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Use of post biomethanated spent wash as a soil amendment for sodic soils

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Abstract
India has 6.73 Mha of salt-affected soils, of which 3.72 Mha is mainly sodic in nature. The amelioration of sodic soils is the first logical step and a prerequisite for improving the fertility of these soils. The basic principle of sodic soil reclamation is to provide a source of calcium (Ca^{2+}) to replace excess sodium (Na^{+}) from the cation exchange sites. The post biomethanated spentwash (PBSW) is available for agriculture use as a plant nutrient source; however, little information is available on its usage as a soil amendment in reclamation of sodic soils, and hence the field experiment was undertaken to study the efficacy of PBSW in reclaiming sodic soil and its effect on yield of sunflower (*Helianthus annuus* L.). The experiment was laid out in randomized block design with nine treatments *viz.*, control, varying doses of post biomethanated spentwash (30, 60, 90, 120, 150 and 180 m^3 ha^{-1}) farm yard manure (FYM) + recommended dose of fertilizer (RDF) and FYM +gypsum @ 50 % gypsum requirement + RDF with three replications. The exchangeable Ca^{2+}, $Mg^{2+,}$ K^{+} were observed to increased significantly with the increased dose of PBSW while exchangeable Na^{+} was reduced significantly with the increased dose of PBSW. The treatment of PBSW application @ 180 m^3 ha^{-1} reduces exchangeable sodium percentage by 65.46 % and exchangeable sodium by 50.5% over control. Thus it can be concluded from the study that the use of PBSW @ 180 m^3 ha^{-1} was beneficial in amelioration of sodic soil and more effective than the use of FYM + gypsum +RDF or only FYM + RDF.

Keywords: Biomethanated, spentwash, exchangeable sodium percentage, sodic soil

Introduction

India has 6.73 Mha of salt-affected soils, of which 3.72 Mha is sodic in nature. Sodic soils are characterized by variable electrical conductivity of soil saturation paste (ECe, mostly < 4 dS m^{-1}), high pHs (>8.2), high exchangeable sodium percentage (ESP >15) and high sodium absorption ratio (SAR >13). The excess sodium content adversely affects the soil properties, the growth, yield and quality of crops grown in sodic soil (Bajwa 1999) [2]. The amelioration of soils is the first logical step and a prerequisite for improving the fertility of these soils. The basic principle of sodic soil reclamation is to provide a source of calcium (Ca2+) to replace excess sodium (Na+) from the cation exchange sites. The amendments generally used to reclaim sodic soils are gypsum, phospho-gypsum, iron pyrites and elemental sulfur. The Gypsum, which was widely used amendment in these soils is also becoming short and needs to be supplemented with alternative amendments. The post biomethanated spent-wash (PBSW) obtained from sugar factories is locally available and can serve as cheap alternative amendment, which has the potential for reclamation of sodic soils in conjunction with gypsum (Singh, *et al.*1980) [17]. It needs to be tested with respect to its influence on soil properties, crop production and for its efficiency of reclamation of sodic soil.

In India about, 40,508 million liters of spentwash is produced per year from 285 distilleries units while in Maharashtra, the amount of spentwash produced per year is about 9367 million litres from 65 distilleries (BASL, 2012) [3]. The spentwash is liquid by-product of sugarcane distillery. When this spentwash is treated for methane production, a liquid remains at the primary stage called as post biomethanated spentwash (PBSW). The PBSW has a high load of suspended organic matter and soluble cations and anions. The PBSW is a potential source of plant nutrients [nitrogen (1200-1500 mg L^{-1}), phosphorus (40-70 mg L^{-1}), potassium (800-1300 mg L^{-1}), and iron (50–150 mg L^{-1})] and is available for agriculture use as a plant nutrient source (Subba Rao 1988) [18]. The beneficial effect of spentwash application in crop production is well documented by Joshi *et al*. (1996) [6]; Rajukkannu and Manickam (1997) [15]. The high concentration of calcium (2050 - 7000 mg L^{-1}) in spentwash may have the potential in reclaiming the sodic soils similar to that of gypsum effect (Rajukkannu and Manickam (1997) [15]; and Murugaragavan (2002) [11]. However, little information is available on its usage as a soil amendment in reclamation of problematic soils. Therefore, this paper aims to examine the potential beneficial or detrimental effects of application of different doses of PBSW on sodic soil properties and yield of sunflower.

Materials and Methods

Collection and Characterization of the Post Biomethanated Spentwash

Post Biomethanated spentwash was collected from disllery of Co-operative sugar factory located in Rahuri, District-Ahmednagar of Maharashtra state. The spent wash was transported in tankers from the disllery to the site of application (field experiment).The physico-chemical properties of spent wash sample were analyzed on the basis of standard methods given by APHA, 1992 [1]. The biological oxygen demand (BOD) of PBSW was estimated using Winkler method and chemical oxygen demand (COD) by using reflux method. The properties of post biomethanated spentwash are given in Table 1.

Table 1: Characterization of post biomethanated spentwash

Sr. No.	Parameters	Value
1	Color	Brown to black
2	Odor	Bad
3	pH	7.52
4	EC (dSm^{-1})	39.5
5	BOD (mg L^{-1})	5532
6	COD (mg L^{-1})	24272
7	Nitrogen (%)	0.14
8	Phosphorus (%)	0.022
9	Potassium (%)	1.03
10	Calcium (mg L^{-1})	3421
11	Magnesium (mg L^{-1})	2982
12	Sodium (mg L^{-1})	2421
13	Bicarbonates (mg L^{-1})	142
14	Chlorides (mg L^{-1})	2330
15	Sulphates (mg L^{-1})	2592
16	Iron (mg L^{-1})	48
17	Manganese (mg L^{-1})	0.43
18	Zinc (mg L^{-1})	8.48
19	Copper (mg L^{-1})	13.40

Field Experiment: Field experiment was conducted on a sodic calcareous soil belonging to Sawargaon series of isohyperthermic family of Vertic haplustepts at Post Graduate Research Farm of the Mahatma Phule Krishi Vidyapeeth, Rahuri which lies between $19^0$47'–$19^0$57'N latitude and $74^0$18'–$74^0$19' E longitude. The initial soil samples were analyzed for physical and chemical properties as detailed in Table 2.The experiment was laid out in randomized block design with nine treatments *viz.*, control, varying doses of Post biomethanated spentwash (30, 60, 90, 120, 150 and 180 m^3 ha^{-1}), FYM + recommended dose of fertilizers (RDF) and FYM + Gypsum @ 50 % gypsum requirement (GR) + RDF with three replications. The one time application of PBSW, FYM and gypsum was done 3 months before sowing sunflower. The RDF for sunflower 60: 30: 30 and gypsum requirement (GR) was 16.21 t/ha as per soil test values

Table 2: Initial characteristics of soil properties

Sr. No.	Parameters	Value
I	**Soil analysis**	
i	Sand (%)	17.55
	Silt (%)	37.80
	Clay (%)	44.65
	Textural class	Clayey
ii	Aggregate stability (MWD) mm	0.10
iii	Bulk density(Mg m^{-3})	1.50
iv	Hydraulic Conductivity (cm hr^{-1})	0.40
v	pH (1:2.5)	8.65
vi	EC dSm^{-1} (1:2.5)	0.86
vii	O.C.%	0.40
viii	$CaCO_3$ %	14.50
ix	Available N (kg ha^{-1})	160
x	Available P (kg ha^{-1})	7.6
xi	Available K (kg ha^{-1})	380
xii	Na^+ (C mol (P^+) kg^{-1})	10.0
xiii	K^+ (C mol (P^+) kg^{-1})	1.46
xiv	Ca^{++} (C mol (P^+) kg^{-1})	19.20
xv	Mg^+(C mol (P^+) kg^{-1})	8.12
xvi	CEC (C mol (P^+) kg^{-1})	42.00
xvii	ESP	23.8
xviii	SAR (m mol L^{-1}) $^{1/2}$	5.82
xix	GR (T ha^{-1})	16.21

Soil Sampling and analysis: The soil sample was collected from the field before sowing and after harvest of crop; air dried in the shade, pounded thoroughly in a wooden mortar with wooden pestle and passed through 2 mm sieve for analysis of different soil parameters. Exchangeable cations (Ca, Mg, K and Na) were extracted with 1 M NH_4OAc (pH 7.0) and exchangeable Ca &Mg were analyzed by Versenate titration method while exchangeable K and Na by flame photometer (Jackson 1973) [4]. The experimental data of soil parameters were statistically analyzed as per methods of randomized block design described by Panse and Sukhatme (1985) [12].

Exchangeable sodium percentage (%) is calculated using the formula:

ESP (%) = {Exchangeable (Na)/ CEC} x 100

Exchangeable sodium Ratio is calculated using the formula:

$$ESR = \frac{ExNa}{CEC - ExNa}$$

Removal sodium efficiency (RSE)

Removal sodium efficiency in percentage of Na-removed from soils at end of the experiment was calculated as follows:

$$\mathbf{RSE} = \frac{(ESP_i - ESP_F)}{ESP_i} \times 100$$

Where: ESPi: exchangeable sodium percentage of the soil before application of PBSW

ESP_F: exchangeable sodium percentage of the soil after application of PBSW at the harvest of crop.

Result and Discussion

Effecton soil exchangeable cations

Exchangeable Calcium: The increase in exchangeable Ca^{2+} was observed from 20.34 C mol (p+) kg^{-1} (control) to 34.60 C mol (p+) kg^{-1} (T_7, 180 m^3 ha^{-1} PBSW) in surface soil layer. Similar trend with respect to Ca^{2+} was found in sub surface soil layer (30-60 cm). In sub surface soil layer the highest exchangeable Ca^{2+} was found in T_7 (29.93 C mol (p+) kg^{-1}).There was increase in exchangeable Ca^{2+} with increase in dose of PBSW in both the layers of soil; however magnitude was more in surface layer. The treatment T_8 (FYM + RDF) did not show any statistical increase in exchangeable Ca^{2+} in both the soil layers, however T_9 (FYM + Gypsum + RDF) showed increase in exchangeable Ca^{2+} which was at par with lower doses of PBSW (60,90 and 120 m^3 ha^{-1} in surface and 60, 90 m^3 ha^{-1} in sub surface soil layer). The increase in value of exchangeable Ca^{2+} of soil might be due to solubilization of native $CaCO_3$ by the production of acid during the decomposition of organic matter as well as high Ca^{2+} content in PBSW, resulting in increase in calcium on the exchangeable complex of soil. These results were close conformity with reports of Malathi (2002) [9], Singh *et al.* (1980) [17] Yadav (1989) [20], and Saliha (2003) [16].

Exchangeable Magnesium: In surface soil layer, the exchangeable Mg^{2+} increased from 8.40 C mol (p^+) kg^{-1} in control to 14.66 C mol (p^+) kg^{-1} in treatment T_7 (180 m^3 ha^{-1} of PBSW), while in sub surface soil layer, T_7 had shown highest exchangeable Mg^{2+} (13.36 C mol (p^+) kg^{-1}) which was significantly superior over all other treatments tested. Treatment T_8 (FYM + RDF) was at par with T_1 control) and T_2 (30 m^3 ha^{-1} PBSW) and T_9 (FYM + Gypsum + RDF) was at par with T_4 (90 m^3 ha^{-1} PBSW). The increase in exchangeable Mg^{2+} in soil was possibly due to dissolution of Ca^{2+} and Mg^{2+} containing minerals in the soil by organic acid produced during decomposition of organic matter as well as high Mg^{2+} content in PBSW contributed to increase in exchangeable Mg^{2+} in soil.

Table 3: Effect of PBSW on soil exchangeable bases after harvest of sunflower

Treatments	Exchangeable bases (C mol (p^+) Kg^{-1})							
	Ca^{++}		Mg^{++}		K^+		Na^+	
	0-30 cm	30-60 cm	0-30 cm	30-60 cm	0-30 cm	30-60 cm	0-30 cm	30-60 cm
T_1 : Control	20.34	19.06	8.40	7.26	1.60	1.38	9.79	11.61
T_2 : PBSW@ 30 m^3 ha^{-1}	25.80	22.46	10.80	8.46	2.03	1.89	8.45	10.90
T_3 : PBSW@ 60 m^3 ha^{-1}	28.33	23.80	11.87	9.26	2.57	2.17	7.57	10.50
T_4 : PBSW@ 90 m^3 ha^{-1}	30.00	25.33	12.47	10.27	3.19	2.46	7.02	10.10
T_5 : PBSW@ 120 m^3 ha^{-1}	30.17	27.40	13.47	11.50	3.77	2.73	6.33	9.50
T_6 : PBSW@ 150 m^3 ha^{-1}	33.03	28.03	13.93	12.40	4.30	3.14	5.69	9.16
T_7 : PBSW@ 180 m^3 ha^{-1}	34.60	29.93	14.66	13.36	5.80	3.66	4.95	8.30
T_8 : FYM 5 Mg ha^{-1} + RDF	20.70	19.00	9.20	7.80	1.80	1.33	8.83	11.21
T_9 : FYM 5 Mg ha^{-1}+ Gypsum+ RDF	28.73	24.93	12.00	9.90	2.40	1.78	8.28	10.41
CD (0.05%)	1.914	1.896	1.473	0.882	0.089	0.681	1.040	0.944

Exchangeable Potassium: The exchangeable K^+ increased from 1.60 C mol (p^+) kg^{-1} (control) to 5.80 C mol (p^+) kg^{-1} in treatment T_7 (180 m^3 ha^{-1} of PBSW) in surface layer of soil, which was significant over all other treatments. The exchangeable K^+ content of T_8 (FYM + RDF, 1.80 C mol (p^+) kg^{-1}) in surface layer was significantly superior over the T_1 (Control, 1.60 C mol (p^+) kg^{-1}), however T_9 (FYM + Gypsum + RDF, 2.40 C mol (p^+) kg^{-1}) had significantly superior exchangeable K^+ than T_1, T_2 and T_8 (1.60, 2.03 and 1.80 C mol (p^+) kg^{-1} respectively) but inferior to all other treatments of PBSW. The increase in exchangeable K^+ in soil was due to application of PBSW which contain high potassium. Similar trend of increase in exchangeable K^+ as in 0-30 cm layer of soil was observed in 30-60 cm layer of soil after application of different levels of PBSW. The increase in exchangeable K^+ of soil due to application of spentwash was also reported by Jadhav *et al.* (1975) [5] and Pawar *et al.* (1992) [14]

Exchangeable Sodium: The exchangeable Na^+ decreased with increase in level of application of PBSW over control in both the soil layers, however more decrease was observed in surface layer than sub surface layer of soil. The exchangeable Na^+ decreased from 9.79 C mol (p^+) kg^{-1} to 4.95 C mol (p^+) in surface soil layer. The reduction in exchangeable Na^+ was highest in T_7 (180 m^3 ha^{-1} of PBSW) in both the soil layers. The small reduction of exchangeable Na^+ was also observed in T_9 (8.28 C mol (p^+) kg^{-1}), however it was at par with T_2 and T_8 (8.45 and 8.83 C mol (p^+) kg^{-1} respectively) which was significantly superior over T_1 (control, 9.79 C mol (p^+) kg^{-1}) in surface soil layer. In sub soil layer, also T_9 (FYM + Gypsum + RDF) was at par with T_8 (FYM + RDF), T_3 (60 m^3 ha^{-1} PBSW) and T_4 (90 m^3 ha^{-1} PBSW). The decrease in exchangeable Na^+ was due to release of calcium from PBSW and gypsum, which replaced Na^+ form clay complex resulting into decrease in exchangeable sodium from soil, (Kaushik *et al.* 2005, Saliha (2003) [7, 16]. This decrease was more notable as the dose of PBSW was increased upto 180 m^3 ha^{-1}.

Exchangeable sodium percentage: The ESP of soil was observed to reduce from 23.23 (control) to 8.22 in Treatment T_7 (180 m^3ha^{-1} of PBSW) in surface layer of sodic soil, however T_7 was at par with T_6 in surface layer and significantly superior over all treatments in sub surface soil layer (table 4.). The ESP of treatment T_9 (15.89) was at par with T_2 (17.25) and T_3 (14.77) in surface layer while, T_9 (21.69) in sub surface layer was at par with T_3 (22.34) and T_4 (20.61), while T_8 (19.31 and 25.46) was at par with T_2 (17.21 and 24.27) in surface and sub surface layer of sodic soil. Thus there was significant decrease in the ESP of soil with increase in the level of PBSW application over control in both the layers of sodic soil; however ESP of surface layer was less than sub surface soil layer.

The RSE of soil increased significantly with increase in the level of PBSW application over control in both the layers of sodic soil; however RSE of surface layer was more than sub surface soil layer. The RSE of soil was observed to increase from 2.39% (control) to 65.46% in Treatment T_7 (180 m^3 ha^{-1} of PBSW) over initial status of sodic soil in surface layer. The decreased ESP and increase in RSE of soil was due to the decrease in exchangeable Na^+, due to the replacement of exchangeable Na^+ from the clay complex by exchangeable Ca^{2+} present in the PBSW as well as dissolved $CaCO_3$ by high organic load of PBSW. The decreased ESP of soil due to application of PBSW was observed by Saliha (2003) [16], Malathi (2002) [9], and Kaushik (2005) [7].

Table 4: Effect of PBSW on soil ESP, RSE and ESR after harvest of sunflower

Treatments	Exchangeable sodium percentage (ESP) (%)		Removal sodium efficiency (RSE) (%)		Exchangeable sodium Ratio (ESR)	
	0-30 cm	30-60 cm	0-30 cm	30-60 cm	0-30 cm	30-60 cm
T_1 : Control	23.23	28.96	2.39	0.41	0.30	0.41
T_2 : PBSW@ 30 m^3 ha^{-1}	17.25	24.27	27.52	16.54	0.21	0.32
T_3 : PBSW@ 60 m^3 ha^{-1}	14.77	22.34	37.94	23.18	0.17	0.29
T_4 : PBSW@ 90 m^3 ha^{-1}	13.09	20.61	45.00	29.13	0.15	0.26
T_5 : PBSW@ 120 m^3 ha^{-1}	11.56	18.31	51.43	37.04	0.13	0.22
T_6 : PBSW@ 150 m^3 ha^{-1}	9.79	17.00	58.87	41.54	0.11	0.20
T_7 : PBSW@ 180 m^3 ha^{-1}	8.22	14.79	65.46	49.14	0.09	0.17
T_8 : FYM 5 Mg ha^{-1} + RDF	19.31	25.46	18.87	12.45	0.24	0.35
T_9 :FYM 5 Mg ha^{-1}+ Gypsum+ RDF	15.89	21.69	33.24	25.41	0.19	0.27
CD (0.05%)	2.087	1.929	-	-	-	-

Yield contributing characters and yield of sunflower: The average height of sunflower increased significantly from 94.33cm to 122 cm. The highest height of plant was 122.0 cm under treatment T_9 (FYM + Gypsum + RDF), while among the spentwash treatments, the highest plant height was 110.33 cm under the treatment T_7 (180 m^3 ha^{-1} PBSW) which was significantly superior over all other PBSW treatment and control. The highest weight of sunflower head was 35.47 gm under the treatment T_9 (FYM + gypsum + RDF). The treatments T_4 (90 m^3 ha^{-1}), T_5 (120 m^3 ha^{-1}), T_6 (150 $m^3 ha^{-1}$), T_7 (180 $m^3 ha^{-1}$) and T_8 (FYM + RDF) were on par with the superior treatment T_9.

Table 5: Effect of application of PBSW on different yield contributing characters

Treatments	Plant height (cm)	Weight of head /plant (gram)
T_1 : Control	94.33	17.01
T_2 : PBSW@ 30 m^3 ha^{-1}	97.00	20.77
T_3 : PBSW@ 60 m^3 ha^{-1}	97.66	21.34
T_4 : PBSW@ 90 m^3 ha^{-1}	98.00	30.64
T_5 : PBSW@ 120 m^3 ha^{-1}	99.00	30.67
T_6 : PBSW@ 150 m^3 ha^{-1}	101.00	30.45
T_7 : PBSW@ 180 m^3 ha^{-1}	110.33	30.90
T_8 : FYM 5 Mg ha^{-1} + RDF	121.33	30.95
T_9 : FYM 5 Mg ha^{-1}+ Gypsum+ RDF	122.00	35.47
CD (0.05%)	8.418	6.346

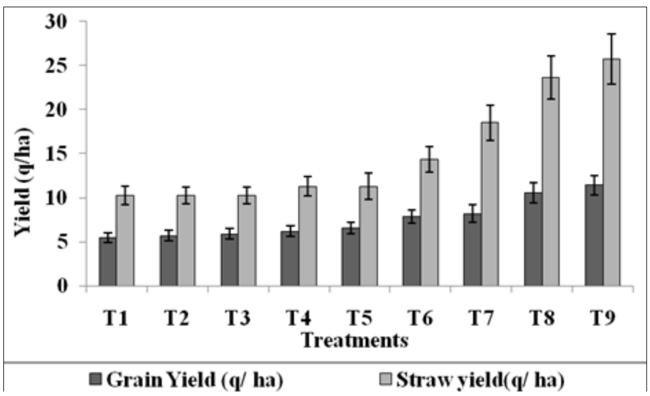

Fig 1: Effect of application of PBSW on Sunflower yield

The grain yield of sunflower increased significantly from 5.49 q ha^{-1} to 11.42 q ha^{-1} while straw yield from T_1 (10.28 q ha^{-1}) to T_9 (25.71 qha^{-1}). The significantly highest grain yield of 11.42 q ha^{-1} was obtained under the treatment T_9 (FYM + gypsum + RDF), however it was at par with the treatment T_8 (10.54 q ha^{-1}).Considering the treatments under PBSW the highest grain yield of 8.21q ha^{-1} was obtained under the treatment T_7 (180 m^3 ha^{-1}PBSW).The increase plant height, Weight of head, grain and straw yield was observed due to the improvement in the of sodic soil properties after the addition of gypsum. Application of FYM, PBSW and fertilizers helped in improving the nutrient availability and there by better plant growth and yield of sunflower. The application of PBSW also helped in increasing grain yield and it was proportional to the increase in quantity of PBSW added.

Conclusion

The application of PBSW @ 180 m^3 ha^{-1} reduces exchangeable sodium percentage by 65.46 % and exchangeable sodium by 50.5% overinitial status of sodic soil in surface layer while the crop yield increased by 33.13% over the control. Thus it can be concluded from the study that the use of PBSW @ 180 m^3 ha^{-1} was beneficial in amelioration of sodic soil and was found for more effective than the use of FYM + gypsum +RDF or only FYM + RDF.

References

1. APHA. Standard methods for the examination of water and waste water. 18th ed. Washington, DC (8 pages), 1992.
2. Bajwa MS. Soil salinity and alkalinity in fundamentals of soil science, Karnal, India: Central Soil Salinity Research Institute, 1999, 291-307.
3. Bannari Amman Sugars Limited (BASL), Executive Summary, Kolundampattu village, Thandarampattu Taluk Tiruvannamalai District, 2012, 1-12.
4. Jackson ML. Soil Chemical Analysis. Prentice Hall of India. Pvt. Ltd. New Delhi, 1973, pp. 498.
5. Jadhav HD, Savant NK. Influence of added spentwash (distillery waste) of chemical and physical properties of soil. Indian J. Agric. Chem. 1975; 8(1-2):71-84.
6. Joshi HC, Pathak H, Anita Choudhary, Kalra N. Distillery effluent as a source of plant nutrients-prospects and problems. Fert. News. 1996; 41(1):41-47.
7. Kaushik A, Nisha R, Jagjeeta K, Kaushik CP. Impact of long term and short term irrigation to sodic soil with distillery effluent in combination with bioamendments. Bioresource Tech. 2005; 96(17):1860-66.
8. Kavita H, Bhaskar S, Shrinivas Murthy CA, Nagarajan. Effect of distillery effluent on plant nutrient content, nutrient uptake, and crop yield of sunflower. Mysore Journal of Agriculture Science. 2008; 42:1-8.
9. Malathi MP. An assessment of distillery spentwash for its possible pollution potential in dryland areas. M.Sc. thesis, Tamil Nadu Agricultural University, Coimbatore, India, 2002.
10. Mallika K, Prabhakaran J, Lakshmanan A. Influence of distillery spentwash application on the microbial population dynamics and enzyme activity of maize soil. Madras Agric. J. 2003; 90(10-12):589-595.
11. Murugaragavan R. Distillery spentwash on crop production in dryland soils. M.Sc (Environmental Sciences) Thesis, Tamil Nadu Agricultural University, Coimbatore, India, 2002.
12. Panse VG, Sukhatme PV. Statistical method of Agricultural workers. New Delhi, India: Indian Council of Agricultural Research, 1985.
13. Patil JD, Sawant NK, Deshmane AN. Rate of decomposition of spentwash in soil. Journal of Indian Society of Soil Science. 1984; 12:32-34.
14. Pawar RB, Desai BB, Chavan UD, Naik RM. Effect of spent wash on the physico-chemical properties of saline calcareous soil. J. Maharashtra Agric. Univ. 1992; 17(1):1-3.
15. Rajukkannu K, Manickam TS. Use of distillery and sugar industry waste in agriculture. In: Proc. of the 6th National symposium on Environmental issues related to agriculture, textile and leather, Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu, India, 1997, pp. 286-290.
16. Saliha BB. Eco-friendly utilization of distillery spentwash for improving agricultural productivity in dryland and high pH soils of Theni district. PhD thesis, Tamil Nadu Agricultural University, Madurai, India, 2003.
17. Singh R, Singh NT, Arora Y. The use of spentwash for the reclamation of sodic soils. Journal of the Indian Society of Soil Science. 1980; 28:38-41.
18. Subba Rao B. Aerobic composting of spentwash. In Proceedings of the National Seminar on Sugar Factory and Allied Industrial Wastes: A new focus, Technical Session Pune, India: Deccan Sugar Institute. 1988; 11:68-75.
19. Valliappan K. Recycling of distillery spentwash and ecofriendly effective reclamation technology for soils, Ph.D. Thesis, Tamil Nadu Agricultural University, Coimbatore, India, 1998.
20. Yadav AM. Effect of spentwash (distillery effluent) on properties of soil and composition of leachate. MSc thesis, Mahatma Phule Krishi Vidyapeeth, Rahuri, India, 1989.