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Piezometer Study to Assess the Impacts of Distillery Spentwash Application on Ground Water Quality

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ABSTRACT

Sugar industry is the second largest agro-based industry in India, which contribute substantially to the economic development of the country. The distillery units mainly use sugarcane molasses as a preferred raw material and for every liters of alcohol production, 10-15 liters of waste water, known as spent wash, is generated which pose serious disposal problems. They are subjected to primary, secondary and tertiary treatments in the sequence of screening, equalization, followed by biomethanation. The non-toxic distillery spentwash contains large quantities of plant nutrients. Though this liquid is a dark colored, high BOD and COD liquid consisting primarily of bio-degradable organics and some inorganic constituents, it could not be disposed off directly into water bodies and growing crops. Thus, the one time land application of spentwash offers benefits of water pollution control and utilization for agricultural production. To assess the impact of spentwash on ground water quality, piezometers were installed at one time spentwash applied Sakthisugars field, Erode. The piezometer study revealed that one time land application of distillery spentwash does not affect the ground water quality.

Keywords Distillery spentwash, One time application, Piezometer, Ground water quality.

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INTRODUCTION

Irrigation water continues to be the single most important factor dictating the success of crop productivity in arid and semi arid agro-climatic zones. In the past five decades, the water availability has reduced to half and further reduction is fast approaching. This necessitates using every drop of water that can be recycled back to the crop production. In agriculture, irrigation water can affect soil characteristics and agricultural crop growth. Besides, the use of effluent reduces fertilizer and irrigation water cost as it is available without any cost and is rich in various plant nutrients (Kumar and Chopra 2012). Unlike other industrial wastewater, the Post Biomethanated Distillery Spentwash (PBDSW) does not contain any hazardous materials detrimental to soil health and plant growth.

The spentwash contains nutrients and salts mostly in dissolved form when spentwash is applied to the soil, due to rain water and or irrigation water, these salts and nutrients leach down into the soil profile and contaminate the ground water and surface water. Though leaching of salts is essential for crop growth its potential in contaminating the ground water cannot be ignored. The application of spentwash increased the rate of water uptake of the soil in laboratory soil column studies. The pH was lowered and the salt content was reduced to safer limits after leaching.

Jain *et al.* (2005) reported that the total dissolved solids and anion / cation levels were higher in the field receiving post methanated distillery effluent than in the unamended field. It was noted that TDS levels in the piezometer and tubewell samples in the amended field ranged from 441.6 to 998.4 mg L^{-1} and 332.8 to 812.8 mg L^{-1}, respectively. High salt content and TDS in ground water due to effluent irrigation have also been reported by Joshi (2001).

Monitoring the chemical composition of the leachates collected from piezometer indicated that there is no possibility of ground water pollution due to the application of higher doses of spentwash from 40 to 100 KL ac-1, since the level of pH, EC, the content of cations, anions, RSC, SAR, SSP and PS in the leachate collected from 1.0 m depth at various stages were well within the critical limits (Nandakumar 2009).

Ashok Kumar *et al.* (2011) reported that higher bicarbonate, pH and salinity in BDS treated condition were well expected due to restricted movement to lower aquifer and the presence of bicarbonate and sodium in ground water collected from spentwash treated areas might have increased the pH of the ground water but those were within the critical limits.

The leaching studies conducted with the application of spentwash at the rate of 150 ml and 250 ml kg^{-1} soil and gypsum have shown that, there was no difference in soil EC between gypsum and spentwash treatments. Likewise, leaching had significant effect in removing the water soluble anions (Cl-, SO_4^{2-}) and cations (K^+, Na^+, Ca^{2+} and Mg^{2+}) substantially with the application of gypsum and spentwash. The sodium absorption ratio and exchangeable sodium percentage of the soils were reduced after two leaching to ≤ 3.16 from ≥ 10.15 and from 4.02 to 27.40, respectively.

Selvakumar (2006) reported that there was limited possibility of polluting the ground water and subsurface soil due to one time pre-sown land application of Post Biomethanated Distillery Spentwash (PMDSW) at the rate of 84 m^3 ha^{-1} because the content of pH, EC, organic carbon, total solids, BOD and COD observed in the PMDSW treated leachate after two to three leaching were within the critical limits.

Susheel Kumar *et al.* (2007) reported that rate of spentwash application had markedly enhanced the leaching of cations and even after seven leaching events vertisol and sodic soils had large accumulation of salts from spentwash application both in the presence and absence of any organic amendments. The accumulation of cations followed: $K^+ > Ca^{2+} > Na^+ > Mg^{2+}$ in vertisol, and $K^+ > Ca^{2+} = Na^+ > Mg^{2+}$ in sodic soil.

Anandhakrishnan *et al.* (2007a and 2007b) conducted piezometer studies to monitor the downward movement of Biomethanated Distillery Spentwash and possible ground water contamination. The results of five year monitoring reported that the spentwash application at 5 lakh liters ha^{-1} as pre plant dose and 4.0 lakh liters ha^{-1} as 1:10 diluted fertigation dose had no influence on the ground water beyond 1.5 m depth and hence, no threat for ground water was observed when applied at these doses in sandy loam soils.

Sakthipriyadharshini (2008) reported that the results of the leaching experiment in soil column provided evidence for the ground water contamination due to the land application of PMDSW.

Jain *et al.* (2005) studied the impact of distillery effluent and its leachate on groundwater quality using lysimeter and reported that the value of Pri-

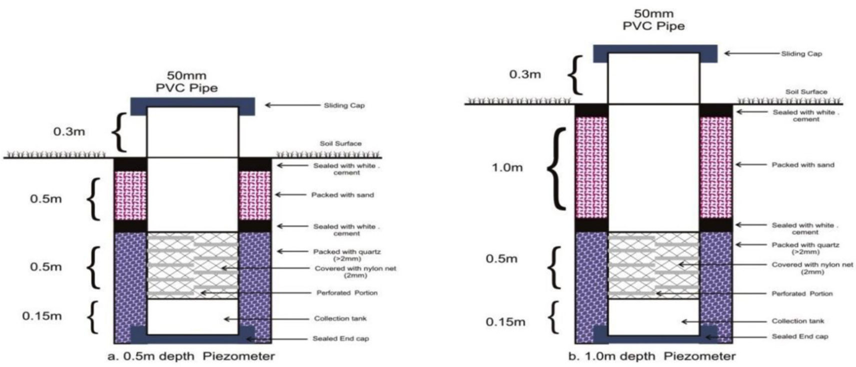

Fig. 1. Schematic diagram of structure and installation of piezometer.

mary Treated Distillery Effluent (PTDE) which was diluted with 50% of water was low as compared to Primary Treated Distillery Effluent (PTDE) and when diluted PTDE passed through lysimeter various chemical constituents of leachate initially showed great reduction but with passing time all the values of physico-chemical constituent were increased. Though, several studies conducted on barren field, the impact distillery spentwash with millet crop may require attention to know the behavior of pearl millet yield along with ground water movement. Hence the proposed study was aimed to find out the utilization of Post Biomethanated Distillery Spentwash (PBDSW) to improve soil health and also to monitor the subsurface movement of salt and groundwater contamination.

MATERIALS AND METHODS

Ground water monitoring

To assess the quality of ground water, the piezometers were installed at 0.5m and 1m depth before the application of treated distillery spentwash in the field during the experimental period.

Structure of piezometers

The PVC pipe of 50mm diameter with a total length of 1.95 m was taken. The bottom of PVC pipe was sealed with end cap without any leakage of the water from the pipe. Leaving the 0.15 m length from the bottom of the pipe for the collection of the leachate, perforation i.e., circular holes or longitudinal slits in a zig zag fashion to the length of 0.5m were made just above the collection tank. Then, the pipe was marked with marker to the height of 1m from the top of the perforated portion in order to maintain the soil column of 1 m depth from the soil surface to the perforated portion. About 0.30 m length pipe was left above the surface layer of the field and the top end of the PVC pipe was fitted with screw cap for easy operation during the collection of the leachate and also to avoid entry of external water sources. The perforated portion of 0.5m length in the pipe was completely covered with 2 mm nylon net and sealed at both end of perforated portion by cello tape. This arrangement of structures facilitated the easy movement of water through the soil column of 1m depth and easy operation during collection.

Installation of piezometers

Piezometers were installed in the experimental field at 0.5 m and 1m depth to measure the shallow and deep ground water to confirm the nutrient distribution. A hand operated piling was used to dig holes for each piezometer installation. The piezometers were made from slotted PVC pipes that were covered with mesh at the base and then inserted into the holes. The space around the tubes was back filled with sand till the level of holes and then with white

Table 1. Analytical methods for the analysis of Post methanated distillery spentwash (PMDSW) and leachate.

Sl.No.	Properties	Methodology	Reference
1	Color	Assessed by visual comparison with distilled water	APHA (1989)
2	Moisture	Oven temp 105º C	A.O.A.C (1962)
3	Density	Weight/Volume	A.O.A.C (1962)
4	pH	pH meter	Jackson (1973)
5	EC	Conductivity meter	Jackson (1973)
6	Biochemical oxygen demand	5 days at 20º C, Dissolved oxygen method	APHA (1965)
7	Chemical oxygen demand	Chromic acid-reflux method	APHA (1965)
8	Total solids	Oven temp 105º C	Ramteke and Moghe (1988)
9	Total dissolved solids	Oven temp 105º C	Ramteke and Moghe (1988)
10	Total suspended solids	Oven temp 105º C	Ramteke and Moghe (1988)
11	Organic carbon	Chromic acid -wWet Digestion method	Walkley and Black (1934)
12	Nitrogen	Bremner method	Jackson (1973)
13	Phosphorus	Vanadomolybdate colorimetric method	APHA (1989)
14	Potassium	Flame photometric method	Jackson (1973)
15	Calcium	Versenate titration method	Jackson (1973)
16	Magnesium	Versenate titration method	Jackson (1973)
17	Chloride	Mohr's method	Jackson (1973)
18	Carbonates and bicarbonates	Titrimetric method	Jackson (1973)
19	Sulfate	Turbidometric method	Jackson (1973)
20	Sodium	Flame photometric method	Jackson (1973)
21	Sodium adsorption ratio (SAR)	Na / [½ (Ca +Mg)] 0.5	USDA (1954)
22	Residual sodium carbonate (RSC)	$(CO_3 + HCO_3) – (Ca + Mg)$	Eaton (1950)
23	Microbial population	Standard serial dilution plating technique	Waksman and Fred (1922)

cement and followed by clay to prevent preferential flow pathways developing outsides of the PVC tubes. A PVC tube was extended above the soil surface for 0.5m to avoid the surface water flow entering into the piezometers. Finally they were end capped to avoid rain filling the tubes. The design of the piezometers are prepared on the models of nested piezometers by Aarons *et al.* (2004) shown in Fig.1 after completing this process of piezometer installation in the individual plot, the treatments were imposed as per treatment details.

Leachate collection

Piezometer water samples were collected at three different intervals viz., 30, 60 and 90 days after the application of spentwash and analyzed for pH and EC immediately after collection. The water samples were preserved safely for further cation and anion analysis outlined in Table 1.

Effect of PMDSW application on characteristics of leachate

pH

There was no significant difference ($p>0.05$) in the pH due to the effect of treatments (Table 2). The pH of leachate slightly increased in PBDSW applied soil as the days progressed (Table 2). With respect to various treatments, T_2 (PBDSW at the rate of 100 KL ha^{-1} along with recommended dose of NPK) recorded the highest mean pH (7.85) and the lowest pH (7.41) was recorded by T_1 (Control - RDF).

Table 2. Impact of Post biomethanated distillery spentwash (PBDSW) on the pH, EC, TDS of the leachate in 0.5 m depth piezometer.

Treat-ment/ stages	pH 30 DAS	pH 60 DAS	pH 90 DAS	pH Mean	EC ($dS\ m^{-1}$) 30 DAS	EC 60 DAS	EC 90 DAS	EC Mean	TDS ($mg\ L^{-1}$) 30 DAS	TDS 60 DAS	TDS 90 DAS	TDS Mean
T_1	7.35	7.42	7.47	7.41	0.56	0.53	0.49	0.53	358.40	339.20	313.60	337.07
T_2	7.81	7.85	7.89	7.85	1.17	1.13	1.09	1.13	748.80	723.20	697.60	723.20
T_3	7.79	7.83	7.86	7.83	1.01	0.96	0.93	0.97	646.40	614.40	595.20	618.67
T_4	7.71	7.73	7.78	7.74	0.83	0.71	0.68	0.74	531.20	454.40	435.20	473.60
T_5	7.63	7.65	7.69	7.66	0.79	0.75	0.73	0.76	505.60	480.00	467.20	484.27
Mean	7.66	7.70	7.74	7.70	0.87	0.82	0.78	0.82	558.08	522.24	501.76	527.36
SEd	NS	NS	NS		0.06	0.06	0.06		42.69	40.54	39.00	
CD	NS	NS	NS		0.15	0.14	0.13		98.46	93.49	89.95	

Among the stages of crop growth, highest pH of 7.74 was recorded at harvest stage (90 DAS) whereas the lowest pH of 7.60 was recorded at vegetative stage (30 DAS).

In general, the pH of leachate collected on 90th day of sowing was significantly increased in PMDSW applied soil. The pH of the leachate collected from PMDSW applied soil was relatively higher compared to control (7.47) and the highest value 7.89 was observed in PBDSW at the rate of 100 KL ha^{-1} along with recommended dose of NPK. Corroborative results were reported by Sridharan (2007) who stated that application of distillery spentwash to pearl miller gradually increased the pH of the leachate as the number of leachings increased. Saliha (2003) also reported that the increase in pH with increase in leaching events in the sodic soil treated with organics and distillery spentwash.

Electrical conductivity (EC)

The effect of treatments on the EC due to the application of PBDSW was found to be significant ($p<0.05$) (Table 2). The EC of leachate decreased over the period of the time. With regard to various treatments, T_2 (PBDSW at the rate of 100 KL ha^{-1} along with recommended dose of NPK) registered the maximum mean EC (1.13 $dS\ m^{-1}$) and the next highest EC (0.97 $dS\ m^{-1}$) was recorded by T_3 (PBDSW at the rate of 100 KL ha^{-1} in split dose along with recommended dose of NPK) and the minimum EC of 0.53 $dS\ m^{-1}$ was recorded by T_1 (Control-RDF). Among the stages of crop growth leachate collected at 30 DAS registered the maximum EC (0.87 $dS\ m^{-1}$)

Table 3. Impact of Post biomethanated distillery spentwash (PBDSW) on the Ca ($meq\ L^{-1}$), Mg ($meq\ L^{-1}$) and Na ($meq\ L^{-1}$) of the leachate in 0.5 m depth piezometer.

Treat-ment/ stages	Ca ($meq\ L^{-1}$) 30 DAS	Ca 60 DAS	Ca 90 DAS	Ca Mean	Mg ($meq\ L^{-1}$) 30 DAS	Mg 60 DAS	Mg 90 DAS	Mg Mean	Na ($meq\ L^{-1}$) 30 DAS	Na 60 DAS	Na 90 DAS	Na Mean
T_1	4.10	3.86	3.45	3.80	1.75	1.68	1.57	1.67	1.36	1.28	1.22	1.29
T_2	6.17	6.08	5.55	5.93	3.14	3.10	3.05	3.10	2.63	2.43	2.36	2.47
T_3	5.82	5.63	5.48	5.64	3.09	3.03	2.98	3.03	1.93	1.86	1.71	1.83
T_4	4.76	4.64	4.38	4.59	2.48	2.35	2.24	2.36	1.46	1.29	1.13	1.29
T_5	4.54	4.48	4.34	4.45	2.39	2.28	2.11	2.26	1.34	1.17	1.06	1.19
Mean	5.08	4.94	4.64	4.89	2.57	2.49	2.39	2.48	1.74	1.61	1.50	1.62
SEd	0.38	0.37	0.34		0.19	0.18	0.18		0.13	0.13	0.12	
CD	0.87	0.85	0.79		0.44	0.43	0.42		0.32	0.30	0.28	

Table 4. Impact of Post biomethanated distillery spentwash (PBDSW) on the K (meq L^{-1}), Cl (meq L^{-1}) and SO_4 (meq L^{-1}) of the leachate in 0.5 m depth piezometer.

Treat-ment/ stages	K (meq L^{-1}) 30 DAS	60 DAS	90 DAS	Mean	Cl (meq L^{-1}) 30 DAS	60 DAS	90 DAS	Mean	SO_4 (meq L^{-1}) 30 DAS	60 DAS	90 DAS	Mean
T_1	0.38	0.32	0.26	0.32	4.15	3.75	3.32	3.74	2.36	2.28	2.21	2.28
T_2	1.86	1.74	1.69	1.76	6.85	6.35	5.92	6.37	4.26	4.03	3.84	4.04
T_3	1.50	1.46	1.42	1.46	6.32	5.87	5.43	5.87	3.86	3.64	3.52	3.67
T_4	1.04	0.93	0.85	0.94	5.46	5.03	4.84	5.11	3.08	3.07	2.97	3.04
T_5	0.96	0.82	0.70	0.83	5.12	4.35	3.52	4.33	3.01	2.86	2.72	2.86
Mean	1.15	1.05	0.98	1.06	5.58	5.07	4.61	5.09	3.31	3.18	3.05	3.18
SEd	0.09	0.08	0.08		0.41	0.38	0.34		0.25	0.23	0.22	
CD	0.21	0.20	0.19		0.96	0.88	0.80		0.58	0.54	0.52	

whereas the minimum was registered at 90 DAS (0.78 dS m^{-1}).

The EC of the leachate (Fig 5.8) collected on 30th day of sowing from PMDSW applied soil was higher to the tune of 1.13 dSm^{-1} in PBDSW at the rate of 100 KL ha^{-1} along with recommended dose of NPK compared to control (0.53 dSm^{-1}) but did not exceed the critical limit of 4.0 dSm^{-1} fixed for any water system. It is noteworthy that the EC of leachate in the PMDSW treatment was drastically reduced to 0.49 dSm^{-1} on 90th day of sowing, which was within the safer limit of 1.0 dSm^{-1}. A significant reduction in EC of subsequent leachate was due to the removal of huge amount of soil cations and anions added through PMDSW in the first instance itself. This is in line with the findings of Banuelos and Lin (2006) who reported that the salt content was reduced to safe limit after progressive leaching. So, the possibility of increasing the salinity of ground water is very limited under field situation when PMDSW is applied as one time land application up to 100 KL ha^{-1}. Valliappan (1998) also pointed out that increase in the salt content of groundwater was only possible where there was not sufficient leaching of soil solution. Malathi (2002) also observed zero pollution of well water in nearby spentwash applied field in Theni District of Tamil Nadu.

Total dissolved solids (TDS)

The application of PBDSW application had marked effect on the TDS content at various treatments (Table 2). The mean TDS content for the treatments ranged from for 337.07 for T_1 (Control-RDF) to 723.20 mg L^{-1} forT_2 (PBDSW at the rate of 100 KL ha^{-1} along with recommended dose of NPK), respectively. Among the stages of crop growth during which leachate was collected, vegetative stage (30 DAS) significantly ($p<0.05$) recorded the highest TDS content (558 mg L^{-1}) while the lowest (501 mg L^{-1}) at harvest (90 DAS). The result of the total solids of the leachate collected from PMDSW treated soil on 30th, 60th and 90th day of sowing indicated that though the level of these parameter was high in the all the leachate collected PBDSW treatments compared to control, it is within the critical limits of Indian standard norms (Appendix I). Large amounts of cations viz., Ca, Mg, Na and K (Fig 5.9) were found in the leachate collected from the PMDSW applied soil. This could be due to large amount of these cations present in the spentwash. The amount of cations leached was decreased in second and third stage (Malathi 2002). Piezometer study found that the leachate collected on every month was having the pH, EC, cations and anions within the permissible limit and there was no threat to the groundwater quality (Anandakrishnan *et al.* 2007a).

Calcium

The influence of treatments on PBDSW application on Calcium (Ca) in the leachate collected from piezometer at 0.5 m depth is furnished in Table 3. With regard to the various treatments, PBDSW at the rate of 100 KL ha^{-1} along with recommended dose of NPK (T_2) recorded the maximum Ca content (5.93 meq L^{-1}) and a minimum content by T_1 (meq L^{-1}) 3.08

(Control - RDF). Within the stages of crop growth during which the leachate was collected, the minimum content (4.64 meq L^{-1}) was recorded at harvest stage (90 DAS) and the maximum content (5.08 meq L^{-1}) was recorded at the vegetative stage (30 DAS).

Magnesium

A significant influence on Magnesium (Mg) content was observed due to the effect of different treatments (Table 3). The highest content Mg content was registeredby PBDSW at the rate of 100 KL ha^{-1} along with recommended dose of NPK (T_2) which was significantly ($p<0.05$) different over other treatments, while the lowest Mg content was recorded in T_1 (Control - RDF). Among the stages of crop growth during which the leachate was collected, highest Mg content of 2.57 meq L_1 was recorded 30 DAS (vegetative stage) whereas the lowest content (2.39 meq L_1) at 90 DAS (harvest).

Sodium

The changes in Sodium (Na) content due to the impact of spentwash application are furnished in Table 3. The effect of treatments as such and at different stages had a significant ($p<0.05$) influence on the Na content. The highest Na content was recorded by T_2 (PBDSW at the rate of 100 KL ha^{-1} along with recommended dose of NPK) (2.47 meq L^{-1}) and the lowest Na content (1.29 meq L^{-1}) recorded in T_1 (Control - RDF). Within the stages of crop growth during which the leachate was collected harvest stage (90 DAS) recorded the lowest Na content (1.50 meq L^{-1}) and the highest content (1.74 meq L^{-1}) was recorded in vegetative (30 DAS).

Potassium

The Potassium (K) content was markedly influenced due to PBDSW application during the leaching (Table 4). With regard to various treatments, the maximum Kcontent (1.76 meq L^{-1}) was recorded in T_2 (PBDSW at the rate of 100 KL ha^{-1} along with recommended dose of NPK) and the minimum content of 0.32 meq L^{-1} was recorded in T_1 (Control - RDF). The vegetative stage (30 DAS) recorded the maximum K content (1.15 meq L^{-1}) and harvest stage (90 DAS) showed the minimum content (0.98 meq L^{-1}).

Chloride

The Chloride (Cl) content was influenced by the application of PBDSW during the crop growth period (Table 4). The effect of treatments at the stages of leachate collection was significant ($p<0.05$). The mean Cl content for the treatments ranged from 3.74 T_1 (RDF) to 6.37 meq L^{-1} T_2 (PBDSW at the rate of 100 KL ha^{-1} along with recommended dose of NPK). The vegetative stage (30 DAS) recorded the highest Cl content (5.58 meq L^{-1}) while harvest (90 DAS) recorded the lowest content (4.61 meq L^{-1}).

Sulfate

The influence on Sulfate (SO_4) content of leachate collected from various treatments was significantly ($p<0.05$) different from each other (Table 4). The treatments T_2 (PBDSW at the rate of 100 KL ha^{-1} along with recommended dose of NPK) significantly recorded the maximum content of SO_4 (4.04 meq L^{-1}) and T_3 (PBDSW at the rate of 100 KL ha^{-1} in split dose along with recommended dose of NPK) (3.67 meq L^{-1}) recorded the next highest content and the minimum SO_4 content (2.28 meq L^{-1}) was recorded by T_1 (Control - RDF), respectively. With respect to various stages of leachate collection, 90 DAS (harvest stage) recorded the minimum SO_4 content (3.05 meq L^{-1}) and 30 DAS (vegetative) recorded the maximum content (3.31 meq L^{-1}).

Application of different doses of PMDSW resulted in large amounts of Cl, SO_4 and HCO_3 in the leachate collected from 0.5 m depth piezometer. As the PMDSW had very high concentration of Cl, SO_4 and HCO_3, it would have enriched the soil solution with soluble Cl, SO_4 and HCO_3 resulted in greater amount in the leachate. In general, Cl salts are more harmful than SO_4 and these two anions significantly contribute towards the salinity hazard associated with irrigation water. However, in most of the treatments, the concentrations of Cl^- and SO_4^{2-} in the leachate were within the safer limits of 600 and 1000 mg L^{-1},

Table 5. Impact of Post biomethanated distillery spentwash (PBDSW) on the HCO_3- (meq L^{-1}), SAR and RSC (meq L^{-1}) of the leachate in 0.5 m depth piezometer.

Treat-ment/ stages	HCO_3- (meq L^{-1})				SAR				RSC (meq L^{-1})			
	30 DAS	60 DAS	90 DAS	Mean	30 DAS	60 DAS	90 DAS	Mean	30 DAS	60 DAS	90 DAS	Mean
T_1	1.17	1.12	1.06	1.12	0.80	0.77	0.77	0.78	-4.68	-4.42	-3.96	-4.35
T_2	2.28	2.17	2.04	2.16	1.22	1.13	1.14	1.16	-7.03	-7.01	-6.56	-6.87
T_3	1.92	1.84	1.76	1.84	0.91	0.89	0.83	0.88	-6.99	-6.82	-6.70	-6.84
T_4	1.54	1.46	1.34	1.45	0.77	0.69	0.62	0.69	-5.70	-5.53	-5.28	-5.50
T_5	1.49	1.38	1.29	1.39	0.72	0.64	0.59	0.65	-5.44	-5.38	-5.16	-5.33
Mean	1.68	1.59	1.50	1.59	0.88	0.82	0.79	0.83	-5.97	-5.83	-5.53	-5.78
SEd	0.12	0.12	0.11		0.07	0.07	0.06		0.44	0.43	0.41	
CD	0.29	0.28	0.26		0.17	0.16	0.14		1.01	0.99	0.95	

respectively as prescribed by the ISI for the disposal of effluent into inland surface water and land for irrigation.

Bicarbonate

The treatments significantly influenced the Bicarbonate (HCO_3) content at different stages of leachate collection (Table 5). The mean HCO_3 content ranged from 1.12 meq L^{-1} for T_1 (Control - RDF) to 2.16 meq L^{-1} for T_2 (PBDSW at the rate of 100 KL ha^{-1} along with recommended dose of NPK), respectively. The bicarbonate content of the leachate decreased from 1.68 to 1.50 meq L^{-1} as the crop growth progressed.

Sodium adsorption ratio (SAR)

The SAR values obtained from this experiment were within the critical limits (Table 5). The mean SAR ranged from 0.78 (T_1) to 1.16 (T_2) for the treatments to, respectively. There was a significant ($p<0.05$) decrease in the SAR observed with the advancement of days of leachate collection (0.88 to 0.79).

Residual sodium carbonate (RSC)

From the data shown (Table 5) all the values of RSC were negative and within the critical limits. The SAR, a measure of sodicity hazard in the leachate showed variability between the treatments. In the leachate of PMDSW applied soil, the value ranged from 0.72 to 1.22 initially which remarkably decreased (0.59 to 1.14) during the course of crop growth. All these observed values were within the critical limit of 10 indicating that spentwash application will not induce the sodium hazard in the ground water.

Irrespective of the treatments and stages of sampling, the RSC of the leachate was in negative value confirming that spentwash application will not induce the sodium hazard in the ground water. Similar results were reported by (Anandakrishnan *et al.* 2007b). In general, EC, anions, cations, TDS, SAR and RSC of the leachate collected at fourth period of leachate collection showed a reduced content compared to first leachate collected. This might be due to the fact that the salt load present in the spentwash might get diluted through the irrigation water supplied throughout the cropping period.

CONCLUSION

The piezometer study revealed that one time land application of PBDSW does not affect the ground water quality. However this result obtained should be confirmed by conducting long term field experiments.

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