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Effect of sugar industry spentwash (diluted) on the characteristics of soil and sugarcane (*Saccharum officinarum* L.) growth in the subtropical environment of Sindh, Pakistan

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Abstract Spentwash is a rich source of organic matter and essential plant nutrients in addition to excess salts. Sugar mills in Pakistan discharge about 3.48 million tons of spentwash annually, with no proper procedures for its disposal or utilization. To test the effect of diluted spentwash on soil and the soil's ability to support plant growth, sugarcane (*Saccharum officinarum* L.) variety CPF-237 was planted. The experiment was conducted in a randomized complete block design involving factorial combination of four concentrations of each spentwash (0, 10, 20, and 30%) and mineral fertilizers (0, 1/3, 2/3, and the full recommended rate of NP). The 10% spentwash plus 2/3 mineral fertilizer treatment substituted 33% each of N and P and 100% of K, saving mineral fertilizer cost (Rs. 48600 ~ US$458) in addition to 29.54% increase in yield over full NP fertilizer. The same treatment also improved the soil organic matter (65%), N (20%), P (25%), and K (230%) over full NP treatment alone. An increase in the salt content of the soil was detected within the prescribed limits, with the exception of HCO_3.

Keywords Spentwash · Mineral fertilizer · Soil characteristics · Sugarcane

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Introduction

The sugar industry plays a vital role in the economy of Pakistan. Among 88 sugar mills in the country, 37 are located in Sindh Province and produce 1.92 million tons of sugar along with 0.85 million tons of molasses (PSMA 2014) which forms the basis for production of ethanol. To elucidate, 1 L of molasses produces 0.37 L of ethanol, which in turn generates about 10–12 L of spentwash. This way, 3.48 million tons of spentwash are annually generated. Industries have a limited capacity to store this liquid in lagoons, and consequently, much of it is disposed off in areas surrounding the mills. Unmanaged handling and disposal creates environmental problems influencing soil environment (Chhonkar et al. 2000).

Spentwash is of two types: the untreated and the treated one. The "untreated" spentwash is directly discharged from distilleries, while the "treated" one is released as a result of methanation process within distilleries. The untreated spentwash is acidic (pH 3.8) in nature with high BOD (8000 mg L^{-1}), COD (30,000 mg L^{-1}), and salt (Na, Cl, and HCO_3) content (Cinthya et al. 2014; Wagh and Nemade 2015) compared with the treated one, which is alkaline in nature (pH 8.0) with a lower BOD (4620 mg L^{-1}), COD (26,000 mg L^{-1}), and salt content (Na, Cl, and HCO_3) (Pugazh et al. 2016). The treated spentwash contains 5.8–15.93% organic matter, 6500–9097 mg L^{-1} K, 947–5100 mg L^{-1} S, in addition to other macro- (N, P, Ca, Mg) and micronutrients (Cu, Fe, Mn, and Zn) (Kalaiselvi and Mahimairaja 2009; Rajagopal et al. 2014). The spentwash from Pakistani sugar mills exhibits the following characteristics: pH 7.74, total soluble solids (TSS) 612 mg L^{-1}, total dissolved solids (TDS) 3010 mg L^{-1}, BOD 1622 mg L^{-1}, and COD 2494 mg L^{-1} (Nadia and Khwaja 2006).

The latest scientific research relating to spentwash application in agriculture emphasizes the potential benefits of diluted spentwash (Chandraju et al. 2013; Chopra et al. 2013) in contrast to the concentrated one having excess anions and cations that may be harmful to plants in the long run (Pandey et al. 2008; Kaloi et al. 2015). Furthermore, the diluted spentwash can increase the chlorophyll content (Rath et al. 2011; Chopra et al. 2013) and ultimately the plant growth. Furthermore, the incubation and field studies pertaining to the use of diluted spentwash have shown increased microbial activity in soils (Adhikary 1989; Saliha et al. 2005; Selvamurugan et al. 2011). Diluted spentwash has been used on sugarcane at various rates or concentrations in Venezuela (50,000 L ha^{-1}—one time application), Cuba (5–40%), India (25–75%), and Mauritius (100,000 L ha^{-1}—one time application), resulting in increased yields of 43, 64, 63, and 10%, respectively (Gomez and Rodriguez 2000; Armengol et al. 2003; Janaki and Velu 2010; Soobadar and Kwong 2012). It is also to have a positive effect on the growth and yield of other crops such as rice, wheat, corn, and sorghum (Benitez et al. 2000; Sukanya and Meli 2004; Tejada and Gonzalez 2007; Das et al. 2010; Kumari and Phogat 2012) and improvement in soil reaction, nutrient status, and biological activity (Pathak et al. 1999; Hati et al. 2007; Jiang et al. 2012).

Sugarcane requires large quantities of nutrients for growth, with a particular requirement for K. To produce 100 tons of sugarcane, 140:34:332 kg of N:P:K is needed (Dang et al. 1995). The soils of Pakistan are deficient in N and P (90%) and K (40%) (Ahmad and Rashid 2004) and have a low organic matter content (Sarwar et al. 2011). Local farmers are often not able to bear the cost of P and K fertilizers, leading to low cane yields (57.55 t ha^{-1}) (PSMA 2014). The waste materials of plant origin can be supplemented with expensive mineral fertilizer (Memon et al. 2012) in a sustainable manner with minimum adverse effects on the environment including soil. The main objective of this research was to test the effect of spentwash on soil and the soil's ability to support sugarcane growth.

Materials and methods

Experimental details

A field study was carried out at the experimental farm of Matiari Sugar Mills, in the district of Matiari (25.59° N and 68.44° E), Sindh, Pakistan, during 2012–2013. Sindh is a subtropical region of the country, experiencing hot summers and mild cold winters. The average temperature in this region is 32 °C, which frequently rises to 45–48 °C during June–August, with an average rainfall of 15–18 cm. The experiment was conducted in a randomized complete block design, with 16 treatments replicated thrice. The treatments were a factorial combination of four spentwash concentrations (0, 10, 20, and 30%) and four mineral fertilizer rates (0, 1/3, 2/3, and full) based on a recommended dose of 250 kg N and 125 kg P_2O_5 ha^{-1} applied in the form of urea and diammonium phosphate. The upper limit of spentwash concentration (30%) used in this study is based on the previous studies (Armengol et al. 2003; Deora et al. 2008; Gahlot et al. 2011; Rath et al. 2013) with majority of them reporting minimum survival of plants above this concentration. A pot study (unpublished data) prior to field experiment on sugarcane germination and initial growth parameters at various spentwash concentrations (0, 5, 10, 20, 40, 60, 80, and 100%) also confirmed the same.

In each treatment (22.5 m^2), two budded sets of sugarcane (variety CPF-237) were planted in five rows, with a 0.75-m row to row space. The crop was irrigated four times with canal water from February to March 2012, followed by 12 spentwash applications from April 2012 to January 2013. The required spentwash concentrations were prepared in plastic barrels for each treatment and applied through a siphon outlet. The quantity of water was based on a 3-acre-inch irrigation using the irrigator's basic equation $Q \times T = A \times D$ (Irrigation Slide Chart 1999), where Q is the water discharge in cusecs, T is the time in hours, A is the area in acres, and D is the depth in inches. A cusec was calculated based on water flow (18 L per min from a 1-in. faucet).

Ten canes were randomly selected from each treatment and cleaned. The tops were removed and labeled separately for measurement of cane growth parameters. Plant height and internode length were recorded using a measuring tape; cane thickness was recorded using a digital Vernier caliper (EK-1114, E& K Tools Inc. Huan, China); and the number of internodes in each plant was just counted. For millable canes, the whole plot was harvested and the cane sticks were simply counted and weighed to obtain the cane yield.

Sampling of spentwash and soil

Spentwash (treated) samples were collected from the distillery of Matiari Sugar Mills at the time of each irrigation. Samples were preserved in a polycarbonyl sterilized air-free containers leaving one quarter of each container empty. The labeled samples were stored, immediately packed into ice boxes, transported to the laboratory, and kept at 4 °C in a refrigerator (APHA, AWWA and WEF 1998).

Soil samples (composite of eight) were secured before planting and after harvesting from each treatment at four soil depths (surface 0–15 cm, subsurface 15–30 cm, sub-lower 30–45 cm, and lower 45–60 cm). The soil samples were air-dried in shade after removing debris or other material (e.g., roots or leaves), crushed gently, ground, passed through a 2-mm nylon sieve, and preserved in plastic containers for analyses.

Methods of analysis

Spentwash samples diluted to 0, 10, 20, and 30% concentration were analyzed for color; odor; electrical conductivity; pH; total solids (TSS + TDS); BOD; COD; total Ca, Mg, and Na; HCO_3; Cl; SO_4; organic matter; and total N, P and K contents as described by APHA, AWWA and WEF (1998). The soil samples were analyzed for texture by the Bouyoucos hydrometer method (Bouyoucos 1962), electrical conductivity and pH (in 1:5 soil:water extract) by using EC (Model HI 8033, Hanna Inst.) and pH meter (Model 960, Schott Inst. GmbH), organic matter by Walkley–Black method (Tahir and Jabbar 1985), total N by Kjeldahl's method (Jackson, 1958), and P and K by ammonium bicarbonate diethylene triamine pentaacetic acid (AB-DTPA) extractable method as given in Ryan et al. (2001). Soluble anions (HCO_3 and Cl) and cations (Ca, Mg, and Na) were determined by the methods given in USSL (1954). The data for soluble Na, Ca, and Mg were used to calculate the sodium adsorption ratio (SAR) using the formula $SAR = Na^+ / [(Ca^{2+} + Mg^{2+} / 2)]^{1/2}$ (Chopra and Kanwar 1982).

Statistical analysis of the data

The data were analyzed using two-way analysis of variance (ANOVA), and means were separated by the least significant difference (LSD) method using the software program Statistix 8.1 (Analytical Software 2005). The mean values of the spentwash characteristics were evaluated based on the quality standards described by FAO (1985) and NEQS (2005).

Results and discussion

The spentwash characteristics are presented in Table 1 while Table 2 presents the data on soil properties before planting of sugarcane. The yield data and growth parameters as affected by spentwash and mineral fertilizers (N and P) are presented in Fig. 1, and statistical analysis of these parameters is given in Table 3. The soil characteristics after harvesting and the effects of spentwash are presented in Figs. 2 and 3, and statistical analysis of these data is shown in Table 4. The soil characteristics were compared with the previously reported categorizations (California Fertilizer Association 1980; Havelin and Soltanpour 1981; Bohn et al. 1985; Soltanpour 1985; Soil Survey Division Staff 1993; Muhammad 1996). The economic analysis of the data is presented in Table 5.

Spentwash characteristics

The analytical data for spentwash samples (10–30%) showed that pH (8.3 to 8.0), TS (5.5 to 18.6 mg L^{-1}), Cl (300 to 980 mg L^{-1}), SO_4 (134 to 410 mg L^{-1}), and SAR (5.04 to 5.80) values were within the respective permissible limit (PL) of these parameters, i.e., 6–9, <2000 mg L^{-1}, <1000 mg L^{-1}, <1000 mg L^{-1}, and 3–9 (Table 1). The BOD (216 mg L^{-1}) was within the PL of <250 mg L^{-1} only for 10% spentwash, and the HCO_3 content (113 and 221 mg L^{-1}) was also within the PL of 45–255 mg L^{-1} for 10 and 20% spentwash concentrations, respectively. However, the EC (7.3 to 14.7 dS m^{-1}), COD (6000 to 11,000 mg L^{-1}), and total P (50 to 74.7 mg L^{-1}) contents were above the PL of 0.7–3.0 dS m^{-1}, <400 mg L^{-1}, and <15 mg L^{-1},

Table 1 Characteristics of spentwash and canal water

Parameters	Spentwash concentrations (%)				Canal water	FAO, 1985
	10	20	30	100		
Color	Light brown	Red brown	Brown	Dark brown	Colorless	–
Odor	Repulsive	Repulsive	Unpleasant	Unpleasant	Odorless	–
EC (dS m^{-1})	7.3 ± 0.5	10.5 ± 0.9	14.7 ± 0.6	42 ± 5.3	0.5 ± 0.1	0.7–3.0
pH	8.3 ± 0.5	8.1 ± 0.35	8 ± 0.3	7.9 ± 0.5	7.5 ± 0.5	6–9[a]
TS (mg L^{-1})	5.5 ± 0.5	11.5 ± 0.6	18.6 ± 0.6	62.7 ± 4	53.9 ± 3.5	<2000
BOD (mg L^{-1})	216 ± 12.5	435 ± 12.3	650 ± 21.5	2000 ± 42.7	58.3 ± 6.5	–
COD (mg L^{-1})	6000 ± 278	9000 ± 233	11,000 ± 403	23,000 ± 206	220.33 ± 6.5	<400[a]
Total Ca (mg L^{-1})	124 ± 4	260 ± 8.5	500 ± 17	1520 ± 14.5	32.1 ± 1.7	–
Total Mg (mg L^{-1})	57.7 ± 4.1	102 ± 4.6	144.7 ± 6.1	468 ± 23.5	14.7 ± 0.7	–
Total Na (mg L^{-1})	260 ± 7.4	425 ± 7	570 ± 9.5	2000 ± 63	53.9 ± 3.4	69–207
HCO_3 (mg L^{-1})	113 ± 13	221 ± 16	348 ± 15	1198 ± 51	–	45–255
Cl (mg L^{-1})	300 ± 9	620 ± 9.5	980 ± 22.5	3300 ± 62.5	65.7 ± 3.5	<1000[a]
SO_4 (mg L^{-1})	134 ± 6.5	275 ± 12.1	410 ± 16.5	1270 ± 35	45.57 ± 0.55	<1000[a]
SAR	5.04 ± 0.15	5.65 ± 0.18	5.80 ± 0.2	11.50 ± 0.23	1.97 ± 0.04	3–9
Organic matter (%)	0.61 ± 0.03	1.25 ± 0.05	1.8 ± 0.02	5.7 ± 0.3	–	–
Total N (mg L^{-1})	410 ± 8.4	955 ± 6.2	1389 ± 51	4680 ± 28	1.43 ± 0.35	–
Total P (mg L^{-1})	50 ± 6	62 ± 4.6	74.7 ± 4.5	175 ± 10.5	0.02 ± 0.01	<15[a]
Total K (mg L^{-1})	2250 ± 42.7	4750 ± 56.9	6875 ± 52.7	23,750 ± 45.8	3.63 ± 0.4	–

[a] NEQS (2005) = National Environmental Quality Standards Pakistan

Table 2 Characteristics of the experimental soil at various depths before spentwash application

Parameters		Soil depth (cm)			
		0–15	15–30	30–45	45–60
EC (dS m^{-1})		1.55	0.63	0.32	0.20
pH		7.19	7.52	7.83	7.94
HCO_3 (mg kg^{-1})		390	250	240	230
Cl (mg kg^{-1})		303	198	128	117
Ca (mg kg^{-1})		806	426	253	220
Mg (mg kg^{-1})		228	148	76	56
Na (mg kg^{-1})		131	98	84	78
SAR		1.40	1.40	1.19	1.24
Organic matter (%)		0.22	0.19	0.09	0.06
Kjeldahl N (mg kg^{-1})		104	95	41	26
AB-DTPA P (mg kg^{-1})		5.92	4.23	0.73	0.58
AB-DTPA K (mg kg^{-1})		64	55	44	38
Particle size (%)	Sand	69.84	70.30	72.28	72.44
	Silt	8.54	8.23	7.44	7.33
	Clay	21.62	21.47	20.27	20.23
Textural class	Sandy clay loam				

respectively, as described by FAO (1985) and NEQS (2005). In the case of the undiluted spentwash (100%), all the measured parameters were above the PL, with the exception of pH (7.9) and TS (62.7 mg L^{-1}).

Soil characteristics

The soil was a sandy clay loam, with 20.69% clay, and non-saline (EC < 2 dS m^{-1}) with pH values ranging from 7.0 to 7.5 throughout the soil profile. The HCO_3 (390 mg k g^{-1}) and Cl (303 mg kg^{-1}) contents showed a decreasing trend with soil depth. The SAR was within the suitable range (<7.5) with values of 1.04–1.24 throughout the soil profile. Organic matter (0.06–0.22%), Kjeldahl's N (26–104 mg kg^{-1}), and available P (0.58–5.92 mg kg^{-1}) and K (38.0–64.0 mg kg^{-1}) decreased with soil depth and were below the respective critical limits of <0.86%, <500 mg kg^{-1}, <8 mg kg^{-1}, and <120 mg kg^{-1} at all soil depths (Table 2).

Effect of spentwash on growth and yield of sugarcane

The application of spentwash significantly ($P < 0.05$) influenced the growth and yield of sugarcane, while the

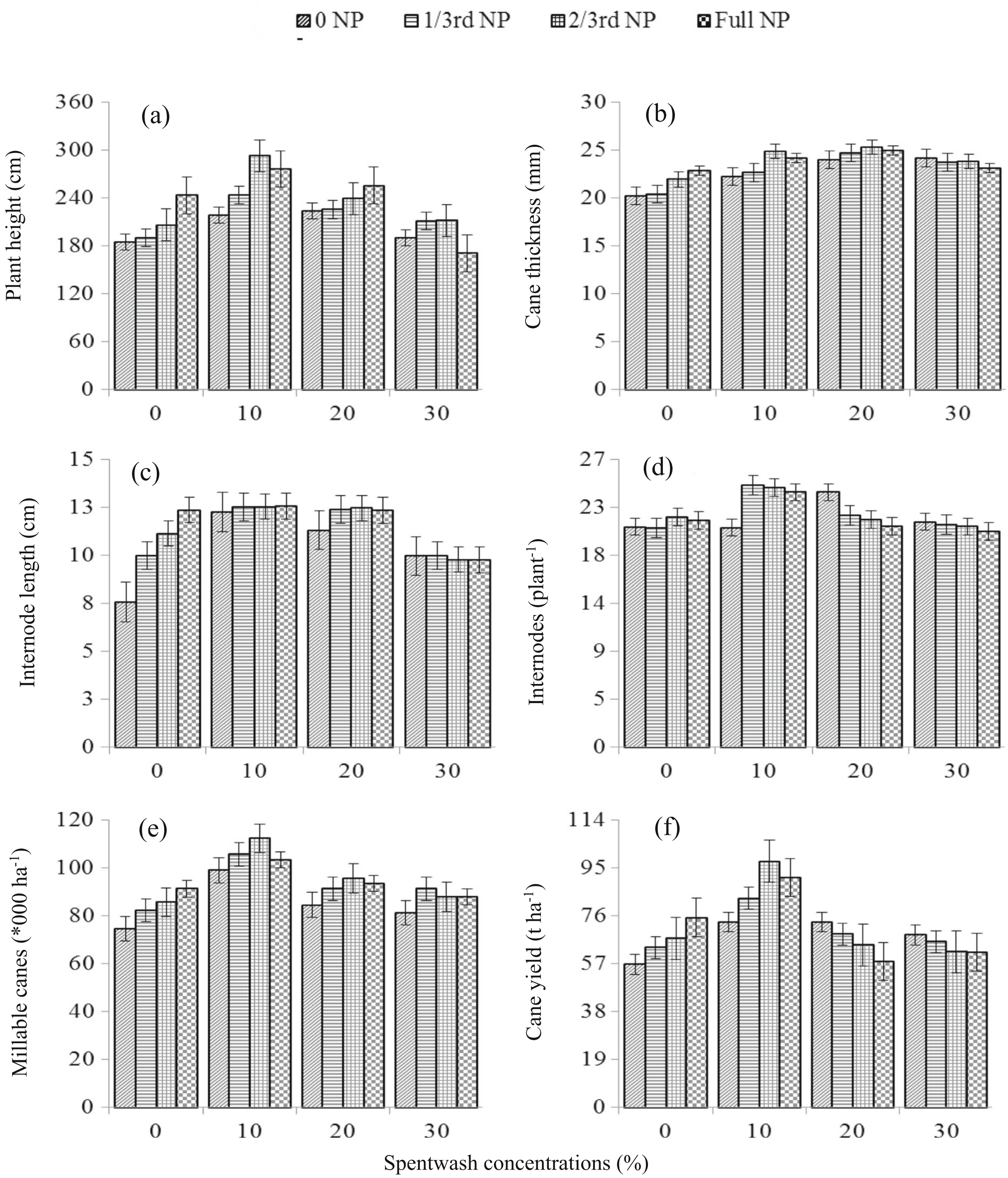

Fig. 1 Effect of diluted spentwash on sugarcane growth. **a** Plant height. **b** Cane thickness. **c** Internode length. **d** Internodes plant^{-1}. **e** Millable canes (*000 = thousand). **f** Cane yield

effect of mineral fertilizers was significant ($P < 0.05$) only for plant height, internode length, and millable canes. However, the interaction between spentwash and mineral fertilizers was significant for plant height, internode length, millable canes, and cane yield (Table 3).

Table 3 Statistical analyses of sugarcane growth parameters and yield as affected by spentwash concentrations and mineral fertilizer rates

Parameters	*F* value			$LSD_{0.05}$		
	SW	MF	SW × MF	SW	MF	SW × MF
Plant height (cm)	23.46	7.45	3.73	16.83	16.83	33.66
Cane thickness (mm)	10.11	2.07	0.79	1.29	NS	NS
Internode length (cm)	46.65	1.25	6.45	0.55	0.55	1.11
No. of internodes (plant^{-1})	4.67	0.21	1.56	1.57	NS	NS
Millable canes (000)	77.69	19.26	2.22	3.15	3.15	6.22
Cane yield (t ha^{-1})	28.46	1.06	4.50	5.66	NS	11.33

SW spentwash, *MF* mineral fertilizers, *NS* non-significant, *000* thousands

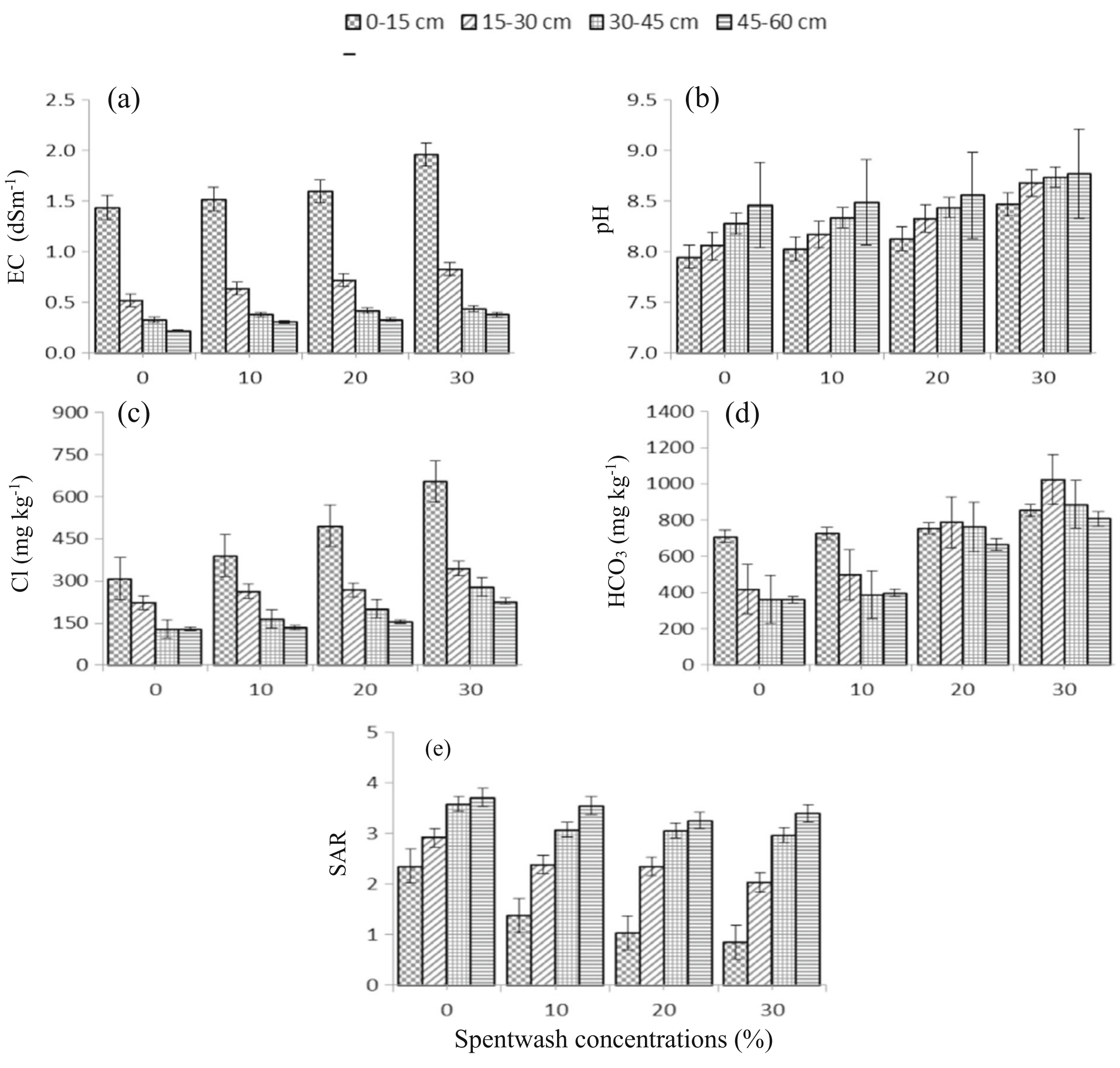

Fig. 2 Effect of spentwash concentration on different soil characteristics at various depths. **a** EC. **b** pH. **c** Cl. **d** HCO_3. **e** SAR

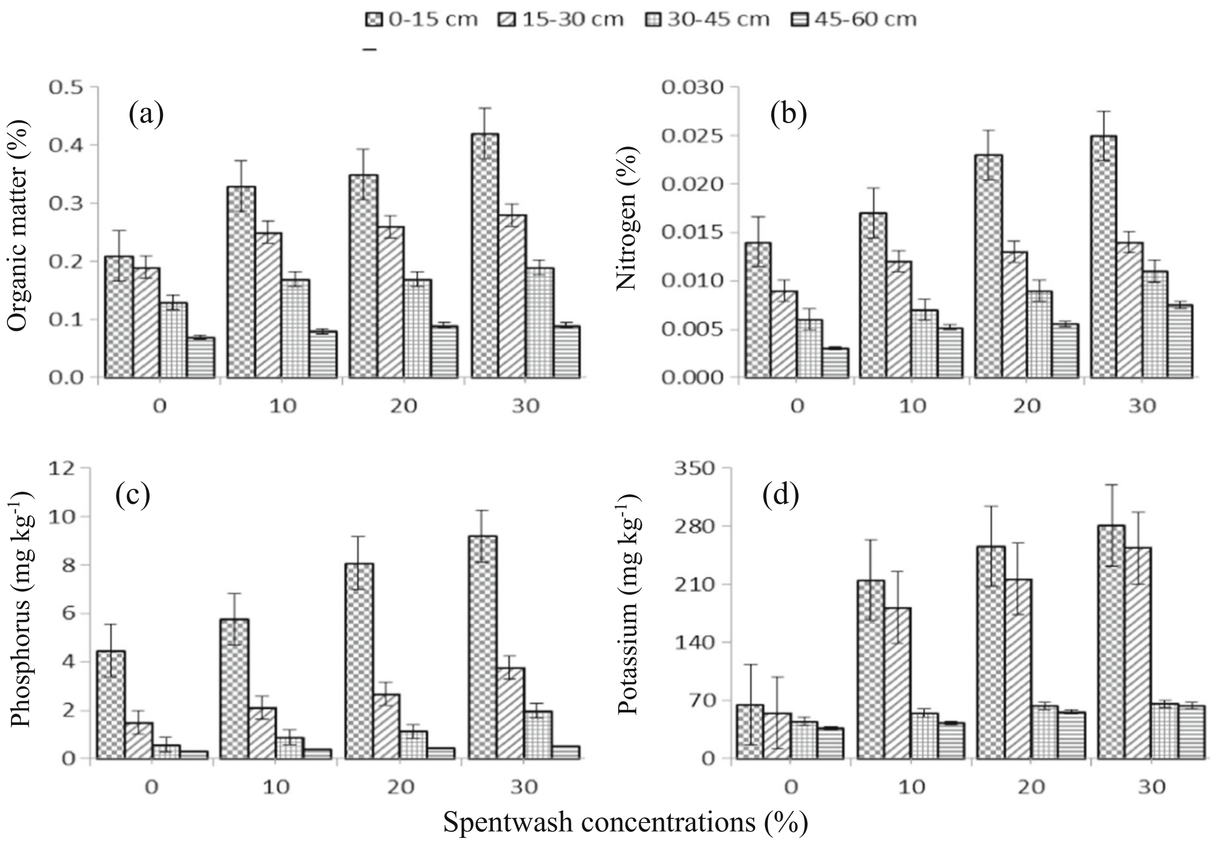

Fig. 3 Effect of diluted spentwash on different soil characteristics at various depths. **a** Organic matter. **b** Nitrogen. **c** Phosphorus. **d** Potassium

The application of lowest concentration of spentwash (10%) enhanced plant growth and increased plant height from 205.94 to 257.44 cm. Further increase in spentwash concentration progressively reduced plant height to 235.67 cm at 20% and 195.55 cm at 30% concentration. With mineral fertilizers, maximum plant height of 237.08 cm was observed at the 2/3 rate, which was similar to that (236.14 cm) obtained at the full rate. The combination of 10% spentwash +2/3 mineral fertilizer rate produced tallest plants (292.44 cm) (Fig. 1a).

A maximum cane thickness of 24.73 mm was obtained with the application of 20% spentwash, followed by 23.70 at 30%, 23.42 mm at 10%, and 21.34 at control treatment, respectively (Fig. 1b). In case of mineral fertilizer treatments, a maximum of 23.92 mm cane thickness was produced at 2/3 rate and minimum of 22.64 mm at control (0 mineral fertilizer). The combination of 20% spentwash plus 2/3 mineral fertilizers produced the highest cane thickness of 25.33 mm.

The application of spentwash at 10 and 20% contributed to increase in internode length to 12.46 and 12.11 cm, respectively, against 10.24 cm at no spentwash treatment. At a higher spentwash concentration of 30%, the internode length was reduced to 9.85 cm. By contrast, mineral fertilizers produced smaller internode lengths of 11.21, 11.45, and 11.74 cm at 1/3, 2/3, and full rate, respectively (Fig. 1c). The combination of 10% spentwash plus 1/3 mineral fertilizer rate produced the largest internode length of 12.52 cm, which was statistically similar to that (12.55 cm) obtained under combined application of 10% spentwash plus full mineral fertilizer rate. The number of internodes increased from 20.99 (control) to 23.33 and 21.91 plant^{-1} for 10 and 20% spentwash, respectively (Fig. 1d), whereas at the higher concentration (30%), the number of internodes was reduced to 20.72 plant^{-1}. The mineral fertilizer rates did not treat differences in the number of internodes (21.55–21.97 plant^{-1}), but the combination of 10% spentwash plus 1/3 mineral fertilizer rate produced the maximum number of internodes (24.55 plant^{-1}).

The number of millable canes increased from 83,330 for control (no spentwash) to 105,000 ha^{-1} at 10%

Table 4 Statistical analyses of soil parameters as affected by spentwash concentrations and mineral fertilizer rates

Parameters	Soil depth (cm)	*F* value			$LSD_{0.05}$		
		SW	MF	SW × MF	SW	MF	SW × MF
pH	0–15	2.89	19.64	0.30	0.15	0.15	NS
	15–30	123.76	8.92	2.27	0.07	0.07	0.14
	30–45	239.88	22.03	7.22	0.04	0.04	0.08
	45–60	239.52	12.25	1.54	0.03	0.03	NS
EC	0–15	48.07	1.55	1.13	0.10	NS	NS
	15–30	54.75	0.18	0.04	0.05	NS	NS
	30–45	31.10	3.09	1.89	0.03	0.03	0.05
	45–60	147.01	9.66	11.71	0.02	0.02	0.03
HCO_3	0–15	70.57	0.03	0.31	22.28	NS	NS
	15–30	1310.09	0.05	0.28	25.55	NS	NS
	30–45	697.00	0.70	0.18	28.99	NS	NS
	45–60	527.09	0.59	0.43	26.97	NS	NS
Cl	0–15	199.21	0.54	0.26	30.39	NS	NS
	15–30	26.10	0.23	0.08	28.88	NS	NS
	30–45	66.05	1.10	0.27	23.12	NS	NS
	45–60	28.32	0.43	0.08	24.86	NS	NS
SAR	0–15	325.60	0.04	0.02	0.1071	NS	NS
	15–30	47.41	0.11	0.1	0.1543	NS	NS
	30–45	22.82	0.16	0.41	0.1696	NS	NS
	45–60	6.53	0.08	0.25	0.2211	NS	NS
Organic matter	0–15	364.36	1.30	1.28	0.01	NS	NS
	15–30	66.56	4.12	0.41	0.01	NS	NS
	30–45	34.69	0.75	0.53	0.01	NS	NS
	45–60	1.56	1.77	0.81	0.00	NS	NS
Nitrogen	0–15	599.91	57.37	3.09	0.006	0.006	NS
	15–30	186.19	7.39	0.61	0.0005	0.0005	NS
	30–45	109.51	16.71	1.64	0.0006	0.0006	NS
	45–60	613.25	66.36	2.93	0.0002	0.0002	NS
Phosphorus	0–15	432.57	24.54	4.88	0.2997	0.2997	0.5993
	15–30	685.06	209.10	22.52	0.1063	0.1063	0.2126
	30–45	1120.03	401.72	133.12	0.0514	0.0514	0.1028
	45–60	122.51	83.39	10.31	0.0250	0.0250	0.050
Potassium	0–15	2067.82	0.11	.01	6.1481	NS	NS
	15–30	407.40	1.03	0.93	12.391	NS	NS
	30–45	209.94	0.43	0.20	1.8888	NS	NS
	45–60	202.28	0.64	0.24	2.5072	NS	NS

SW spentwash, *MF* mineral fertilizers, *NS* non-significant

spentwash. Further increase in spentwash concentration progressively reduced the number of millable canes to 86,940 ha^{-1} at 30%. The application of mineral fertilizers produced the maximum number of millable canes (95,280 ha^{-1}) at 2/3 mineral fertilizer rate, followed by 93,890 canes ha^{-1} at the full rate, and 92,500 ha^{-1} at 1/3 fertilizer rate. The combination of 10% spentwash with 2/3 mineral fertilizer rate gave the highest number of millable canes (112,220 ha^{-1}) (Fig. 1e). Similar trend of the data was observed for cane yields. The maximum

Table 5 Economic analysis

Treatment (SW + MF)	Yield (kg ha^{-1})	Gross income (Rs. ha^{-1})	Seed cost (Rs. ha^{-1})	Fertilizer cost (Rs. ha^{-1})	Labor charges (Rs. ha^{-1})	Cane trans portation (Rs.)	SW transportation (Rs.)	Total cost (Rs. ha^{-1})	Net return (Rs. ha^{-1})	Cost benefit ratio ($^2/_1$)
0 + 0	56,660	169,980	61,775	0	28,330	11,714	0	101,819	68,160	0.67
0 + 1/3 NP	63,330	189,990	61,775	14,536	31,665	13,093	0	121,069	68,920	0.57
0 + 2/3 NP	67,440	202,320	61,775	28,987	33,720	13,943	0	138,425	63,894	0.46
0 + Full	75,220	225,660	61,775	43,260	37,610	15,551	0	158,196	67,463	0.43
10 + 0	73,440	220,320	61,775	0	36,720	15,183	10,200	123,878	96,441	0.78
10 + 1/3 NP	82,770	248,310	61,775	14,536	41,385	17,112	10,200	145,008	10,330	0.71
10 + 2/3 NP	97,440	292,320	61,775	28,987	48,720	20,145	10,200	169,827	122,492	0.72
10 + Full	91,110	273,330	61,775	43,260	45,555	18,836	10,200	179,627	93,703	0.52
20 + 0	3440	220,320	61,775	0	36,720	15,183	20,000	133,678	86,641	0.65
20 + 1/3 NP	68,660	205,980	61,775	14,536	34,330	14,195	20,000	144,836	61,143	0.42
20 + 2/3 NP	64,330	192,990	61,775	28,987	32,165	13,300	20,000	156,227	36,762	0.24
20 + Full	57,770	173,310	61,775	43,260	28,885	11,943	20,000	165,863	7446	0.04
30 + 0	68,330	204,990	61,775	0	34,165	14,127	31,000	141,067	63,922	0.45
30 + 1/3 NP	65,660	196,980	61,775	14,536	32,830	13,575	31,000	153,716	43,263	0.28
30 + 2/3 NP	61,660	184,980	61,775	28,987	30,830	12,748	31,000	165,340	19,639	0.12
30 + Full	61,370	184,110	61,775	43,260	30,685	12,688	31,000	179,408	4701	0.03

1/3 = 84 N + 42 P_2O_5 kg ha^{-1}, 2/3 = 167 N + 84 P_2O_5 kg ha^{-1}, full = 250 N + 125 P_2O_5 kg ha^{-1}. SW at Rs.600 per tanker (44,000 L), N at Rs. 83.47 kg^{-1}, P_2O_5 at Rs.179.13 kg^{-1}, seed at Rs. 16 kg^{-1}, cane sale at Rs. 3 kg^{-1}

SW spentwash (%), *MF* mineral fertilizers (N + P_2O_5 kg ha^{-1}), *VCR* value cost ratio cane yield of 86.19 t ha^{-1} was obtained at 10% spentwash compared with 65.66 t ha^{-1} for the control. Cane yields of 66.05 and 64.26 t ha^{-1} achieved at 20 and 30% spentwash, respectively, were statistically similar to the control treatment (Fig. 1f). While the mineral fertilizer treatments showed minor variation in cane yield, the combination of 10% spentwash plus 2/3 mineral fertilizer rate produced the highest cane yield of 97.44 t ha^{-1}.

These data reveal that application of 10% spentwash enhanced all the growth parameters and cane yield to their maximum observed levels, with the exception of cane thickness which was higher at 20% spentwash. Expressed on percent basis, 10% spentwash application increased plant height, internode length, the number of internodes $plant^{-1}$, millable canes, and cane yield by 25.01, 21.68, 11.14, 26.00, and 31.27%, respectively, compared to the values for the control treatment. This benefit in cane growth and yield decreased with increase in spentwash concentration from 10 to 30%.

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The improvement in growth parameters and cane yield at the lower concentration of spentwash (10%) might be due to the less salt content, BOD and COD (Table 1). This might have increased the microbial activity in the soil (Rajkishore and Vignesh 2012) that ultimately increased the nutrient availability to plants. By contrast, spentwash concentrations above 10% may have caused higher salt accumulation to enhance osmotic pressure within the root zone (Ramana et al. 2001). This condition within soil can reduce nutrient uptake that ultimately affected cane yield and yield contributing parameters. Local works on the effect of spentwash on sugarcane are rather scarce. Kaloi et al. (2015) reported increase in sugarcane growth parameters using 10% spentwash generated from Matiari Sugar Mills, Pakistan. Sivaloganathan et al. (2013) used spentwash of Eid Parry distillery, district Cuddalore, India, which had more or less similar characteristics to the one used in this study. They obtained a cane yield of 115 t ha^{-1} with a 47.43% increase at 10% spentwash over control. On the other hand, Armengol et al. (2003) obtained 64% increase in cane yield at 20% concentration due to its low salt content (EC = 1.98 dS m^{-1}).

Effect of spentwash on the soil characteristics

The application of spentwash significantly ($P < 0.05$) influenced EC, pH, Cl, HCO_3, SAR, organic matter, N, P, and K throughout the soil profile. While, the effect of mineral fertilizers was significant ($P < 0.05$) only for pH, N and P throughout the soil profile, and EC at the sub-lower and lower horizons. The combined effect of spentwash and mineral fertilizers had a significant effect on pH only at the subsurface and sub-lower horizon, EC at the sub-lower and lower horizon, and soil P throughout the profile (Table 4). The soil characteristics EC, pH, Cl, HCO_3, organic matter, and N, P, and K contents increased with the increase in spentwash concentration (0–30%) and decreased (except pH) with the soil depth (0–15 to 45–60 cm), while the SAR followed the opposite trend.

The EC values increased from 1.44 to 1.97 dS m^{-1} at the surface of the soil, 0.52 to 0.83 dS m^{-1} at the subsurface, 0.32 to 0.44 dS m^{-1} at the sub-lower horizon, and 0.22 to 0.38 dS m^{-1} at the lower horizon, respectively (Fig. 2a). These changes correspond to 6.14, 7.14, 5.26, and 3.53% at the respective soil depths. In terms of percentages, there was a minimum (36.80%) rise in EC at the surface of soil (0–15 cm), which gradually increased to a maximum (72.72%) at lower depth (45–60 cm); however, the soil EC remained within the non-saline (<2 dS m^{-1}) category even after the application of 30% spentwash. Considering 10% spentwash concentration, as growth parameters showed a decline above this concentration, EC values increased only by 5.5% when initial EC of the surface soil was 1.44 dS m^{-1}. Apart from spentwash concentration itself, the percent increase depends upon the initial EC values of the soil. This is in conformation with the studies by Sivaloganathan et al. (2013) reporting higher (200%) increase in EC values due to very low salt content (0.1 dS m^{-1}) of the soil itself. Furthermore, the study by Srivastava et al. (2012) obtained lower (15%) increase in EC values when initial EC of the soil was much higher (EC = 2.17 dS m^{-1}).

The pH increased from 7.95 to 8.47 at the surface of the soil, 8.05 to 8.68 at the subsurface, 8.28 to 8.74 at the sub-lower horizon, and 8.46 to 8.77 at the lower horizon, correspondingly, from control to 30% spentwash (Fig. 2b). These changes correspond to 6.54, 7.69, 5.55, and 3.66% increase at surface, subsurface, sub-lower horizon, and lower horizon of the soil. The pH values for the control treatment were in the moderately alkaline range (7.9–8.4) and remained within this range in the surface soil after spentwash application. The pH of soil is dependent on the anions (HCO_3, CO_3, and OH) (Tavakkoli et al. 2015). Smaller amounts of HCO_3 from diluted spentwash slightly increased the pH of soil. Armengol et al. (2003) reported pH increase of 0.65% under 5% spentwash application over control treatment. In contrast, 100% spentwash application increased the pH by 9.9% (Patil and Patil 2013). In another study, one-time application (35,000 L ha^{-1}) of 100% spentwash increased the pH by 4.3% (Selvamurugan et al. 2013).

The maximum Cl (653.33 mg kg^{-1}) and HCO_3 (1025 mg kg^{-1}) contents were recorded at 30% spentwash as presented in Fig. 2c, d). The Cl content increased by 112.28, 55.26, 118.18, and 77.84% and the HCO_3 content by 20.42, 144.05, 144.82, and 124.30% at the surface, subsurface, sub-lower horizon, and lower horizon, respectively. After spentwash application, the Cl content changed from medium category (140–350 mg L^{-1}) to high (>350 mg L^{-1}), whereas the HCO_3 content remained in the high category (>350 mg kg^{-1}). The increase in Cl and HCO_3 is the consequence of an increase in EC. Considering, 10% spentwash concentration for surface soil, Cl increased by 26.13%, while HCO_3 increased by a minor quantity (2.54%). The results were comparable with the results given by Adhikary (2014) for spentwash of Aska Co-operative Distilleries, district, India. They reported higher Cl (5626 mg kg^{-1}) and HCO_3 (1220 mg kg^{-1}) contents as compared to the spentwash of Matiari Sugar Mills (Cl - 3300, HCO_3 1198 mg kg^{-1}). The percent increase was higher in case of Aska distilleries, reporting 58.5% increase in Cl and 75% in HCO_3 at 25% spentwash concentration, while Patil and Patil (2013) reported only a 14% increase in the Cl content after one-time surface application of concentrated spentwash.

The SAR decreased from 0.13 to 0.05 at the soil surface, 0.17 to 0.12 at the subsurface level, 0.21 to 0.17 at the sub-lower horizon, and 0.22 to 0.19 at the lower horizon under control and 30% spentwash concentration, respectively. Overall, these values fell into the normal soil category (<15) as classified by Bohn et al. (1985). On a percentage basis, SAR decreased by 61.53, 29.41, 19.05, and 13.63% at the surface, subsurface, sub-lower horizon, and lower horizon, respectively. These results also illustrated that the SAR values were minimum at the surface compared with the lower horizon (Fig. 2e). This might be due to the leaching of salts caused by spentwash. This finding also supports the idea of the reclamation of sodic soils by spentwash (Valliapan 2001; Mahendra et al. 2010).

The organic matter content was minimum (0.21%) at control and maximum (0.42%) at 30% spentwash. On percentage basis, the organic matter content increased by 57.14, 38.88, 23.07, and 14.28% at 10% spentwash; 61.90, 44.44, 30.76, and 14.28% at 20% spentwash; and 100, 50, 38.46, and 14.28% at 30% spentwash at the surface, subsurface, sub-lower horizon, and lower horizon, respectively (Fig. 3a). Selvamurugan et al. (2013) reported 41% increase in the organic matter content after spentwash application. By contrast, Chopra et al. (2013) used the full range of spentwash concentrations (0 to 100%). They reported a 791% increase in the organic matter content at spentwash concentration (i.e., 25%) similar to that used in this experiment (30%). In general, the organic matter content of Pakistani soils is low (<1%), often as low as 0.5% (Sarwar et al. 2011). The organic matter content of the experimental soil (surface) before sowing of sugarcane was 0.22%. The percent increase in this single experiment was significant, indicating that the further use of spentwash can enrich the soils with organic matter. This, in turn, would increase the salt content, which can be minimized by lagooning before spentwash application (Melamane et al. 2007). Furthermore, the application of 30% spentwash improved the C:N ratio (9.76:1) of surface soil compared with the control (8.71:1). A C:N ratio below 15:1 has been reported to be effective in N mineralization (Miller et al. 1983).

In case of soil nutrients, 30% spentwash increased N from 0.014 to 0.025% (Fig. 3b), P from 4.46 to 9.2 mg kg^{-1} (Fig. 3c), and K from 64.83 to 280.92 mg kg^{-1} (Fig. 3d) over control, indicating a significant K contribution. On percentage basis, N, P, and K increased by 78.57, 106.27, and 333% at the surface; 55.55, 150.66, and 363.67% at the subsurface; 83.33, 233.89, and 46.78% at the sub-lower horizon; and 150, 76.66, and 73.98% at the lower horizon, respectively, over the control. In contrast, the results given by Chopra et al. (2013) reported an increase in N, P, and

K contents of 338, 28, and 35% at 25% spentwash concentration. Patil and Patil (2013) reported that application of 100% spentwash increased N by 722%, P by 140%, and K by 136% in the soil, left for a period of one year with no plantation. However, N, P, and K contents in this study followed a different trend. Considering 10% spentwash concentration, N increased by 17%, P by 29%, and K by 232% after nutrient utilization by the sugarcane crop itself.

Economic analysis

The highest gross income of Pakistani Rupee (Rs.) 292,320 ha^{-1} (≈US$2758) with a net return of Rs. 122,492 ha^{-1} (≈US$1155) was obtained from treatment with 10% spentwash and 2/3 (176 kg N and 84 kg P_2O_5) of the recommended mineral fertilizers. The next highest net return of Rs. 93,703 (91.11 t ha^{-1}) (≈US$884) was obtained with 10% spentwash plus the full (250 kg N and 125 kg P_2O_5) recommended rate of mineral fertilizers. The minimum gross income of Rs. 184,110 ha^{-1} (≈US$1736) with a net income of Rs. 4701 ha^{-1} (≈US$45) was accomplished using the combination of 30% spentwash plus full (250 kg N and 125 kg P_2O_5) recommended rate of mineral fertilizers. In terms of the cost/benefit ratio, the highest value (0.78) was obtained at 10% spentwash plus 0 mineral fertilizers, followed by 0.72 at 2/3 mineral fertilizers (176 kg N and 84 kg P_2O_5), and 0.71 at 1/3 mineral fertilizers (84 kg N and 42 kg P_2O_5). Although the cost/benefit ratio was higher (0.78) at 10% spentwash plus 0 mineral fertilizers, a low net return of Rs. 96,441 ha^{-1} (≈US$910) was obtained. The most economical combination was therefore 10% spentwash plus 2/3 mineral fertilizers (176 kg N and 84 kg P_2O_5), which gave a cost/benefit ratio of 0.72 and a net return of Rs. 122,492 ha^{-1} (≈US$1156).

Conclusion

This is the first detailed study on the use of locally produced spentwash in the province of Sindh, Pakistan. The findings provide insight into the effects of spentwash application and valuable information for local farmers. Treatment with 10% spentwash plus 2/3 mineral fertilizers generated the highest sugarcane yield of 97.44 t ha^{-1} with 29.54% increase over full NP fertilizers. This treatment combination was the most economical, substituting 33% of both N and P, and 100% of K from the 10% spentwash, saving a total cost of Rs. 48,600 (the cost of K fertilizer alone is Rs. 34,320) with net income of Rs. 122,492 ha^{-1} (≈US$1156). Considering surface soil, where maximum plant nutrient uptake occurs, the treatment combination 10% spentwash and 2/3 mineral fertilizers improved fertility of soil by 65% increase in organic matter and 20, 25, and 230% increase in N, P, and K, with minimum increase in EC (4.79%), and pH (2.55%) over full NP treatment. However, the further build-up of salt levels may depend on the original characteristics of the soil and its usage.

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