67.33^{f}	53.08^{h}
	V1	12.69^{f}	2.21^{f}	0.657^{e}	0.660^{e}	337.83^{g}	73.25^{de}	61.08^{f}
	V2	13.95^{d}	2.43^{d}	0.753^{d}	0.730^{d}	436.02^{d}	76.67^{d}	68.10^{d}
	V3	14.64^{c}	2.55^{c}	0.813^{bc}	0.723^{c}	492.75^{b}	81.33^{d}	77.25^{c}
B2	V0	13.42^{e}	2.33^{e}	0.603^{f}	0.590^{ef}	367.83^{f}	82.54^{c}	68.47^{d}
	V1	13.78^{d}	2.40^{d}	0.803^{c}	0.640^{d}	412.17^{e}	87.5^{b}	75.33^{c}
	V2	15.22^{b}	2.65^{b}	0.850^{b}	0.760^{b}	435.92^{d}	90.00^{b}	86.33^{b}
	V3	15.60^{a}	2.71^{a}	0.957^{a}	0.886^{a}	510.42^{a}	102.5^{a}	105.50^{a}
Means of Sugar beet residual	B0	11.96^{C}	2.03^{C}	0.480^{C}	0.530^{C}	360.29^{C}	62.15^{C}	55.71 ^{C}
	B1	13.46^{B}	2.34^{B}	0.685^{B}	0.643^{B}	396.08^{B}	74.65^{B}	64.90 ^{B}
	B2	14.51^{A}	2.52^{A}	0.803^{A}	0.726^{A}	431.58^{A}	90.63^{A}	83.91 ^{A}
Means of Vinasse	V0	12.41^{D}	2.16^{D}	0.500^{D}	0.542^{D}	330.14^{D}	67.42^{D}	56.43^{D}
	V1	12.68^{C}	2.20^{C}	0.630^{C}	0.585^{C}	361.42^{C}	73.69^{C}	63.03^{C}
	V2	13.67^{B}	2.38^{B}	0.714^{B}	0.664^{B}	403.86^{B}	77.69^{B}	70.67^{B}
	V3	14.11^{A}	2.45^{A}	0.780^{A}	0.726^{A}	488.47^{A}	84.42^{A}	82.56^{A}
LSD $_{0.05}$ of Sugar beet residual (B)		0.154	0.027	0.018	0.035	7.19	2.67	1.96
LSD $_{0.05}$ of vinasse (V)		0.188	0.328	0.023	0.018	5.21	4.28	1.79
LSD-interaction (Bx V)		0.325	0.057	0.041	0.036	9.03	NS	1.96

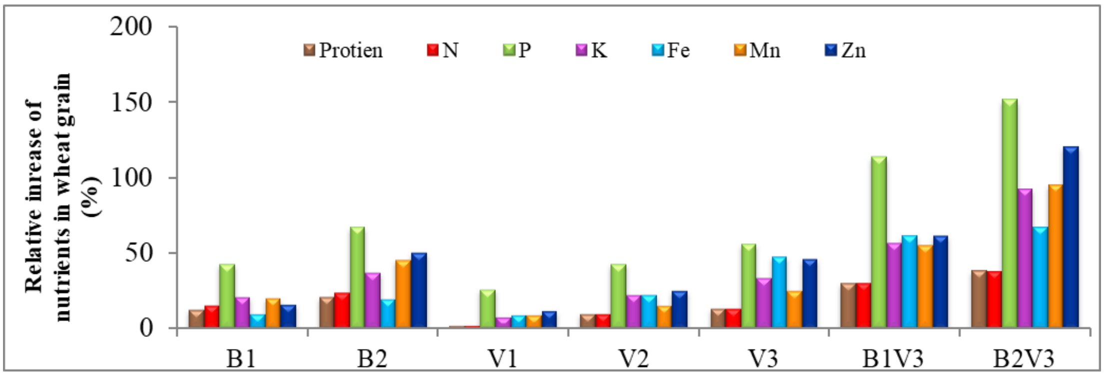

Fig. 3. The relative increase in wheat grains content of protein and macro- and micronutrients affected by of sugar beet residual and vinasse treatments

The effect of sugar beet residual and vinasse on soil organic matter and nutrients availability

Table (6) presents data on soil organic matter and available nutrients content affected by sugar beet residual and vinasse treatments in calcareous soil. The results of the ANOVA conducted on the combined analysis of two growing seasons revealed that soil organic matter in calcareous soil significantly intensified when the sugar beet residual were raised from 3 to 6 ton fed^{-1}. Therefore, soil organic matter markedly exceeded from 11 to 25.7% in plots receiving B2 (6 ton fed^{-1}) compared with the control. The impact of vinasse on OM content could be arranged in the following descending order: V0 > V1 > V2 > V3. Consequently, a higher and more significant increment of soil organic matter was observed due to V3 (30%). Soil organic matter increased with increasing rates of sugar beet residual and vinasse, which may be attributed to their high content of organic matter (22.26% and 73.02%, respectively). Sugar beet residual applied at a rate of 6 ton fed-1 caused the highest significant increment of available N, P, K, Fe, Mn, and Zn in the soil, which were 84.8, 26.5, 30, 68.4, 48.1, and 30%, respectively. Moreover, the maximum significant increments of available N, P, K, Fe, Mn, and Zn reached 34, 24.1, 17.2, 42.8, 34, and 17.1%, respectively, that was a result of vinasse application at a rate of 30 (Fig. 4) On the other hand, data revealed that applying sugar beet residual combined with vinasse led to a non-significant increase in organic matter and soil nutrient availability except for Mn where the increase was statistically significant.

Table 6. Effect of sugar beet residual and vinasse on organic matter and nutrient availability in calcareous soil under the wheat crop (combined analysis of two seasons)

Sugar beet residual	Vinasse	OM %	Nutrient availability (mg kg^{-1})					
			N	P	K	Fe	Mn	Zn
B0	V0	0.90^{f}	40.67^{g}	8.00^{d}	189.3^{h}	3.58^{g}	0.83^{e}	0.293^{h}
	V1	1.11^{de}	43.00^{g}	10.80^{c}	195.9^{gh}	$4.10f^{g}$	1.02^{de}	0.323^{gh}
	V2	1.13^{de}	46.67^{fg}	12.00^{bc}	207.0^{fg}	$4.93b^{c}$	1.13^{cde}	0.340^{fgh}
	V3	1.24^{cde}	61.67^{ef}	12.6^{abc}	225.8^{e}	$5.25d^{e}$	1.18^{cde}	0.370^{efg}
B1	V0	1.06^{ef}	63.00^{e}	13.10^{ab}	206.7^{fg}	5.06^{ef}	0.91^{bcde}	0.390^{def}
	V1	1.17^{cde}	64.33^{de}	13.93^{ab}	214.0^{ef}	5.40^{de}	1.26^{abcde}	0.397^{cde}
	V2	1.26^{bcd}	71.67^{cde}	13.87^{ab}	223.9^{e}	6.21^{d}	1.29^{abcd}	0.430^{abcd}
	V3	1.35^{abc}	86.67^{abc}	14.0^{ab}	250.3^{cd}	7.32^{b}	1.42^{abc}	0.447^{abc}
B2	V0	1.21^{cde}	80.17^{bcd}	12.00^{bc}	248.6^{d}	6.21^{cd}	1.43^{abc}	0.403^{bcde}
	V1	1.34^{abc}	83.00^{abc}	13.44^{ab}	262.9^{bc}	6.97^{bc}	1.46^{abc}	0.417^{bcde}
	V2	1.43^{ab}	93.67^{ab}	14.37^{a}	272.7^{ab}	7.82^{ab}	1.63^{ab}	0.473^{a}
	V3	1.50^{a}	98.00^{a}	14.46^{a}	279.5^{a}	8.65^{a}	1.65^{a}	0.457^{ab}
Means of sugar beet residual	B0	1.09^{B}	48.00^{B}	10.85^{B}	204.5^{C}	4.4^{C}	1.04^{C}	0.337^{B}
	B1	1.21^{B}	71.42^{A}	13.57^{A}	223.7^{B}	5.99^{B}	1.22^{B}	0.416^{A}
	B2	1.37^{A}	88.71^{A}	13.73^{A}	265.9^{A}	7.41^{A}	1.54^{A}	0.438^{A}
Means of vinasse	V0	1.06^{C}	61.28^{B}	11.03^{B}	214.9^{D}	4.95^{C}	1.06^{C}	0.362^{B}
	V1	1.21^{B}	63.44^{B}	12.72^{A}	224.3^{C}	5.49^{C}	1.25^{B}	0.379^{B}
	V2	1.27^{AB}	70.66^{B}	13.41^{A}	234.5^{B}	6.32^{B}	1.35^{A}	0.414^{A}
	V3	1.36^{A}	82.11^{A}	13.69^{A}	251.9^{A}	7.07^{A}	1.42^{A}	0.424^{A}
$LSD_{0.05}$ of Sugar beet residual (B)		0.110	18.19	1.47	17.5	0.59	0.07	0.049
$LSD_{0.05}$ of vinasse (V)		0.123	9.22	1.32	7.52	0.633	0.070	0.319
LSD-interaction (Bx V)		NS	NS	NS	NS	NS	0.456	NS

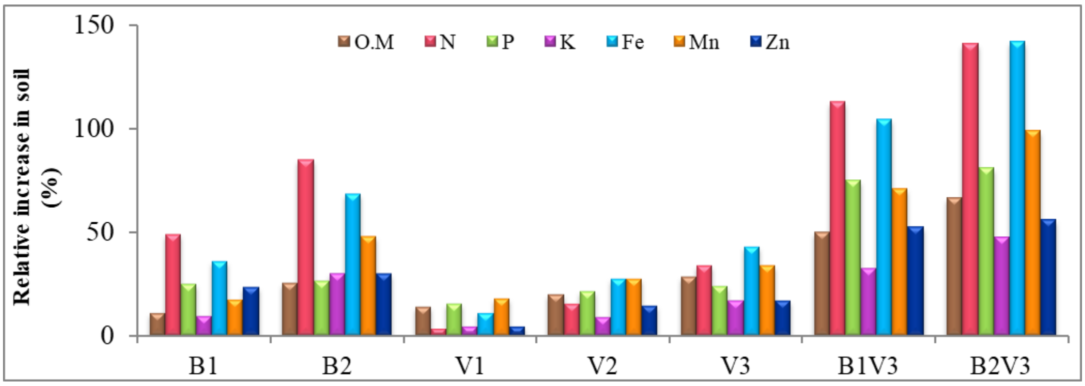

Fig. 4. The relative increase in soil organic matter and nutrients availability affected by of sugar beet residual and vinasse treatments

Discussion

The increase in wheat yield and its components (biological yield, grain yield, number of spikes, and weight of 1000 grains) due to sugar beet residual soil application and vinasse foliar application individually and together (Table 3) demonstrated that the most significant increase was observed with a higher addition of both treatments. As shown in Table 2, both sugar beet residual and vinasse are rich in organic matter, with 22.26% and 73.02%, respectively, along with appreciable amounts of N and K up to 2.4% and 6.9% in vinasse and fair amounts of macronutrients in sugar beet residual. These results are consistent with Taha (2020), who used foliar application of vinasse containing K up to 8 kg m^{-3} and 30% organic matter at four diluted rates (0%, 2%, 4%, 6%, and 8%) on turfgrass plants that increased the tolerance of plant to various stresses by enhancing shoot water potential through regulating stomatal function. These findings align with Gaafar *et al.* (2019), who applied vinasse foliar treatments at 4% and 6% on sweet pepper, where, the higher dose resulting in improved yield components such as plant length, stem diameter, number of branches, number of leaves per plant, leaf area per plant, and dry weight of plant, as well as fruit yield and fruit characteristics. Our results are further supported by a study where, changes in grain yield and leaf nutrient content due to vinasse treatments were monitored under field conditions in Brazil, where manual application of vinasse at one-time treatments at rates of 50, 100, 150, 200, and 250 m^{3} ha^{-1} in combination with NPK mineral fertilizer resulted in a grain yield exceeding 13 t ha^{-1} at a rate of 100 m^{3} ha^{-1} (da Silva *et al.*, 2020).

Regarding the nutrient content in straw and grains of wheat, the observed increase in the percentage of N, P, K, Fe, Zn, and Mn due to the combination of sugar beet residual and vinasse (B2V3) could be explained by the increased availability of nutrients in the soil resulting from the addition of sugar beet residual, as well as the high K content and significant amount of other nutrients in vinasse foliar application. Additionally, the bio-stimulation effect of naturally occurring glycine betaine in vinasse (Vukusic et al., 2019) when exogenously applied to plants caused enhancing in plant tolerance to various abiotic stress factors and improving plant nutrient uptake and utilization (Dima *et al*., 2023). The findings of our study are consistent with the results of applying vinasse with a mean K concentration of 2.98 g L^{-1} to soil without field runoff conditions, which directly affected the K concentration in maize plant leaves grown in 2013, 2014, and 2015, with increases of 21.39%, 26.02%, and 8.69%, respectively, compared to plots receiving only NPK fertilizer (da Silva *et al.,* 2020). These results are supported by a study that applied five different vinasse rates (0, 150, 300, 600, 1200 m^3 ha^{-1}) along with mineral fertilization to assess micro- and macronutrient levels in sugarcane plants. Regardless of the vinasse dose applied, there was a need for nitrogen and phosphorus fertilization due to inadequate supply from vinasse. However, high rates of vinasse application provided adequate levels of K in plants (Costa *et al*., 2021).

The increase in soil organic matter and available nutrients (N, P, K, Fe, Zn, and Mn) as a result of the treatments in the current study could be explained by the chemical and physical analysis of sugar beet residual (Table 2). The C/N ratio was up to 16.8, and the organic matter content was up to 22.26%, creating favorable conditions for N mineralization and overall nutrient availability in the soil. These results are supported by Locker (2021), who estimated sugar beet residue to be 0.065 and 0.080 kg of fresh matter per kg of fresh underground-grown crop, resulting in 124,070 and 152,219 tonnes of fresh matter residual per year for potato and sugar beet, respectively. The author also reported the dry matter and nutrient content in potato residue as follows: fresh matter quantity 267, 290 tonnes, dry matter content 65%, dry matter 179,588 tonnes, N 1.79 g kg^{-1}, P 0.21 g kg^{-1}, and K 0.14 g kg^{-1} in dry matter. Therefore, reusing sugar beet residue after phytosanitary measures can help minimize soil fertility loss associated with soil losses due to crop harvesting (SLCH).

Parlak *et al*. (2008) performed calculations based on 2005 sugar beet production reports in Turkey, that approximately 4.28 Mg ha^{-1} of fertile soil is lost as sugar beet residue is removed from the original field each year. The economic value of the macronutrients N, P, and K that are taken from the soil was estimated to be around 4 million US dollars. In a study conducted on nine fields in Germany with 43.7 ha under intensive agricultural use, where winter wheat is the dominant crop followed by sugar beet, crop nutrient losses of N, P, and K due to SLCH of sugar beets were calculated to be 373.64, 5.52, and 752.08 kg, respectively. These findings highlight the significant impact on soil erosion and emphasize the need for a comprehensive assessment of SLCH on a larger scale (e.g., national or pan-European scale) (Saggau *et al*., 2024). Therefore, sugar beet residual can improve calcareous soil properties by increasing soil organic matter content and enhancing plant nutrient availability, ultimately leading to improved wheat productivity.

As no prior research has been conducted on the utilization of sugar beet residual (comprising adherent soil and rootlets collected during the initial wash cycle at sugar factories) in agricultural practices, it is important to highlight the novelty of this study. The findings of this study address issues raised regarding SLCH. Therefore, the authors recommend further exploration and implementation of sugar beet residual in crop production, following the appropriate precautions and soil analyses.

CONCLUSION

Findings of this study indicated that the interaction between sugar beet residual (soil application) and vinasse (foliar spray) at higher rate B2V3 (6 ton/fed for sugar beet residual and 30% of vinasse) induced higher wheat yield than control in calcareous soil. Moreover, treatments resulted in improving soil organic matter and soil available nutrients content, that is considered as a choice of ensuring sustainable wheat production. Therefore, farmers should be familiar with sustainable agricultural practices, involving organic fertilizers and other eco-friendly approaches to transform the residual and waste negative environmental impact into positive. Frequent soil analysis should be taken into consideration when continuously applying the residual and organic wastes for crop production.

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تأثير مخلفات بنجر السكر والفيناس على خواص التربة وإنتاجية القمح تحت ظروف الأرض الجيرية

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الملخص

الفيناس ومخلفات بنجر السكر هى منتجات ثانوية اقتصادية ناتجة من تصنيع السكر والتي يمكن استخدامها كمحسنات للتربة ومحفزات نباتية نظرا لإحتوائها على المادة العضوية والعناصر الأساسية للنبات. أجريت تجربة حقلية بالمزرعة البحثية بمحطة البحوث الزراعية بالنوبارية بمحافظة البحيرة. مركز البحوث الزراعية، وزارة الزراعة واستصلاح الأراضي، مصر. خلال موسمي النمو الشتوي 2023/2022 و2024/2023 لتقييم تأثير إضافة مخلفات بنجر السكر والفيناس على محتوى العناصر المعدنية والمادة العضوية وإنتاجية محصول القمح تحت ظروف الأرض الجيرية. كان التصميم التجريبي عبارة عن قطع منشقة مرة واحده حيث كانت المعاملات الرئيسية هي بقايا بنجر السكر B0 (صفر طن/فدان)، B1 (3 طن/فدان) B2 (6 طن/فدان) بينما كانت المعاملات الفرعية هى الفيناس : الكنترول (V0)، (V1) %10، (V2) %20، و (V3) 30 و التي تم رشها بعد 45، 60، 90 يوم من الزراعة. أظهرت النتائج المتحصل عليها أن بقايا بنجر السكر مع الفيناس كانت اعلى معنويه لكل من الصفات المدروسة. اوضحت النتائج ان مخلفات بنجر السكر مع الفيناس كانت أفضل عند معدل B2V3 لجميع الصفات المدروسة. المعاملة B2 (6 طن/فدان) أدت إلى زيادة المادة العضوية في التربة بنسبة 25% وزيادة نسبة المحصول البيولوجى للقمح بنسبة 58% وزيادة محصول الحبوب بنسبة 90% عن معاملة الكنترول. كما سجلت معاملة 6 طن/فدان من بقايا بنجر السكر + 30% فيناس (B2V3) سجلت أعلى القيم في إرتفاع النبات (122 سم)، وعدد السنابل/م2 (738.67)، ومحصول الحبوب (3.40 طن/فدان)، والمحصول البيولوجي (14.18 طن/فدان)، ووزن 1000 حبة (65.08 جم). كما لوحظ أعلى محتوى من النيتروجين والفوسفور والبوتاسيوم والحديد والمنجنيز والزنك والبروتين في حبوب القمح نتيجة المعاملة B2V3