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Research Article

Sugar Mill Effluent Utilization in the Cultivation of Maize (*Zea mays* L.) in Two Seasons

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The aim of present investigation is to study the effects of sugar mill effluent fertigation on soil properties and agronomical characteristics of Maize (*Zea mays* L. cv. NMH 589) in two seasons. Six treatments of sugar mill effluent, namely, 0% (control), 20%, 40%, 60%, 80%, and 100%, were used for the cultivation of *Z. mays*. Fertigation with different concentrations of sugar mill effluent resulted in significant ($P < 0.01$) changes in EC, pH, OC, Na^+, K^+, Ca^{2+}, Mg^{2+}, TKN, PO_4^{3-}, SO_4^{2-}, Fe^{3+}, Zn^{2+}, Cd^{2+}, Cu^{2+}, Mn^{2+}, and Cr^{3+} of the soil in both seasons. The maximum agronomic performance of *Z. mays* was noted with 40% concentration of sugar mill effluent. Biochemical components like crude proteins, crude fiber, and total carbohydrates were recorded highest with 40% concentration of sugar mill effluent in both seasons. The contamination factor (Cf) of various heavy metals was observed in order of $Mn^{2+} > Zn^{2+} > Cu^{2+} > Cd^{2+} > Cr^{3+}$ for soil and $Mn^{2+} > Zn^{2+} > Cu^{2+} > Cr^{3+} > Cd^{2+}$ for *Z. mays* in both seasons after fertigation with sugar mill effluent. It appears that sugar mill effluent can be used as a biofertigant after appropriate dilution to improve the yield.

1. Introduction

In many agroindustrial processes, some by-products may be utilized as useful products [1, 2]. In India, the sugar industry is one of the greatest industries, based on sugar cane. Presently India has nearly 650 sugar mills that produce about 15 million tons of sugar and 13 million tons of molasses annually [3, 4]. The high production of sugar generates high quantities of the sugar industry wastes such as effluent, filter mud cake, vinasse, molasses, bagasse, and bagasse ash [5]. A few years ago, these by-products were considered as a waste and were often disposed of causing environmental problems such as aquatic and terrestrial pollution [6]. Recently, it has been recognized that such by-products should be considered as useful materials [7]. These by-products are of great agricultural interest because of their high organic matter, N and K contents, and probably other elements [3, 8, 9]. Therefore, some of these sugar industry by-products may represent an important source of nutrients and thereby could be used as a substitute for chemical and organic fertilizers [2, 8, 10, 11].

Use of wastewater in agricultural fields may be a viable method of disposal and would sustain agriculture in nonirrigated areas where the availability of fresh water is scarce [12, 13]. It reduces fertilizer and irrigation water cost as it is available without paying any cost and rich in various plant nutrients [12]. Although, metals like Cu, Fe, Ni, and Zn and other trace elements are important for proper functioning of biological systems, and their deficiency, or excess could lead to a number of disorders [14–16]. But long term irrigation with effluents increases accumulation of metals in soil and plants and increases chances of their entrance in food chain [17]. Contamination of agricultural soils with metals can pose long term environmental problems and is not without health implications [17–19].

Maize (*Zea mays* L.) is the most important grain crop and is cultivated for food and fodder throughout the world under diverse environments [20, 21]. Maize biomass is variously used for the production of energy, fiber, or paper, as well as for syrup and animal feed [22, 23]. In India, it ranks fourth after rice, wheat, and sorghum. It is cultivated for food and fodder in the northwestern states of the country in all the seasons, namely, rainy, winter, and summer, with a production of 14.71 million tonnes from an area of 7.23 million hectares with productivity of 19.04 quintals per hectare [4]. It also has the ability to tolerate and survive under adverse conditions of intermittent and continuing drought [24, 25]. Therefore, maize has received considerable attention during the last years as an alternative source for food, fodder, and energy production [4, 11].

Some crops have higher potential yields with wastewater irrigation, reduce the need for chemical fertilizers, and result in net cost savings to farmers [13, 26]. It is important to understand the specificity of crop-effluent interaction for appropriate applications in irrigation [13]. In some studies characteristics of the effluent of industries and agronomic properties of various crop plants have been determined [10, 27–31]. Most studies were conducted on few agronomic stages with limited parameters in various crops, but there are few reports on comprehensive agronomic studies at various agronomic stages of these plants [26]. Use of industrial effluents on cultivation of *Z. mays* is receiving attention [4] but additional information is needed on how this crop responds to various concentrations of different types of effluents. The investigation was undertaken to study the effects of sugar mill effluent fertigation on soil properties and agronomical characteristics of *Z. mays* in two seasons.

2. Materials and Methods

2.1. Experimental Design. A field study was conducted at the Experimental Garden of the Department of Zoology and Environmental Sciences, Faculty of Life Sciences, Gurukula Kangri University, Haridwar, India (29°55′10.81″N and 78°07′08.12″E), to determine the effects of sugar mill effluent fertigation on *Z. mays*. Six plots (each plot had an area of 9 m^2) were selected for six treatments of sugar mill effluent, namely, 0% (control), 20%, 40%, 60%, 80%, and 100%, for the cultivation of *Z. mays*. The six treatments were placed within randomized complete block design.

2.2. Sowing of Seeds of Z. mays. Seeds of *Z. mays* were sown at the end of April 2010 and 2011 for the summer season crop and at the end of July 2010 and 2011 for the rainy season crop. Seeds of *Z. mays*, cv. NMH 589, were procured from Indian Council of Agriculture Research (ICAR), Pusa, New Delhi, and sterilized with 0.01% mercuric chloride and soaked in water for 12 hours. Seeds were sown in 10 rows with a distance of 30.0 cm between rows, while distance between the seeds was 15 cm. The thinning was done manually after 15 days of germination to maintain the desired plant spacing and to avoid competition between plants.

2.3. Effluent Collection and Analysis. The effluent samples were collected from the R.B.N.S. Sugar Mill, Laksar, Haridwar, Uttarakhand, India (29°44′46″N 78°1′46″E), which produces sugar from sugar cane at the rate of 150 ton sugar per day. The effluent was collected in the plastic container from the outlet of the settling tank situated in the campus of the sugar mill to reduce the biological oxygen demand (BOD) and solids from the effluent. The effluent was brought to the laboratory and then analyzed for total dissolved solids (TDS), pH, electrical conductivity (EC), dissolved oxygen (DO), BOD, chemical oxygen demand (COD), chlorides (Cl^-), bicarbonates (HCO_3^-), carbonates (CO_3^{2-}), sodium (Na^+), potassium (K^+), calcium (Ca^{2+}), magnesium (Mg^{2+}), total Kjeldahl nitrogen (TKN), nitrate (NO_3^{2-}), phosphate (PO_4^{3-}), sulphate (SO_4^{2-}), iron (Fe^{3+}), zinc (Zn^{2+}), cadmium (Cd^{2+}), copper (Cu^{2+}), manganese (Mn^{2+}), chromium (Cr^{3+}), standard plate count (SPC), and most probable number (MPN) following [32, 33] and used as fertigant.

2.4. Irrigation Pattern, Soil Sampling, and Analysis. The soil in each plot was fertigated twice in a month with 50 gallons of sugar mill effluent with 20%, 40%, 60%, 80%, and 100% concentrations along with bore well water as the control. The soil was analyzed before sowing and after harvesting of the crop for various physicochemical parameters, namely, bulk density (BD), water holding capacity (WHC), soil texture, soil pH, EC, OC, Na^+, K^+, Ca^{2+}, Mg^{2+}, TKN, PO_4^{3-}, SO_4^{2-}, Fe^{3+}, Zn^{2+}, Cd^{2+}, Cu^{2+}, Mn^{2+}, and Cr^{3+}, following standard methods [33].

2.5. Study of Crop Parameters. The various agronomic parameters of *Z. mays* at different stages (0–90 days) were noted by standard methods for seed germination, plant height, root length, number of leaves per plant, cob length, and crop yield [34]; fresh and dry weight [35]; chlorophyll content [36]; relative toxicity (RT) [37]; leaf area index (LAI) [38]; and harvest index (HI) [39]. The nutrient quality of the crop was determined by using the following parameters: crude protein and crude fiber [40] and the total carbohydrates in dry matter were determined by the anthrone reagent method [41].

2.6. Extraction of Metals and Their Analysis. For heavy metal analysis 5 mL sample of sugar mill effluent and 1.0 g of air-dried soil or plants were digested in tubes with 3 mL of concentrated HNO_3 digested in an electrically heated block for 1 hour at 145°C. To this mixture 4 mL of $HClO_4$ was added and heated to 240°C for 1 hour. The mixture was cooled and filtered through Whatman # 42 filter paper and made with 50 mL and used for analysis. Heavy metals were analyzed using an atomic absorption spectrophotometer (PerkinElmer, Analyst 800 AAS, Gen Tech Scientific Inc., Arcade, NY) following APHA [32] and Chaturvedi and Sankar [33]. The contamination factor (Cf) for heavy metals accumulated in sugar mill effluent irrigated soil and *Z. mays* was calculated following Hakanson [42].

2.7. Statistical Analysis. Data were analyzed with SPSS (version 12.0, SPSS Inc., Chicago, IL). Data was subjected to two-way ANOVA. Duncan's multiple range test was also performed to determine that the difference was significant or nonsignificant. Mean standard deviation and coefficient of correlation (r-value) of soil and crop parameters with effluent concentrations were calculated with MS Excel (version 2003, Microsoft Redmond Campus, Redmond, WA) and graphs produced with Sigma plot (version 12.3, Systat Software, Inc., Chicago, IL).

3. Results and Discussion

3.1. Characteristics of Sugar Mill Effluent. Values of physico-chemical and microbiological parameters were different over sugar mill effluent concentration (Table 1). The sugar mill effluent was highly alkaline with a pH 8.98. The alkaline nature of the sugar mill effluent might be due to the presence of high concentrations of alkalis used in the sugar manufacturing process. The BOD, COD, Cl^-, Ca^{2+}, Fe^{3+}, TKN, SO_4^{2-}, MPN, and SPC were beyond the prescribed limit of the Indian irrigation standards [43]. Higher BOD and COD might be due to the presence of more oxidizable organic matter and rapid consumption of dissolved inorganic materials. The higher bacterial load (SPC and MPN) in sugar mill effluent might be due to the presence of more dissolved solids and organic matter in sugar mill effluent as earlier reported by Kumar and Chopra [12]. The presence of MPN in sugar mill effluent may be due to sewage received from the toilet of staff quarters and offices. The TKN, PO_4^{3-}, K^+, Ca^{2+}, and Mg^{2+} in effluent were higher than the prescribed standards. In the present study, the values of BOD, COD, TKN, Cl^-, SO_4^{2-}, and PO_4^{3-} were more in sugar mill effluent than the values of BOD (2769.00 mgL^{-1}), COD (4830.00 mgL^{-1}), chlorides (789.00 mgL^{-1}), sulphate (374.95 mgL^{-1}), and phosphate (23.00 mgL^{-1}) in sugar mill effluent reported by Ezhilvannan et al. [4]. In case of metals, the contents of Fe^{3+}, Zn^{2+}, Cd^{2+}, Cu^{2+}, Cr^{3+}, and Mn^{2+} were higher than the permissible limit for industrial effluent [43]. The content of these metals in sugar mill effluent was also higher than the content of Zn (16.34 mgL^{-1}), Cd (3.47 mgL^{-1}), and Cu (8.62 mgL^{-1}) in sugar mill effluent reported by Borole and Patil [44].

3.2. Effects of Sugar Mill Effluent on Soil Properties. Physico-chemical characteristics of the soil changed after fertigation with sugar mill effluent (Tables 2–5; Figure 1). At harvest of *Z. mays* (90 days after sowing) there was no significant change in the soil texture (loamy sand; 40% sand: 40% silt: 20% clay). Irrigation with 100% sugar mill effluent had the most increase in EC, OC, Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe^{2+}, TKN, PO_4^{3-}, SO_4^{2-}, Zn^{2+}, Cd^{2+}, Cu^{2+}, Mn^{2+}, and Cr^{3+} in both seasons (Tables 3 and 4). WHC and BD were reduced from their initial (control) values 44.36% and 1.42 $gm\,cm^{-3}$ to 42.48, 41.86%, and 1.41 $gm\,cm^{-3}$, respectively, with 100% concentration of sugar mill effluent. Seasons, sugar mill effluent concentrations and interaction of seasons, and sugar mill effluent concentrations showed insignificant ($P > 0.05$) effect on WHC and BD in both seasons (Table 2). WHC is related to the number and size distribution of soil pores, soil moisture content, textural class, structure, salt content, and organic matter. The BD of soil changes with the application of organic manure to soil that substantially modifies and lowers the soil bulk density. It is used for determining the amount of pore space and water storage capacity of the soil. Organic matter supplied through the sugar mill effluent and other kinds of wastes, like sludge, can lower the BD and WHC [45]. The findings were also in accordance with Baskaran et al. [46].

Sugar mill effluent concentrations significantly ($P < 0.05$) affected the pH and EC of the soil. But cropping seasons showed insignificant ($P > 0.05$) effect on pH and EC of the soil. Seasons, sugar mill effluent concentrations, and their interaction affected the OC and TKN of the soil (Table 2). The 40% to 100% concentrations of sugar mill effluent significantly ($P < 0.01$) affected the EC, OC, Na^+, K^+, Ca^{2+}, Mg^{2+}, TKN, Fe^{3+}, PO_4^{3-}, SO_4^{2-}, Zn^{2+}, Cu^{2+}, and Cr^{3+} in the soil in both seasons. The 20% sugar mill effluent concentration also significantly ($P < 0.05$) affected OC, Na^+, Ca^{2+}, Mg^{2+}, TKN, PO_4^{3-}, and SO_4^{2-} in both seasons (Tables 3 and 4). Soil pH was significantly ($P < 0.05$) affected with 60% to 100% sugar mill effluent concentrations while Mn was affected by 80% and 100% sugar mill effluent concentrations (Table 4). The EC, OC, Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe^{3+}, TKN, PO_4^{3-}, SO_4^{2-}, Zn^{2+}, Cd^{2+}, Cu^{2+}, Mn^{2+}, and Cr^{3+} were positively correlated with all concentrations of sugar mill effluent in both seasons (Table 5). In the present study, more irrigation of *Z. mays* with sugar mill effluent considerably increased the OC, Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe^{3+}, TKN, PO_4^{3-}, SO_4^{2-}, Zn^{2+}, Cd^{2+}, Cu^{2+}, Mn^{2+}, and Cr^{3+} in the soil (Table 2).

Baskaran et al. [46] reported that sugar mill effluent increased EC, pH, total organic carbon (TOC), total Kjeldahl nitrogen (TKN), available phosphorus, and exchangeable Na, K, Ca, and Mg in soil. Effluent irrigation generally adds PO_4^{3-}, HCO_3^-, Cl^-, Na^+, Ca^{2+}, K^+, Mg^{2+}, Zn^{2+}, Cd^{2+}, Cr^{3+}, Cu^{2+}, Ni^{2+}, and Mn^{2+} to the soil [17]. The soil pH is an important parameter as many nutrients are available to plants only within a particular pH range. A pH range of 6.00 to 8.30 enhances nutrient availability for plants, and a pH below 6.00 and above 8.80 inhibits the availability of nutrients for plants [47]. In the present study, pH of the soil was between 8.63 and 8.72 after irrigation with 100% sugar mill effluent that may increase various soil nutrients.

Total organic matter content in the soil irrigated with effluent was higher than the soil irrigated with bore well water. The more organic matter in effluent irrigated soil might be due to the more organic nature of the effluent. Kumar and Chopra [13] found the higher organic matter in the soil irrigated with distillery effluent. Average values of TKN, PO_4^{3-}, and K^+ in the effluent irrigated soil were found to be higher than the control soil and it might be due to the higher values of TKN, PO_4^{3-}, and K^+ in the sugar mill effluent. The content of Na^+ and SO_4^{2-} were observed higher in the soil irrigated with sugar mill effluent indicating a link between soil Na^+ and SO_4^{2-} and higher EC in the sugar mill effluent.

Seasons, sugar mill effluent concentrations, and their interaction affected all metals like Zn, Cd^{2+}, Cu^{2+}, Mn^{2+}, and

Table 1: Physicochemical and microbiological characteristics of R.B.N.S. sugar mill effluent.

Parameter	0 (BWW)[a]	Sugar mill effluent concentration (%)					[b]BIS for irrigation water
		20	40	60	80	100	
TDS ($mg\,L^{-1}$)	198.50	1456.00**	2948.00**	4368.00**	5676.00**	6182.00**	1900
Turbidity (NTU)	4.46	13.68*	18.88**	24.67**	30.98**	34.67**	10
EC ($dS\,cm^{-1}$)	0.34	2.68*	4.76*	6.89**	8.96**	9.85**	—[c]
pH	7.50	7.78ns	7.87ns	7.98ns	8.82*	8.98*	5.5–9.0
DO ($mg\,L^{-1}$)	8.24	4.89*	3.78*	2.56**	2.34**	1.23**	—
BOD ($mg\,L^{-1}$)	3.83	184.36**	368.89**	779.68**	1238.96**	1637.58**	100
COD ($mg\,L^{-1}$)	5.88	235.68**	576.45**	1138.78**	1699.78**	2267.96**	250
CL^{-} ($mg\,L^{-1}$)	15.68	148.52**	339.84**	658.47**	947.58**	1249.82**	500
HCO_3^{-} ($mg\,L^{-1}$)	282.00	313.15*	337.14*	379.48*	518.23**	669.86**	—
CO_3^{-2} ($mg\,L^{-1}$)	105.75	137.47*	178.85*	199.69*	216.36**	249.59**	—
Na^{+} ($mg\,L^{-1}$)	9.65	35.36**	84.25**	148.71**	219.58**	288.96**	—
K^{+} ($mg\,L^{-1}$)	5.54	46.58**	98.67**	189.47**	278.37**	359.82**	—
Ca^{2+} ($mg\,L^{-1}$)	23.46	113.26*	258.93*	454.45**	662.39**	852.79**	200
Mg^{2+} ($mg\,L^{-1}$)	12.15	34.64*	69.46*	112.58**	158.96**	197.95**	—
TKN ($mg\,L^{-1}$)	24.27	44.54*	65.88*	96.37**	118.24**	149.78**	100
NO_3^{2-} ($mg\,L^{-1}$)	25.17	104.74*	236.55*	422.87**	495.64**	788.88**	100
PO_4^{3-} ($mg\,L^{-1}$)	0.04	32.44**	73.69**	146.57**	219.78**	296.89**	—
SO_4^{2-} ($mg\,L^{-1}$)	17.64	114.12*	252.36*	464.85**	684.36**	892.77**	1000
Fe^{3+} ($mg\,L^{-1}$)	0.28	7.36**	14.86**	21.48**	28.44**	34.68**	1.0
Zn^{2+} ($mg\,L^{-1}$)	0.06	4.79**	9.84**	13.78**	18.98**	22.36**	15
Cd^{2+} ($mg\,L^{-1}$)	0.01	1.86**	3.12**	5.24**	6.48	8.36**	2.00
Cu^{2+} ($mg\,L^{-1}$)	0.04	1.55**	2.98**	4.99**	6.78**	8.96**	3.00
Mn^{2+} ($mg\,L^{-1}$)	0.02	4.45**	7.98**	9.25**	11.22**	16.48**	1.00
Cr^{3+} ($mg\,L^{-1}$)	0.01	0.28**	0.59**	1.26**	1.45**	1.67**	2.00
SPC ($SPC\,mL^{-1}$)	4.8×10^{3}	5.79×10^{6}**	4.98×10^{8}**	7.96×10^{10}**	6.97×10^{12}**	8.78×10^{14}**	10000
Total coliforms ($MPN100\,mL^{-1}$)	2.4×10^{2}	4.48×10^{4}**	5.79×10^{6}**	6.87×10^{8}**	7.78×10^{10}**	6.99×10^{12}**	5000

ns, *, **: nonsignificant or significant at $P \leq 0.05$ or $P \leq 0.01$, respectively, least squares means.
[a]BWW: well water control.
[b]BIS: Bureau of Indian standard.
[c]"—": not given in standard.

Table 2: ANOVA for the effect of sugar mill effluent on soil characteristics.

Source	WHC	BD	EC	pH	OC	Na^{+}	K^{+}	Ca^{2+}	Mg^{2+}	Fe^{3+}	TKN	PO_4^{3-}	SO_4^{-2}	Zn^{2+}	Cd^{2+}	Cu^{2+}	Mn^{2+}	Cr^{3+}
Season (S)	ns	ns	ns	ns	*	*	*	*	*	*	*	*	*	*	*	*	ns	*
SME concentration (C)	ns	ns	**	*	**	**	*	*	*	**	**	**	**	**	**	**	*	**
Interaction S × C	ns	ns	*	*	**	**	**	**	**	**	**	**	**	**	**	**	**	**

ns, *, **: nonsignificant or significant at $P \leq 0.05$ or $P \leq 0.01$, ANOVA; SME: sugar mill effluent.

Cr^{3+} in the soil (Table 2). The values of Zn^{2+}, Cd^{2+}, Cu^{2+}, Mn^{2+}, and Cr^{3+} in the soil were increased when the effluent concentrations increased (Table 4). The concentration of Mn was highest while that of Cr was lowest after sugar mill effluent irrigation in both seasons. The contamination factor (Cf) of the heavy metals indicated the contamination after sugar mill effluent irrigation. The Cf of heavy metals in the soil was in the order of $Mn^{2+} > Zn^{2+} > Cu^{2+} > Cd^{2+} > Cr^{3+}$ after irrigation with sugar mill effluent in both seasons (Figure 1). Thus, fertigation increased the nutrients as well as metals in the soil.

3.3. *Effects of Sugar Mill Effluent Fertigation on Z. mays*

3.3.1. Effects on Germination. Seed germination of *Z. mays* was affected by sugar mill effluent treatment (Table 6, Figure 2). At 0–15 days after sowing, the best germination (96.00% and 94.00%) was noted with 40% sugar mill effluent and the least (86.00% and 85.00%) was recorded with 100% sugar mill effluent. Germination of *Z. mays* was observed to be negatively correlated with sugar mill effluent concentrations in both seasons (Table 9). The ANOVA indicated that the seasons showed insignificant ($P > 0.05$) effect on seed

Table 3: Effects of sugar mill effluent concentration and season interaction on physicochemical characteristics of soil used in the cultivation of *Z. mays* in both seasons.

Season × %SME	EC ($dS\cdot m^{-1}$)	pH	OC ($mg\cdot kg^{-1}$)	Na^+ ($mg\cdot kg^{-1}$)	K^+ ($mg\cdot kg^{-1}$)	Ca^{2+} ($mg\cdot kg^{-1}$)	Mg^{2+} ($mg\cdot kg^{-1}$)
Rainy							
0	1.92	7.63	0.52	25.48	164.53	16.52	23.43
20	2.98ns	7.82ns	3.68*	33.96*	188.55ns	29.67*	38.86*
40	5.66*	8.01ns	6.34**	60.85*	237.94**	69.88**	59.96**
60	7.78*	8.26*	10.92**	77.86*	265.68**	98.65**	7.36**
80	9.86*	8.43*	15.88**	87.63**	290.98*	128.52**	74.82*
100	12.88**	8.63*	18.86**	96.76**	324.75*	144.87**	88.69*
Summer							
0	1.94	7.64	0.54	25.68	165.88	17.86	23.69
20	3.72ns	7.94ns	4.01*	35.69*	192.86ns	31.75*	48.85*
40	6.36*	8.15ns	6.96**	65.25*	248.68**	79.84**	72.32**
60	8.48*	8.37*	17.86**	87.36*	278.98*	117.56**	78.69**
80	11.55*	8.52*	19.78**	89.69**	299.36*	148.69**	85.55*
100	14.96**	8.72*	21.84**	99.36**	334.88*	159.96**	98.69*

ns, *, ** : nonsignificant or significant at $P \leq 0.05$ or $P \leq 0.01$, respectively, least squares means; SME: sugar mill effluent.

Table 4: Effects of sugar mill effluent concentration and season interaction on physicochemical characteristics of soil used in the cultivation of *Z. mays* in both seasons.

Season × %SME	TKN ($mg\,kg^{-1}$)	PO_4^{3-} ($mg\,kg^{-1}$)	SO_4^{2-} ($mg\,kg^{-1}$)	Fe^{3+} ($mg\,kg^{-1}$)	Zn^{2+} ($mg\,kg^{-1}$)	Cd^{2+} ($mg\,kg^{-1}$)	Cu^{2+} ($mg\,kg^{-1}$)	Mn^{2+} ($mg\,kg^{-1}$)	Cr^{3+} ($mg\,kg^{-1}$)
Rainy									
0	36.88	63.69	84.58	4.58	0.56	0.33	1.14	0.59	0.29
20	82.36**	98.47*	131.36*	8.86ns	2.96ns	1.22ns	4.40ns	3.05ns	0.29ns
40	174.33**	145.64*	156.78**	19.96*	4.30*	1.56*	6.68*	6.09ns	0.74*
60	295.29**	176.93**	186.68**	38.78*	6.87*	1.94*	9.36**	8.15ns	0.99*
80	358.75**	183.3**	254.36**	58.47**	8.96**	2.11**	12.36**	10.25**	1.58*
100	438.64*	248.75**	287.96**	75.68**	12.68**	3.66**	15.48**	13.69*	1.96**
Summer									
0	37.45	64.24	84.88	4.60	0.57	0.34	1.16	0.62	0.32
20	86.49**	96.79*	139.69*	9.36ns	3.29ns	1.34ns	4.76ns	3.36ns	0.45ns
40	182.88**	143.85*	177.84**	23.25*	4.64*	1.78*	7.81*	6.84ns	0.84*
60	324.24**	184.25**	196.55**	45.63*	7.49*	2.06*	10.15**	9.63ns	1.86*
80	398.96**	193.8**	268.41**	67.75**	9.76**	2.36*	13.48**	12.44**	1.96*
100	460.88**	258.69**	294.68**	78.87**	14.12**	4.25*	16.78**	15.56*	2.36**

ns, *, **: nonsignificant or significant at $P \leq 0.05$ or $P \leq 0.01$, respectively, least squares means analysis; SME: sugar mill effluent.

germination and relative toxicity. Sugar mill effluent concentrations and their interaction with seasons affected seed germination of *Z. mays*, but not relative toxicity (Table 6).

The maximum RT (106.25% and 104.78%) of sugar mill effluent against germination of *Z. mays* was observed with 100% sugar mill effluent and it was positively correlated with all concentrations of sugar mill effluent in both seasons (Table 9, Figure 3). The findings were very much in accordance with Radhouane [34], who reported that the germination of millet cultivars was decreased when concentration of waste effluent increased from 0% to 100%.

In the present investigation, the higher concentration of sugar mill effluent did not support seed germination. The higher concentration of sugar mill effluent lowered the seed germination of *Z. mays*, and it is likely due to the presence of higher salt content in the effluent at these concentrations. The excessive quantities of inorganic salts and the higher EC, since these biotoxic substances present in the effluent at higher concentrations, increase the salinity and osmotic pressure, which might have inhibited seed germination by altering the interaction of seed and water which is necessary for triggering enzyme activity as also reported by findings of earlier researchers [26, 34, 48, 49].

3.3.2. Effects on Vegetative Growth Stage. Vegetative growth of *Z. mays* at 45 days was affected in both seasons (Table 6). The minimum root length (12.15 and 13.21 cm), number of leaves (10.00 and 12.00), and dry weight/plant (55.87 and

Table 5: Coefficient of correlation (r) between sugar mill effluent and soil characteristics in both seasons.

Effluent/soil characteristics	Season	r-value
Sugar mill effluent versus soil WHC	Rainy	−0.97
	Summer	−0.97
Sugar mill effluent versus soil BD	Rainy	−0.96
	Summer	−0.96
Sugar mill effluent versus soil EC	Rainy	+0.98
	Summer	+0.98
Sugar mill effluent versus soil pH	Rainy	−0.96
	Summer	−0.96
Sugar mill effluent versus soil OC	Rainy	+0.99
	Summer	+0.99
Sugar mill effluent versus soil Na^+	Rainy	+0.97
	Summer	+0.97
Sugar mill effluent versus soil K^+	Rainy	+0.87
	Summer	+0.87
Sugar mill effluent versus soil Ca^{2+}	Rainy	+0.76
	Summer	+0.76
Sugar mill effluent versus soil Mg^{2+}	Rainy	+0.63
	Summer	+0.63
Sugar mill effluent versus soil TKN	Rainy	+0.99
	Summer	+0.99
Sugar mill effluent versus soil $PO_4{}^{3-}$	Rainy	+0.99
	Summer	+0.99
Sugar mill effluent versus soil $SO_4{}^{2-}$	Rainy	+0.96
	Summer	+0.96
Sugar mill effluent versus soil Fe^{3+}	Rainy	+0.99
	Summer	+0.99
Sugar mill effluent versus soil Zn^{2+}	Rainy	+0.94
	Summer	+0.94
Sugar mill effluent versus soil Cd^{2+}	Rainy	+0.97
	Summer	+0.97
Sugar mill effluent versus soil Cu^{2+}	Rainy	+0.99
	Summer	+0.99
Sugar mill effluent versus soil Mn^{2+}	Rainy	+0.99
	Summer	+0.99
Sugar mill effluent versus soil Cr^{3+}	Rainy	+0.99
	Summer	+0.99

57.98 g) of *Z. mays* were recorded with control while moderate root length (12.44 and 13.63 cm), number of leaves (12.00 and 13.00), and dry weight/plant (44.78 and 45.96 g) of *Z. mays* were observed with 100% sugar mill effluent in both seasons. The maximum root length (14.24 and 16.12 cm), number of leaves (14.00 and 16.00), and dry weight/plant (65.47 and 68.68 g) of *Z. mays* were noted with 40% concentration of sugar mill effluent in both seasons. Sugar mill effluent concentrations, the seasons, and their interaction had no effect on root length, number of leaves, and dry weight of the *Z. mays* (Table 6).

Maximum plant height, fresh weight, chlorophyll content, and LAI/plant of *Z. mays* were due to the treatment with the 40% concentration of sugar mill effluent in both seasons (Table 7). The ANOVA indicated that sugar mill effluent concentrations affected plant height, fresh weight, chlorophyll content, and LAI/plant of *Z. mays* (Tables 6 and 7). The seasons had no effect on plant height, fresh weight, chlorophyll content, and LAI/plant of *Z. mays*. The interaction of seasons and sugar mill effluent concentrations affected plant height, fresh weight, chlorophyll content, and LAI/plant of *Z. mays* (Tables 6 and 7).

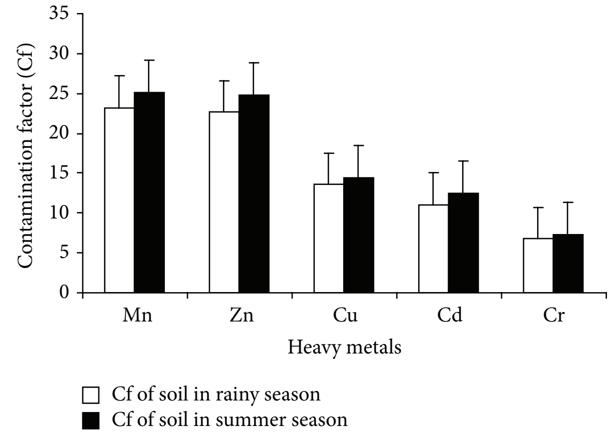

Figure 1: Contamination factor of heavy metals in soil after irrigation with sugar mill effluent. Error bars are standard error of the mean.

Plant height, number of leaves, fresh weight, dry weight, chlorophyll content, and LAI/plant of *Z. mays* were noted to be positively correlated with sugar mill effluent concentrations in both seasons (Table 9). Root length was observed to be positively correlated with sugar mill effluent concentrations in the rainy season while it was noted to be negatively correlated in summer season (Table 9). Osaigbovo and Orhue [11] reported the maximum plant height, number of leaves, and chlorophyll content at 25% of pharmaceutical effluent treatment on maize plant. Khan et al. [10] reported that treated effluent irrigation increases chlorophyll and protein contents in pearl millet plants (*P. glaucum* L.) at the 25 and 50% sugar mill effluent concentrations followed by a decrease in 75% and 100% sugar mill effluent.

Vegetative growth of *Z. mays* was lowered at higher concentrations of sugar mill effluent. A high EC indicates higher salt content in the higher sugar mill effluent concentrations, which lowered the plant height, root length, number of leaves, fresh weight, dry weight, chlorophyll content, and LAI/plant of *Z. mays*. Vegetative growth is associated with the development of new shoots, twigs, leaves, and leaf area. Plant height, fresh weight, chlorophyll content, and LAI/plant of *Z. mays* were recorded higher at 40% of sugar mill effluent; it may be due to the maximum uptake of nitrogen, phosphorus, and potassium by plants. The improvement of vegetative growth may be attributed to the role of potassium in nutrient and sugar translocation in plants and turgor pressure in plant cells [50]. It is also involved in cell enlargement and in triggering young tissue or meristematic growth [51]. Chlorophyll content was noted higher due to the use of 40% sugar mill effluent in both seasons and is likely due to Fe^{3+},

Table 6: ANOVA for the effect of sugar mill effluent on agronomical characteristics of *Z. mays*.

Source	Seed germination	Relative toxicity	Plant height	Root length	Number of leaves	Fresh weight	Dry weight	Chlorophyll content	LAI	Cob length	CY/plant	HI
Season (S)	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	*	*
SME concentration (C)	*	ns	*	ns	ns	*	ns	*	*	*	*	*
Interaction S × C	*	ns	*	ns	ns	*	ns	*	*	*	*	*

ns, *: nonsignificant or significant at $P \leq 0.05$, ANOVA; SME: sugar mill effluent.

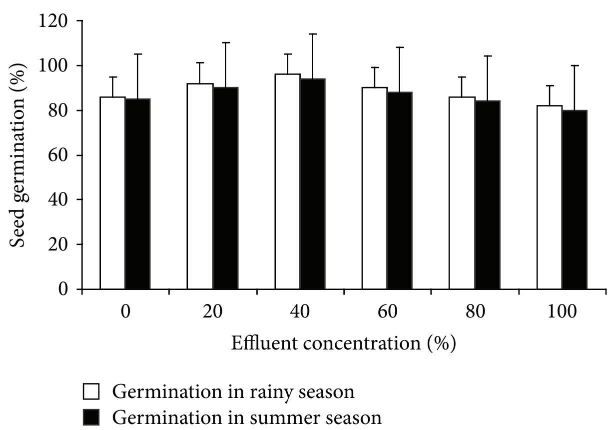

Figure 2: Seed germination of *Z. mays* after irrigation with sugar mill effluent. Error bars are standard error of the mean.

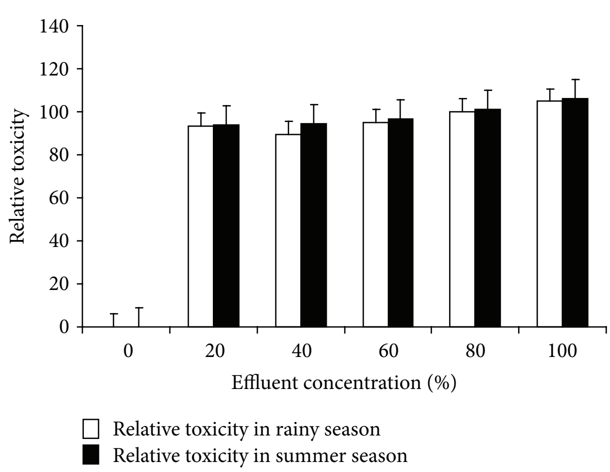

Figure 3: Relative toxicity of sugar mill effluent against seed germination of *Z. mays*. Error bars are standard error of the mean.

Mg^{2+}, and Mn^{2+} contents in the sugar mill effluent, which are associated with chlorophyll synthesis (Porra [36]). Thus, 40% sugar mill effluent concentration contains optimum contents of nutrients required for maximum vegetative growth of *Z. mays*.

3.3.3. Effects on Maturity Stage. At maturity stage (90 days after sowing) the cob length and crop yield/plant of *Z. mays* were noted with 40% sugar mill effluent in both seasons. Cob length and crop yield of *Z. mays* were decreased as the sugar mill effluent concentration increased (Table 7). Maximum HI (156.04 and 157.76%) of *Z. mays* was recorded with 40% concentration of sugar mill effluent while minimum HI (134.58% and 138.92%) was observed with 100% sugar mill effluent in both seasons. Sugar mill effluent concentrations affected cob length and crop yield of *Z. mays* but not seasons; interaction of seasons and sugar mill effluent concentrations had an effect on cob length and crop yield of *Z. mays* (Table 6). The seasons and sugar mill effluent concentrations had no effect on harvest index (HI) of *Z. mays*. Crop yield of *Z. mays* was observed to be positively correlated with sugar mill effluent concentrations in the rainy season while it was noted to be negatively correlated in the summer season (Table 9). The results were supported by Zalawadia and Raman [52], who observed that crop yield of sorghum was decreased with increase in distillery effluent concentrations.

Nitrogen (N) and phosphorus (P) are essential for flowering and grains filling. More quantity of N can delay or prevent flowering while P deficiency is sometimes associated with poor flower production or flower abortion. Maximum cob length of *Z. mays* was with the 40% sugar mill effluent; it might be due to the fact that this concentration contains sufficient N and P. Furthermore, N and P prevent flower abortion so grains filling occurs [53]. Cob length of *Z. mays* was decreased at higher concentrations of sugar mill effluent. This is likely due to the higher content of metals in the soil, which inhibits uptake of PO_4^{3-} and K^+ by plants at higher concentrations [54]. The role of K^+, Fe^{3+}, Mg^{2+}, and Mn^{2+} at maturity is important and associated with synthesis of chlorophyll and enhances the formation of grains at harvest [53, 55]. The K^+, Fe^{3+}, Mg^{2+} and Mn^{2+} contents could benefit cob formation, grains filling, and yield of maize (*Z. mays* L.) as reported by Ezhilvannan et al. [4]. The 40% concentration of sugar mill effluent favored the grains formation and crop yield of *Z. mays*. This is likely due to the presence of K^+, Fe^{3+}, Mg^{2+}, and Mn^{2+} contents in 40% sugar mill effluent, while higher sugar mill effluent concentrations lowered grains formation and crop yield of *Z. mays*.

3.4. Effects on Biochemical Constituents and Micronutrients in Z. mays. Seasons, sugar mill effluent concentrations, and the interaction of seasons and sugar mill effluent concentrations affected all the metals like crude proteins, crude fiber, total carbohydrates, Zn^{2+}, Cd^{2+}, Cu^{2+}, Mn^{2+}, and Cr^{3+} in *Z. mays* (Table 8). Maximum crude proteins, crude fiber, and total

Table 7: Effects of sugar mill concentration and season interaction on agronomical parameters of *Z. mays*.

Season × %SME	Plant height (cm)	Fresh weight (g)	Chlorophyll content (mg/g.f.wt.)	LAI	Cob length (cm)	Crop yield/plant (g)
Rainy						
0	176.86	123.13	3.32	2.35	16.58	54.42
20	184.56*	143.56*	3.95ns	3.55ns	18.63ns	68.75ns
40	204.58*	165.34*	4.81*	5.19*	22.36*	80.59*
60	192.85*	152.98*	4.71*	4.76*	20.36*	75.32*
80	188.37*	142.34*	4.42*	4.43*	19.48*	69.67ns
100	180.59*	130.56ns	3.45ns	3.81ns	18.18ns	62.88ns
Summer						
0	170.69	115.34	3.12	2.12	14.46	50.74
20	180.25*	137.56*	3.46ns	3.46ns	16.63ns	62.36ns
40	198.86*	158.76*	4.62*	5.12*	20.26*	76.89*
60	184.77*	147.23*	4.29*	4.29*	21.66*	71.74ns
80	178.55*	135.55*	4.18*	4.37*	20.75*	65.96ns
100	172.64*	124.78ns	3.38ns	3.68ns	16.56ns	60.47ns

*Significant at $P \leq 0.05$, least means squares analysis; SME: sugar mill effluent.

Table 8: ANOVA for the effect of sugar mill effluent on concentrations of metals and biochemical components of *Z. mays*.

Source	Zn^{2+}	Cd^{2+}	Cu^{2+}	Mn^{2+}	Cr^{3+}	Crude proteins	Crude fiber	Total carbohydrates
Season (S)	*	*	*	*	*	*	*	*
SME concentration (C)	**	**	**	**	**	**	**	**
Interaction S × C	**	**	**	**	**	**	**	**

*, **: significant at $P \leq 0.05$ or $P \leq 0.01$, ANOVA; SME: sugar mill effluent.

carbohydrates were recorded with 40% sugar mill effluent concentrations in both seasons (Figures 4, 5, and 6). Content of crude proteins ($r = +0.21$ and $r = +0.34$), crude fiber ($r = +0.20$ and $r = +0.18$), and total carbohydrates ($r = +0.06$) were noted to be positively correlated with all concentrations of sugar mill effluent in both seasons. The contamination factor (Cf) was affected in both seasons (Figures 7–9). The 20% to 100% sugar mill effluent concentrations affected Zn^{2+}, Cd^{2+}, Cu^{2+}, Mn^{2+}, and Cr^{3+} contents in *Z. mays*. Increased irrigation frequency could lead to increase of metals in tissues. The Zn^{2+}, Cd^{2+}, Cu^{2+}, Mn^{2+}, and Cr^{3+} contents in *Z. mays* were noted highest with 100% sugar mill effluent (Figures 7 and 8). They were correlated with the content of Zn^{2+}, Cd^{2+}, Cu^{2+}, Mn^{2+}, and Cr^{3+} in *Z. mays* and were positively correlated with sugar mill effluent concentrations in both seasons (Table 9). The Cf of various heavy metals was in the order of $Mn^{2+} > Zn^{2+} > Cu^{2+} > Cr^{3+} > Cd^{2+}$ in *Z. mays* after irrigation with sugar mill effluent (Figure 9). The highest contamination factor was noted for Mn^{2+}; the least was observed for Cd^{2+} in *Z. mays* with 100% sugar mill effluent in both seasons. The contents of heavy metals were noted higher at higher concentrations of sugar mill effluent and likely inhibited the growth of *Z. mays*. The 40% concentration of sugar mill effluent was favored in vegetative growth, grain filling, and maturity of *Z. mays*. This is likely due to the optimal uptake of these metals by crop plants, which support various biochemical and physiological processes.

4. Conclusions

This study concluded that the sugar mill effluent increased the EC, OC, Na^{+}, K^{+}, Ca^{2+}, Mg^{2+}, Fe^{3+}, TKN, PO_4^{3-}, SO_4^{2-}, Zn^{2+}, Cd^{2+}, Cu^{2+}, Mn^{2+}, and Cr^{3+} of the soil in both the rainy and summer season. The effluent irrigation significantly changed the soil quality and affected the natural composition of the soil. Such alterations improved the fertility and enhanced the nutrient status of soil at lower concentrations of effluent irrigation. The accumulations of heavy metals, namely, Cd^{2+}, Cr^{3+}, Cu^{2+}, Mn^{2+}, and Zn^{2+}, in soil and *Z. mays* were increased with an increase in sugar mill effluent concentrations in both seasons. These were recorded maximum with 100% concentration of sugar mill effluent. The agronomic performance of *Z. mays* was gradually increased from 20% to 40% and decreased from 60% to 100% concentration of sugar mill effluent in both seasons. The maximum growth performance of *Z. mays* was noted with 40% concentration of sugar mill effluent in both seasons. It may be due to the fact that, at lower concentrations, the nutrients and heavy metals may provide better and much

TABLE 9: Coefficient of correlation (r) between sugar mill effluent and *Z. mays* in both seasons.

Effluent/*Z.mays*	Season	r-value
Sugar mill effluent versus seed germination	Rainy	−0.47
	Summer	−0.53
Sugar mill effluent versus RT	Rainy	+0.74
	Summer	+0.73
Sugar mill effluent versus plant height	Rainy	+0.10
	Summer	+0.07
Sugar mill effluent versus root length	Rainy	+0.13
	Summer	−0.14
Sugar mill effluent versus number of leaves	Rainy	+0.58
	Summer	+0.41
Sugar mill effluent versus fresh weight	Rainy	+0.07
	Summer	+0.10
Sugar mill effluent versus dry weight	Rainy	+0.05
	Summer	+0.03
Sugar mill effluent versus chlorophyll content	Rainy	+0.16
	Summer	+0.28
Sugar mill effluent versus LAI	Rainy	+0.50
	Summer	+0.50
Sugar mill effluent versus cob length	Rainy	+0.32
	Summer	+0.33
Sugar mill effluent versus crop yield/plant	Rainy	+0.05
	Summer	−0.15
Sugar mill effluent versus HI	Rainy	+0.10
	Summer	+0.09
Sugar mill effluent versus Zn^{2+}	Rainy	+0.95
	Summer	+0.97
Sugar mill effluent versus Cd^{2+}	Rainy	+0.86
	Summer	+0.87
Sugar mill effluent versus Cu^{2+}	Rainy	+0.99
	Summer	+0.99
Sugar mill effluent versus Mn^{2+}	Rainy	+0.99
	Summer	+0.98
Sugar mill effluent versus Cr^{3+}	Rainy	+0.89
	Summer	+0.90

effective stimulation to the agronomic performance of the *Z. mays*, while more irrigation increased the accumulation of nutrients/heavy metals at higher effluent concentrations (i.e., 60% and 100%), thus inhibiting the overall performance of the crop plants. Biochemical components like crude proteins, crude fiber, and total carbohydrates were also highest with 40% sugar mill effluent in both seasons. The contamination factor (Cf) of various heavy metals was in the order of Mn^{2+} > Zn^{2+} > Cu^{2+} > Cd^{2+} > Cr^{3+} for soil and Mn^{2+} > Zn^{2+} > Cu^{2+} > Cr^{3+} > Cd^{2+} for *Z. mays* in both seasons after fertigation with sugar mill effluent. It appears that sugar mill effluent can be used as a biofertigant after appropriate dilution to improve the yield. Further studies on the agronomic growth and changes in biochemical composition of *Z. mays* after sugar mill effluent irrigation are required.

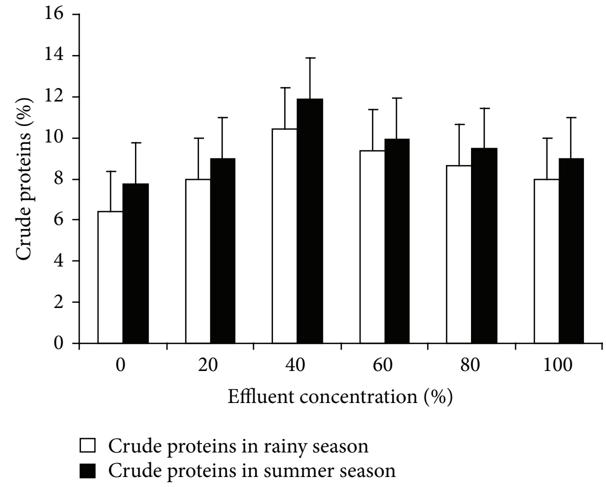

FIGURE 4: Crude proteins in *Z. mays* after irrigation with sugar mill effluent. Error bars are standard error of the mean.

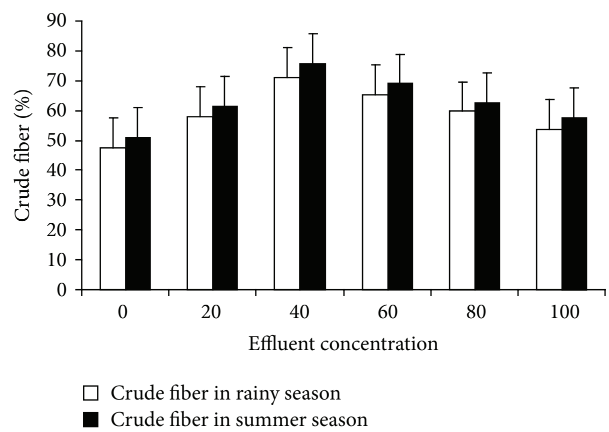

FIGURE 5: Crude fiber in *Z. mays* after irrigation with sugar mill effluent. Error bars are standard error of the mean.

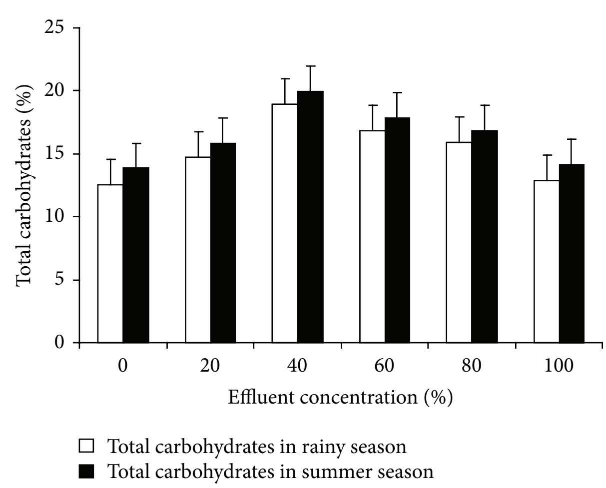

FIGURE 6: Total carbohydrates in *Z. mays* after irrigation with sugar mill effluent. Error bars are standard error of the mean.

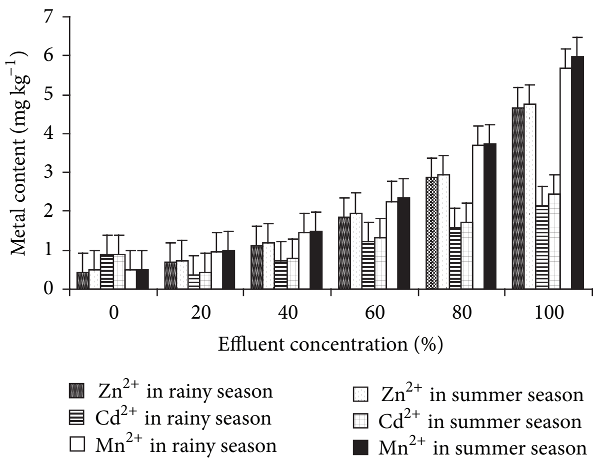

Figure 7: Content of Zn, Cd, and Mn in *Z. mays* after irrigation with sugar mill effluent. Error bars are standard error of the mean.

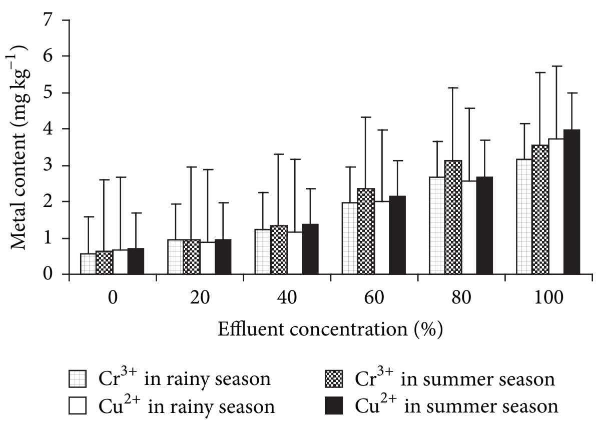

Figure 8: Content of Cr and Cu in *Z. mays* after irrigation with sugar mill effluent. Error bars are standard error of the mean.

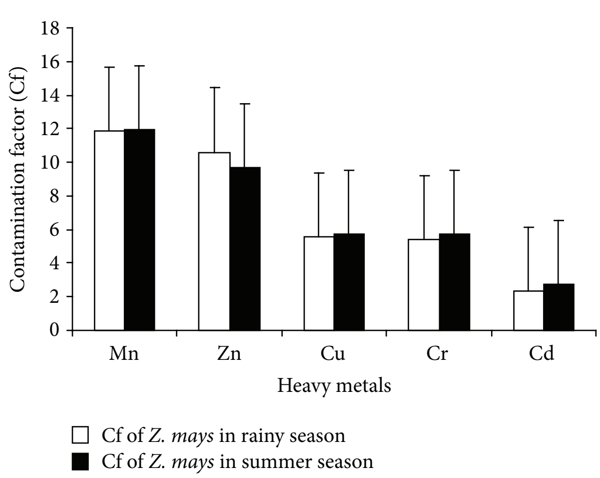

Figure 9: Contamination factor of heavy metals in *Z. mays* after irrigation with sugar mill effluent. Error bars are standard error of the mean.

Abbreviations

ANOVA: Analysis of variance
BD: Bulk density
BIS: Bureau of Indian standards
BWW: Bore well water
CD: Critical difference
Cf: Contamination factor
HI: Harvest index
LAI: Leaf area index
MPN: Most probable numbers
RT: Relative toxicity
SPC: Standard plate count
WHC: Water holding capacity.

Conflict of Interests

The author declares that there is no conflict of interests regarding the publication of this paper.

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