PLANT SCIENCE TODAY
Vol 12(3): 1-9
https://doi.org/10.14719/pst.6285

eISSN 2348-1900

RESEARCH ARTICLE

Evaluating the residual effects of distillery wastes on soil resilience in paddy (*Oryza sativa* L.) cultivation

Leninraja D[1], Radha P[*2], Elanchezhyan K[3], Suganya Kanna S[4], Venudevan B[5], Manobharathi K[6] & Sureshkumar R[7]

[1]Department of Natural Resource Management, Horticultural College and Research Institute, Tamil Nadu Agricultural University (TNAU), Periyakulam 625 604, Tamil Nadu, India

[2]Department of Forest Biology and Tree Improvement, Forest College and Research Institute, Tamil Nadu Agricultural University (TNAU), Mettupalayam 641 301, Tamil Nadu, India

[3]Department of Agricultural Entomology, V.O.C Agricultural College and Research Institute, Tamil Nadu Agricultural University (TNAU), Killikulam, Vallanadu 628 252, Tamil Nadu, India

[4]Department of Plant Protection, Horticultural College and Research Institute, Tamil Nadu Agricultural University (TNAU), Periyakulam 625 604, Tamil Nadu, India

[5]Krishi Vigyan Kendra, Kovilangulam, Virudhunagar, Tamil Nadu Agricultural University (TNAU), Aruppukottai 626107, Tamil Nadu, India

[6]Mother Teresa College of Agriculture, Affiliated to TNAU, Illuppur, Pudukkottai 622 102, Tamil Nadu, India

[7]School of Agricultural Sciences, Amrita Vishwa Vidyapeetham University, Coimbatore 642109 Tamil Nadu, India

*Correspondence email - pradha@tnau.ac.in

Received: 23 November 2024; Accepted: 12 March 2025; Available online: Version 1.0: 17 May 2025; Version 2.0: 29 July 2025

Cite this article: Leninraja D, Radha P, Elanchezhyan K, Suganya KS, Venudevan B, Manobharathi K, Sureshkumar R. Evaluating the residual effects of distillery wastes on soil resilience in paddy (*Oryza sativa* L.) cultivation. Plant Science Today. 2025; 12(3): 1-9. https://doi.org/10.14719/pst.6285

Abstract

In India, the sugar industry is the second largest agro-based sector producing significant quantities of by-products like molasses, pressmud etc. Distillery waste, once considered an undesirable by-product of the sugar industry is now being repurposed to support sustainable agriculture. Among these by-products, treated distillery effluent (TDE), a type of wastewater, presents a valuable opportunity for reuse in agricultural practices. TDE can serve both as a source of irrigation water and as a provider of essential plant nutrients. The positive impact of organic matter on soil fertility and crop productivity are well documented. Therefore, applying TDE to soil can provide a dual benefit: it facilitates the safe disposal of industrial waste while enhancing agricultural production. To investigate this potential, a field experiment was conducted to assess the residual effect of TDE and bio-compost on the chemical and biological properties of soil, using paddy (*Oryza sativa* L. variety BPT-5204) as the test crop. The results indicate that applying TDE at a rate of 1.5 lakh L ha^{-1} (M4) combined with 100 % nitrogen supplied through bio-compost (S4) significantly improves soil chemical and biological properties. Therefore, this combination can be recommended as a nutrient source for residual paddy crop.

Keywords: bio-compost; paddy; residual effect; soil fertility; treated distillery effluent

Introduction

The utilization of industrial effluents in agriculture has emerged as a sustainable approach to recycling waste while improving soil fertility and crop productivity. Among these, TDE stands out due to its high concentrations of essential macronutrients such as nitrogen, phosphorus and potassium, as well as a variety of micronutrients crucial for plant metabolism, enzyme activation and chlorophyll synthesis (1). The application of TDE has been shown to enhance nutrient bioavailability, supporting efficient nutrient uptake by plants and reducing dependence on synthetic fertilizers. Furthermore, TDE application has demonstrated significant benefits for soil health (2). By improving soil water retention, aggregate stability and organic matter content, TDE enhances physical and chemical properties that are essential for maintaining long-term soil productivity. The microbial activity in soils, which drives nutrient cycling and organic matter decomposition, can also be positively influenced by the organic compounds present in TDE, fostering a more dynamic soil ecosystem. Soil nutrient status is a critical determinant of plant growth, as it governs processes like root proliferation, photosynthetic efficiency and biomass accumulation. The interaction between soil nutrient availability and crop demands becomes particularly important in residual cultivation systems, such as paddy farming, where soil quality can diminish over successive growth cycles (3, 4). This study mainly aims to assess the residual impact of varying application rates of Treated Distillery Effluent on the chemical properties of soil, including pH, organic carbon content, nutrient availability and biological soil properties, such as microbial biomass, enzymatic activities and overall soil health. This study aims to determine the effectiveness of TDE as a soil amendment in enhancing crop productivity and nutrient use efficiency in residual paddy cultivation and provide insights into sustainable management practices for utilizing industrial effluents in agriculture while minimizing environmental risks. This research will not only enhance the understanding of TDEs' role in sustainable agriculture but also provide a foundation for policy formulation and the development of innovative strategies to manage distillery effluents in an environmentally responsible manner.

Materials and Methods

Field experiment was conducted using paddy as a test crop (BPT- 5204). The first field experiment was conducted in a split plot design with four main plots *viz*., control; TDE @ 0.5 lakh L ha^{-1}; TDE @ 1.0 lakh L ha^{-1}; TDE @ 1.5 lakh L ha^{-1}. Different levels of nitrogen fertilizers *viz.,* 100 per cent nitrogen as urea, 75 per cent nitrogen as urea, 100 per cent nitrogen as bio-compost, 75 per cent nitrogen as bio-compost, 75 per cent nitrogen as urea and 25 per cent nitrogen as bio-compost, 37.5 per cent nitrogen as urea and 37.5 per cent nitrogen as bio-compost and control were imposed as seven subplot treatments and the treatments were replicated twice.

A residue crop of paddy (BPT 5204) was raised in the same plots in which first main field experiment was conducted without disturbing the layout. After giving mammutty digging and levelling, the crop was transplanted during thaladi season. For all the plots including control, a uniform level of nitrogen as urea at 50 kg N ha^{-1} was applied in three splits (50 % basal, 25 % each at tillering stage and panicle initiation stage) besides 50 kg each of P and data collected on various parameters during the investigation were statistically analysed by ANOVA and critical differences were calculated at a 5 % (0.05) probability level. The standard methods followed for the analysis of soil and organic amendments are given in table 1.

During the first field experiment, bio-compost and treated distillery effluent were applied and their characteristics are as follows. Bio-compost is produced using pressmud, an organic solid by-product from sugar industries, as the primary raw material. The composting process employs a mechanized open-window system, utilizing TDE and bio-inoculants over a period of 70 to 80 days. After this period, the compost is sun-dried, ground and sieved using a mechanical separator and it is ultimately enriched with bio-fertilizers.

Soil enzyme activity

Dehydrogenase

Fresh composite soil sample (5 g) was taken in a boiling tube along with 1 mL of 3 per cent 2, 3, 5-Triphenyl tetrazolium chloride and 1 mL of 1 per cent glucose. To this 2.5 mL distilled water was added and incubated for 24 h. Then 10 mL methanol was added to the setup and incubated for another 6 h. The sample was then filtered using Whatman No.1 filter paper. The filtrate obtained was red in colour. The colour developed was read at 485 nm and the concentration of dehydrogenase (X) in the sample was obtained from the standard graph drawn by using Tri Phenyl Formazan (TPF) as standard (5).

Dehydrogenase activity of the sample (µg of TPF/g) = X/5

Phosphatase

Five gram (w) of the fresh composite soil was taken in a boiling tube with 10 ml distilled water. To this 0.25 mL toluene and 1 mL *p*-nitrophenol phosphate (PNPP) were added and incubated at room temperature for an hour. Then 5 mL of 0.5 M sodium chloride and 20 mL of 0.5 M sodium hydroxide was added to the sample and filtered through Whatman No.42 filter paper. The colour intensity was read at 420 nm and the concentration of phosphatase (X) in the sample was obtained from the standard graph (6).

Phosphatase activity of the sample (µg of PNPP/g) = X/w.

Urease

Ten gram of dry and sieved soil was taken in a 100 mL volumetric flask. To this 1.5 mL of toluene was added, mixed well and incubated for 15 minutes. Then 10 mL of 10 per cent urea solution and 20 mL of citrate buffer were added, mixed thoroughly, stoppered and incubated for 3 h at 37^0 C. Then the volume was made up to 100 mL with distilled water, mixed by shaking immediately. The contents were filtered through Whatman No.1 filter paper and 1ml of filtrate was pipetted out into 50 mL volumetric flask. To this 9 mL of distilled water, 4 mL of phenate and 3 mL of NaOCl were added, mixed well and allowed to stand for 20 minutes. The

Table 1. Standard methods followed for the analysis of soil and organic amendments

S.No	Parameter	Method	Reference
1.	Bulk Density	Cylinder method	(8)
2.	Particle Density	Cylinder method	(8)
3.	pH	pH meter, 1:2.5 (soil: water)	(9)
4.	EC	Conductivity meter 1:2.5 (soil: water)	(19)
5.	Organic Carbon	Wet Digestion method	(10)
6.	Total nitrogen	Macrokjeldahl's method	(8)
7.	Total phosphorus	Vanadomolybdate phosphoric yellow colour method	(9)
8.	Total potassium	Flame photometric method	(9)
9.	Available nitrogen	Alkaline permanganate method	(11)
10.	Available phosphorus	$NaHCO_3$ extract-Colorimetric method	(12)
11.	Available potassium	Flame photometer	(9)
12.	CEC	Neutral normal ammonium acetate	(9)
13.	Exchangeable calcium	Neutral normal ammonium acetate (Versenate method)	(9)
14.	Exchangeable magnesium	Neutral normal ammonium acetate (Versenate method)	(9)
15.	Exchangeable sodium	Flame photometery (Neutral NormalAmmonium Acetate)	(9)
16.	Exchangeable potassium	Flame photometery (Neutral NormalAmmonium Acetate)	(9)
17.	Free $CaCO_3$	Volumetric method	(8)
18.	Available micronutrients	Atomic absorption spectrophotometry (DTPA extractant)	(13)
19.	Microbial population	Serial dilution plate technique	(14)
20.	BOD	Dissolved oxygen method	(15)
21.	COD	Chromic acid-reflux method	(16)

volume was made up to 50 mL and mixed well. The bluish green colour developed was read at 630 nm. Simultaneously a blank was also run (without urea solution). The concentration of urease in the sample was obtained from the standard graph using diammonium sulphate (7).

Results

Initial characteristics

The soil of the experimental field is classified as Typic Haplustert, characterized by a neutral pH of 7.58 and low electrical conductivity (EC) of 0.30 dSm^{-1}. The organic carbon content was measured at 4.00 g kg^{-1} and the alkaline $KMnO_4$-nitrogen level was found to be low at 162 kg ha^{-1}. The Olsen-phosphorus level was moderate at 16 kg ha^{-1}, while NH_4OAc-potassium was measured at a medium level of 205 kg ha^{-1}. Microbial populations in the soil included a bacterial count of 10.2 x 10^6 CFU g^{-1}, fungal population of 14 x 10^4 CFU g^{-1} and actinomycetes at 5.1 x 10^3 CFU g^{-1}. Enzyme activities were assessed, revealing urease activity at 4.5 μg NH_4-N g^{-1} dry soil hr^{-1} and dehydrogenase activity at 2.5 μg TPF g^{-1} dry soil hr^{-1}.

Analysis of the bio-compost revealed that it has a neutral reaction with a pH of 7.56 and a considerable EC of 6.74 dSm^{-1}. It is rich in organic carbon (21.86 %), nitrogen (1.58 %), phosphorus (2.32 %), potassium (4.56 %), calcium (2.78 %), magnesium (1.62 %) and sodium (1.76 %). Additionally, it contains trace amounts of micronutrients such as zinc (Zn), iron (Fe), copper (Cu) and manganese (Mn), along with a favourable carbon-to-nitrogen ratio of 20.4. The bio-compost also demonstrates significant enzyme activity and a robust microbial population. Overall, bio-compost produced from distillery effluent is characterized by a neutral pH ranging from 6.5 to 7.5, making it an excellent amendment for enhancing soil health.

The TDE exhibited a dark brown colour, attributed to melanoidin and was characterized by an unpleasant odour likely due to compounds such as skatole, indole and various sulphur compounds. The effluent had a neutral pH of 7.71 but was rich in both organic and inorganic salts, resulting in a high electrical conductivity (EC) of 34.6 dS m^{-1}. Analysis of the TDE revealed total solids of 51,200 mg L^{-1}, suspended solids of 5,610 mg L^{-1} and dissolved solids of 45,590 mg L^{-1}. Due to its plant-based origins, the TDE was high in organic carbon (28,500 mg L^{-1}), potassium (12,650 mg L^{-1} as K_2O), calcium (2,250 mg L^{-1}) and magnesium (1,560 mg L^{-1}), with a significant nitrogen content of 2,000 mg L^{-1}. Phosphorus levels were relatively low at 246 mg L^{-1} and micronutrients were present in the following order: iron (Fe) > manganese (Mn) > zinc (Zn) > copper (Cu). The TDE contained substantial amounts of basic cations, predominantly calcium, followed by magnesium and sodium. The biochemical oxygen demand (BOD) and chemical oxygen demand (COD) of the TDE designated for land application were 7,890 mg L^{-1} and 38,562 mg L^{-1}, respectively. Additionally, the TDE exhibited appreciable counts of fungi, bacteria and actinomycetes. Importantly, the sodium adsorption ratio, residual sodium carbonate and soluble sodium percentage were below critical limits; however, the potential salinity exceeded critical levels according to irrigation water quality standards.

Residual effect of TDE and bio-compost on soil nitrogen availability

The available nitrogen content of soil ranged from 132 kg ha^{-1} in M1S1 at post-harvest stage to 305 kg ha^{-1} in M4S4 at active tillering stage (Table 2). The available nitrogen content of the soil showed a marked decline at the post-harvest stage (220 kg ha^{-1}) compared to the panicle initiation stage (227 kg ha^{-1}) and active tillering stage (231 kg ha^{-1}).

Among the main plot treatments, the application of TDE @ 1.5 lakh L ha^{-1} (M4) during the first crop registered higher available nitrogen status of 285 kg ha^{-1} when compared to other treatments *viz*., M3 (257 kg ha^{-1}), M2 (212 kg ha^{-1}) and M1 (150 kg ha^{-1}).

Among the subplot treatments, application of 100 % nitrogen as bio-compost (S4) to the earlier crop registered higher available nitrogen of 239 kg ha^{-1}, followed by 75 % nitrogen as bio-compost (S5), which was comparable with 75 % nitrogen as urea+ 25 % nitrogen as bio-compost(S6) and 37.5 % nitrogen as urea + 37.5 % nitrogen as bio-compost (S7), registering higher available nitrogen contents of 235 kg ha^{-1}, 229 kg ha^{-1} and 230 kg ha^{-1} respectively, in the soil over the rest of the treatments. The control recorded the lowest content of 204 kg ha^{-1}. Interaction of main X subplot treatment was found to be non-significant.

Residual effect of TDE and bio-compost on soil phosphorus availability

The available phosphorus content of the soil showed a progressive decline over stages of crop growth, from 18.89 kg ha^{-1} at the tillering stage to 18.21 kg ha^{-1} at the post-harvest stage (Table 3). Among the main plot treatments, the residual effect caused by the application of TDE @ 1.5 lakh L ha^{-1} registered higher phosphorus availability of 21.17 kg ha^{-1}, while the control recorded the lowest of 15.20 kg ha^{-1}.

Among the sub plot treatments, the application of 100 % nitrogen as bio-compost (S4) at earlier crop registered higher available phosphorus content of 19.48 kg ha^{-1}, followed by 75 % nitrogen as bio-compost (S5) and 37.5 % nitrogen as urea +37.5 % nitrogen as bio-compost (S7). Application of 75 % nitrogen as urea +25 % nitrogen as bio-compost (S6) recorded higher phosphorus content than rest of the treatments but it was on par with S7. The control (S1) recorded the lowest value of 16.89 kg ha^{-1}. The above trend of results was found at all stages of crop growth. Interaction of main plot X subplot treatments was found to be non-significant.

Residual effect of TDE and bio-compost on soil potassium availability

Available potassium content of the soil showed a marked decline over the stages of crop growth. The available potassium content ranged from 125 kg ha^{-1} in M1S1 at the post-harvest stage to 441 kg ha^{-1} in M4S4 at the active tillering stage (Table 4). Among the main plot treatments, application of TDE @ 1.5 lakh L ha^{-1} to first crop registered higher potassium availability (405 kg ha^{-1}) and the control recorded the lowest value of 156 kg ha^{-1}.

Among the subplot treatments, the application of 100 % nitrogen as bio-compost at earlier crop registered higher available potassium content of 333 kg ha^{-1} which is

Table 2. Residual effect of TDE and bio-compost on soil available nitrogen (kg ha^{-1}) in paddy

Treatments	Active Tillering Stage (St 1)					Panicle Initiation stage (St 2)					Post-Harvest Stage (St 3)					Pooled Mean (Stages)				
	M1	M2	M3	M4	Mean	M1	M2	M3	M4	Mean	M1	M2	M3	M4	Mean	M1	M2	M3	M4	Mean
S1	144	201	238	263	**211**	138	195	231	256	**205**	132	186	223	249	**197**	138	194	230	256	**204**
S2	152	215	262	290	**229**	148	211	258	286	**225**	142	204	248	274	**217**	147	210	256	283	**224**
S3	149	213	259	287	**227**	144	209	255	283	**222**	139	199	244	268	**212**	144	207	252	279	**220**
S4	165	229	275	305	**243**	162	226	272	300	**240**	154	222	265	292	**233**	160	226	270	299	**239**
S5	162	225	272	301	**240**	158	220	268	296	**235**	152	213	263	289	**229**	157	219	267	295	**235**
S6	156	219	266	294	**233**	152	215	262	290	**229**	146	209	255	284	**223**	151	214	261	289	**229**
S7	158	221	268	296	**235**	154	216	263	292	**231**	148	211	257	286	**225**	153	216	262	291	**230**
Mean	**155**	**217**	**262**	**291**	**231**	**151**	**213**	**258**	**286**	**227**	**145**	**206**	**250**	**277**	**220**	**150**	**212**	**257**	**285**	**226**

	Stage	M	S	M at St	S at M	S at St	S at St x M
SEd	2	3	3	4	7	6	11
CD(5%)	4	5	7	NS	NS	NS	NS

Table 3. Residual effect of TDE and bio-compost on soil available phosphorus (kg ha^{-1}) in paddy

Treatments	Active Tillering Stage (Stage 1)					Panicle Initiation Stage (Stage 2)					Post-Harvest Stage (Stage 3)					Pooled mean (Stages)				
	M1	M2	M3	M4	Mean	M1	M2	M3	M4	Mean	M1	M2	M3	M4	Mean	M1	M2	M3	M4	Mean
S1	14.31	16.38	19.60	19.90	**17.55**	13.78	16.03	19.11	19.41	**17.08**	12.68	15.12	18.02	18.41	**16.06**	13.59	15.84	18.91	19.24	**16.89**
S2	15.36	17.36	20.79	21.30	**18.70**	15.48	17.16	20.59	21.20	**18.61**	14.69	16.91	20.38	20.99	**18.24**	15.18	17.14	20.59	21.16	**18.51**
S3	15.17	17.16	21.59	21.11	**18.76**	15.42	16.97	20.40	21.00	**18.44**	14.59	16.81	20.22	20.80	**18.10**	15.06	16.98	20.73	20.97	**18.43**
S4	16.32	18.53	21.88	22.39	**19.78**	16.08	18.33	21.68	22.20	**19.57**	15.59	17.85	21.19	21.79	**19.10**	16.00	18.23	21.58	22.13	**19.48**
S5	15.94	18.24	21.58	22.09	**19.46**	15.75	18.06	21.39	21.99	**19.29**	15.46	17.60	20.97	21.56	**18.90**	15.71	17.96	21.31	21.88	**19.22**
S6	15.55	17.55	20.99	21.49	**18.90**	15.63	17.36	20.79	21.40	**18.79**	14.98	17.17	20.52	21.15	**18.45**	15.39	17.36	20.77	21.34	**18.71**
S7	15.75	17.85	21.19	21.69	**19.12**	15.50	17.65	20.99	21.49	**18.91**	15.17	17.31	20.69	21.30	**18.62**	15.47	17.60	20.96	21.49	**18.88**
Mean	**15.48**	**17.58**	**21.09**	**21.42**	**18.89**	**15.37**	**17.36**	**20.71**	**21.24**	**18.67**	**14.74**	**16.96**	**20.28**	**20.85**	**18.21**	**15.20**	**17.30**	**20.69**	**21.17**	**18.59**

	Stage	M	S	M at St	S at M	S at St	S at St x M
SEd	0.05	0.06	0.08	0.11	0.17	0.15	0.29
CD(5%)	0.11	0.13	0.17	NS	NS	NS	NS

Table 4. Residual effect of TDE and bio-compost on soil available potassium (kg ha^{-1}) in paddy

Treatments	Active Tillering Stage (Stage 1)					Panicle Initiation Stage (Stage 2)					Post-Harvest Stage (Stage 3)					Pooled mean (Stages)				
	M1	M2	M3	M4	Mean	M1	M2	M3	M4	Mean	M1	M2	M3	M4	Mean	M1	M2	M3	M4	Mean
S1	138	264	347	389	**284**	133	256	338	380	**276**	125	246	328	368	**266**	132	255	337	379	**276**
S2	156	283	376	410	**306**	150	273	367	400	**297**	137	258	353	382	**282**	147	271	365	397	**295**
S3	149	278	372	405	**301**	144	268	362	394	**292**	130	245	339	369	**270**	141	264	357	389	**288**
S4	192	327	406	441	**341**	187	321	400	436	**336**	173	303	386	420	**320**	184	317	397	432	**333**
S5	183	322	401	436	**335**	178	312	391	426	**327**	163	298	376	410	**312**	174	311	389	424	**324**
S6	167	297	386	420	**317**	159	287	376	409	**307**	135	268	356	380	**285**	153	284	373	403	**303**
S7	173	303	394	426	**324**	163	294	385	414	**314**	152	283	367	399	**300**	163	293	382	413	**313**
Mean	**165**	**296**	**383**	**418**	**316**	**159**	**287**	**374**	**408**	**307**	**145**	**271**	**358**	**390**	**291**	**156**	**285**	**371**	**405**	**304**

	Stage	M	S	M at St	S at M	S at St	S at St x M
SEd	3	3	5	6	9	10	16
CD(5%)	6	7	9	NS	NS	NS	NS

being on par with 75 % nitrogen as bio-compost (324 kg ha^{-1}). This was followed by the application of 37.5 % nitrogen as urea +37.5% nitrogen as bio-compost (S7) (313 kg ha^{-1}), control recorded the lowest value of 276 kg ha^{-1}. Interaction of main plot X subplot treatments was found to be non-significant.

Residual effect of TDE and bio-compost on soil phosphatase activity

The application of TDE and bio-compost to the first crop significantly increased soil phosphatase activity in the residue crop. Among the main plot treatments, the application of TDE @ 1.5 lakh L ha^{-1} (M4) at earlier crop recorded highest phosphatase activity of 2.41 µg p-nitrophenol g^{-1} dry soil hr^{-1}, followed by M3 (application of TDE @ 1.0 lakh L ha^{-1}) recording 2.16 µg p-nitrophenol g^{-1} dry soil hr^{-1}(Table 5). The control (S1) recorded the lowest phosphatase activity of 1.21 µg p-nitrophenol g^{-1} dry soil hr^{-1}.

Among the nitrogen fertilizer levels, S4 (100 % nitrogen as bio-compost) recorded highest phosphatase activity of 2.00 µg p-nitrophenol g^{-1} dry soil hr^{-1}which was followed by S5 (1.96 µg p-nitrophenol g^{-1} dry soil hr^{-1}) and S7 (1.93 µg p-nitrophenol g^{-1} dry soil hr^{-1}).

The interaction effect of M X S treatment was found to be significant. Application of TDE @ 1.5 lakh L ha^{-1} along with 100 % nitrogen as bio-compost (M4S4) recorded highest phosphatase activity of 2.54 µg p-nitrophenol g^{-1} dry soil hr^{-1} followed by the application of TDE @ 1.5 lakh L ha^{-1} along with 75% nitrogen as bio-compost (M4S5) recording higher phosphatase activity of 2.51 µg p-nitrophenol g^{-1} dry soil hr^{-1}.

Residual effect of TDE and bio-compost on soil urease activity

Among the main plot treatments, the application of TDE @ 1.5 lakh L ha^{-1} (M4) to first crop recorded highest urease activity of 7.41 µg NH4-N g^{-1} dry soil hr^{-1}followed by M3 (application of TDE @ 1.0 lakh L ha^{-1}) recording 6.66 µg NH4-N g^{-1} dry soil hr^{-1}. The control recorded the less urease activity of 3.73 µg NH4-N g^{-1} dry soil hr^{-1}(Table 6).

Among the nitrogen fertilizer levels, S4 (100 % nitrogen as bio-compost) at earlier crop recorded highest urease activity of 6.15 µg NH4-N g^{-1} dry soil hr^{-1}which was followed by S5 (6.04 µg NH4-N g^{-1} dry soil hr^{-1}) and S7 (5.95 µg NH4-N g^{-1} dry soil hr^{-1}).

The interaction effect of M X S treatment was found to be significant. Application of TDE @ 1.5 lakh L ha^{-1} along with 100 % nitrogen as bio-compost (M4S4) recorded highest urease activity of 7.80 µg NH4-N g^{-1} dry soil hr^{-1}followed by the application of TDE @ 1.5 lakh litres ha^{-1} along with 75 % nitrogen as bio-compost (M4S5) recording higher urease activity of 7.72 µg NH4-N g^{-1} dry soil hr^{-1}.

Residual effect of TDE and bio-compost on soil dehydrogenase activity

Among the main plot treatments, the application of TDE @ 1.5 lakh L ha^{-1} (M4) during the first crop recorded the highest dehydrogenase activity of 25.02 µg TPF g^{-1}dry soil hr^{-1}. followed by M3 (application of TDE @ 1.0 lakh litres ha^{-1}) recording 22.47 µg TPF g^{-1}dry soil hr^{-1}(Table 7). The control recorded the lowest dehydrogenase activity of 12.58 µg TPF g^{-1}dry soil hr^{-1}.

Table 5. Residual effect of TDE and bio-compost on soil phosphatase activity

Treatments	Phosphatase activity (μg p-nitrophenol g^{-1} soil hr^{-1})							
	S1	S2	S3	S4	S5	S6	S7	Mean
M1	1.11	1.19	1.16	1.29	1.27	1.22	1.24	**1.21**
M2	1.58	1.74	1.70	1.88	1.81	1.78	1.80	**1.75**
M3	1.93	2.14	2.10	2.29	2.27	2.20	2.22	**2.16**
M4	2.16	2.38	2.33	2.54	2.51	2.46	2.48	**2.41**
Mean	**1.69**	**1.86**	**1.82**	**2.00**	**1.96**	**1.91**	**1.93**	**1.88**

	M	S	M at S	S at M
SEd	0.03	0.01	0.03	0.01
CD(5%)	0.08	0.02	0.08	0.02

Table 6. Residual effect of TDE and bio-compost on soil urease activity

Treatments	Urease activity (μg NH_4-N g^{-1} soil hr^{-1})							
	S1	S2	S3	S4	S5	S6	S7	Mean
M1	3.39	3.66	3.58	3.96	3.91	3.77	3.82	**3.73**
M2	4.86	5.35	5.22	5.80	5.57	5.46	5.52	**5.39**
M3	5.93	6.59	6.48	7.04	6.98	6.77	6.82	**6.66**
M4	6.66	7.33	7.17	7.80	7.72	7.58	7.63	**7.41**
Mean	**5.21**	**5.73**	**5.61**	**6.15**	**6.04**	**5.89**	**5.95**	**5.80**

	M	S	M at S	S at M
SEd	0.08	0.01	0.08	0.01
CD(5%)	0.25	0.02	0.25	0.02

Table 7. Residual effect of TDE and bio-compost on soil dehydrogenase activity

Treatments	Dehydrogenase activity (μg TPF g^{-1} soil hr^{-1})							
	S1	S2	S3	S4	S5	S6	S7	Mean
M1	11.45	12.37	12.10	13.37	13.19	12.71	12.89	**12.58**
M2	16.40	18.04	17.59	19.58	18.79	18.44	18.62	**18.21**
M3	20.02	22.21	21.86	23.74	23.56	22.85	23.03	**22.47**
M4	22.47	24.72	24.18	26.35	26.07	25.58	25.76	**25.02**
Mean	**17.58**	**19.33**	**18.93**	**20.76**	**20.40**	**19.89**	**20.07**	**19.57**

	M	S	M at S	S at M
SEd	0.27	0.01	0.27	0.03
CD(5%)	0.85	0.03	0.86	0.06

Among the subplot treatments, S4 (100 % nitrogen as bio-compost) at the earlier crop recorded highest dehydrogenase activity of 20.76 μg TPF g^{-1}dry soil hr^{-1}, followed by S5 (20.40 μg TPF g^{-1}dry soil hr^{-1}) and S7 (20.07 μg TPF g^{-1}dry soil hr^{-1}).

The interaction effect of M X S treatment was found to be significant. Application of TDE @ 1.5 lakh L ha^{-1} along with 100 % nitrogen as bio-compost (M4S4) recorded highest dehydrogenase activity of 26.35 μg TPF g^{-1}dry soil hr^{-1} followed by the application of TDE @ 1.5 lakh L ha^{-1} along with 75 % nitrogen as bio-compost (M4S5) recording higher dehydrogenase activity of 26.07 μg TPF g^{-1}dry soil hr^{-1}.

Discussion

Residual impact of distillery wastes on soil nitrogen

The results of the residual crop have shown that N transformation and the plant availability in soil were greatly influenced by the TDE and bio-compost applied during the first crop. Among the different treatments, the application of TDE @ 1.5 lakh L ha^{-1}(M4), recorded the highest available nitrogen to a tune of 285 kg ha^{-1}, representing a 47 % increase over the control. The higher rate of mineralization and the release of N from soil, fertilizers and TDE likely contributed to the increased availability of N in the soil.

Among the subplot treatments, application of 100 % nitrogen as bio-compost (S4) registered high available nitrogen (239 kg ha^{-1}) followed by 75 % nitrogen as bio-compost (S5) registering 235 kg ha^{-1}. The effect of bio-compost almost at all the stages of observations was found superior to control. This increase could be attributed to release of nitrogen upon sustained mineralization of organic manures (17, 18).

Higher nitrogen availability in soil could be due to the direct contribution of nitrogen supply as well as increased microbial activity due to the added organic matter and partial pressure of carbon dioxide in the effluent treated soil (TDE and bio-compost added during the first crop) resulting in an enhanced availability of nitrogen in soil (19, 20) Significant and positive correlation observed between the available nitrogen and yield ($r = 0.975^{**}$) also supported the above findings.

A marked decline in the available nitrogen in soil was observed with the advancement of crop growth which might be due to the continuous removal of nitrogen by the crop, losses due to transformation. Marginal decrease in available nitrogen content was observed at the time of harvest stage, which could be due to loss of nitrogen through volatilization. However, during crop growth reduction in the soil available nitrogen could be due to the uptake by growing crop.

Residual impact of distillery wastes on soil phosphorus

Treated distillery effluent and bio-compost applied during the first crop remarkably increased the available phosphorus in soil after the residual crop. Among the different treatments, application of TDE @ 1.5 lakh L ha^{-1}(M4) recorded the highest available phosphorus. The increase in available phosphorus may be due to the application of TDE applied during the first crop as well as the consequent dissolution of soil mineral phosphorus (apatite phosphorus). Although TDE was not acidic, its decomposition released organic acids that may have solubilised native soil phosphorus, thereby increasing $NaHCO_3$-P during the first crop, with this effect also observed in the residual crop (18, 21, 22)

Among the sub plot treatments, application of 100 % nitrogen as bio-compost (S4) registered high available phosphorus. It was followed by 75 % nitrogen as bio-compost (S5) registering 235 kg ha^{-1}. The effect of bio-compost almost at all the stages of observations was found superior to check (23-25). The decomposition processes of easily degradable organics might have reduced the binding energy and phosphorus sorption capacity of the soil, favouring higher phosphorus availability in the soil (26). Significant and positive correlation observed between the available phosphorus and yield ($r = 0.970^{**}$) also supported the above findings.

The decline in available phosphorus at harvest stage could be due to crop uptake, physico-chemical transformations of phosphorus (adsorption, precipitation) into insoluble forms or due to microbial immobilization (27).

Residual impact of distillery wastes on soil potassium

The application of TDE @ 1.5 lakh L ha^{-1} (M4) resulted in significantly higher potassium availability compared to the other main plot treatments. A change of 405 kg ha^{-1} in available potassium was observed due to the application of TDE over control. Increase in the available potassium content of the surface soil was sustained even after the harvest and the available potassium in soil increased due to the application of effluent (22, 28).

Among the subplot treatments, application of 100 % nitrogen as bio-compost registered higher available potassium content of 333 kg ha^{-1} (17.1 % increase over control) which is followed by 75 % nitrogen as bio-compost registering 324 kg ha^{-1} (14.8 % increase over control). The increase may be attributed to the release of mineral potassium and addition of potassium rich manures (applied to the first crop) led to the release of potassium into the soil solution (18, 29-33). Significant and positive correlation observed between the available potassium and yield ($r = 0.975^{**}$) also supported the above findings.

The availability of potassium in the soil decreased as crop growth advanced, likely due to uptake by the crop.

Residual impact of distillery wastes on soil enzyme activities

Enzyme activity in soil is an indirect indication of the microbial activity, which is directly correlated with soil microbial population. In the present investigation, greater activities of dehydrogenase, urease and phosphatase were associated with the TDE application. The treatment that received TDE @ 1.5 lakh L ha^{-1} along with 100 % nitrogen as bio-compost (M4S4) was found to have higher enzyme activities than the control.

The TDE being liquid organic manure increased the organic matter and nutrients content of the soil and subsequently enhanced the microbial biomass. The high dose of TDE along with the recommended dose of NPK recorded the highest value. It implies that organic and inorganic nutrient inputs provided a nutrient rich environment, which is essential for the development of microbes and synthesis of enzymes (34). A positive correlation was found between the organic residues and dehydrogenase, β-glucosidase, urease and protease activities of the soil (35). The enzyme activities were increased due to the application of distillery effluent (36). Generally, organic manure addition was found to enhance the microbial activities which in turn favoured the synthesis of various enzymes in soil. These three enzymes play a significant role in the bio-transformation of nutrients in soil, thereby influencing nutrients availability and crop uptakes. The mineralization rate of organic phosphorus is relevant to both phosphorus nutrition of crops and phosphatase activity in soil. Therefore, higher enzyme activities in soil suggested that the mineralization of nitrogen and phosphorus was greater due to the application of spent wash (18).

Conclusion

This study highlights the potential of TDE as liquid organic manure, demonstrating its capacity to significantly enhance soil organic matter, nutrient content and microbial biomass. The application of higher doses of TDE, in conjunction with recommended NPK levels, optimized nutrient availability and enzymatic activity in the soil. The residual effect of TDE and bio-compost applied during the first crop substantially increased soil nutrients availability for the subsequent crop, indicating that integrating organic and inorganic nutrient inputs creates a nutrient-rich environment conducive to microbial growth and enzyme synthesis. Therefore, it can be concluded that the application of TDE @ 1.5 lakh L ha^{-1} (M4) during the first crop resulted in the highest availability of soil nutrients and enzymatic activity which was significantly superior over the other treatments. Among fertilizer levels, S4 (100 % nitrogen as bio-compost) recorded the highest availability of soil nutrients and enzymatic activity. Regarding the treatment combinations, application of TDE @ 1.5 lakh L ha^{-1} along with 100 % nitrogen as bio-compost (M4S4) which were applied to the earlier crop recorded the highest availability of soil nutrients and enzymatic activity.

Acknowledgements

We gratefully acknowledge the contributions of all the authors for their expert guidance and valuable insights, which were instrumental in the successful completion of this research manuscript

Authors' contributions

All the authors have contributed equally to data collection, analysis, writing the original manuscript draft, editing and reviewing.

Compliance with ethical standards

Conflict of interest: Authors do not have any conflict of interests to declare.

Ethical issues: None

References

1. Rath P, Pradhan G, Mishra MK. Effect of sugar factory distillery spent wash (DSW) on the growth pattern of sugarcane (*Saccharum officinarum*) crop. J Phytol. 2010;2(5):33–39. https://updatepublishing.com/journal/index.php/jp/article/view/2109
2. Biswas AK, Mohanty M, Hati KM, Misra AK. Distillery effluents effect on soil organic carbon and aggregate stability of a Vertisol in India. Soil and Tillage Res. 2009;104(2):241–46. https://doi.org/10.1016/j.still.2009.02.012
3. Selvamurugan M, Doraisamy P, Maheswari M, Valliappan K. An integrated approach to achieve a circular bioeconomy in the treatment and disposal of distillery spent wash. Biomass Conver and Biorefinery. 2024;1–6. https://doi.org/10.1007/s13399-024-05581-7
4. Jain R, Srivastava S. Nutrient composition of spent wash and its impact on sugarcane growth and biochemical attributes. Physiol and Molecular Biol of Plants. 2012;95–99. https://doi.org/10.1007/s12298-011-0087-1
5. Chendrayan K, Adhya TK, Sethunathan N. Assay of dehydrogenase activity in soils. Soil Biol Biochem. 1980;12:271–73. https://doi.org/10.1016/0038-0717(80)90073-5
6. Tabatabai MA, Bremner MJ. Use of p-nitrophenol phosphate for assay of soil phosphatase activity. Soil Biol Biochem. 1969;1:301–07. https://doi.org/10.1016/0038-0717(69)90012-1
7. Bremner JM, Mulvany RL. Urease activity in soils. In: Soil enzymes. (Ed.) Burns RG. Acadamic Press, New York, USA; 1978. p. 149–96
8. Piper CS. Soil and plant analysis. Inter Sci Publication Inc. New York; 1966. https://journals.lww.com/soilsci/citation/1945/03000/Soil_and_Plant_Analysis.9.aspx
9. Jackson ML. Soil chemical analysis. Pub: Prentice Hall of India. Pvt. Ltd., NewDelhi; 1973
10. Walkley A, Black CA. An estimation of methods for determining organic carbon and nitrogen in soils. J Agric Sci. 1934;25:598–609. https://doi.org/10.1017/S0021859600019687
11. Subbiah BV, Asija CL. A rapid procedure for estimation of available nitrogen in soils. Curr Sci. 1956;25:259–60. https://www.cabidigitallibrary.org/doi/full/10.5555/19571900070
12. Olsen SR, Cole CV, Watanabe FS, Dean AL. Estimation of available phosphorous in soils by extraction with sodium bicarbonate. (USDA). 1954; Circular No. 939.
13. Lindsay WL, Norvell WA. Development of DTPA soil test for zinc, iron, manganese and copper. Soil Sci Soc Am J. 1978;42:421–28. https://doi.org/10.2136/sssaj1978.03615995004200030009x
14. Aneja KR. Experiments in microbiology, plant pathology and biotechnology. New Age Publishers; 2005. P. 69
15. Young JC, McDermott GN, Jenkins D. Alteration in the BOD procedure for the 15th edition of standard method for the examination of water and wastewater. J Water Pollut Control Federation. 1981;53:1253. https://www.jstor.org/stable/25041460
16. Moore WA, Kronel RC, Ruchhoff CC. Dichromate reflux method for determination of oxygen consumed. Anal Chem. 1949;21:953. https://doi.org/10.1021/ac60032a020
17. Suganya K. Recycling options of one-time application of distillery spent wash to maize and groundnut and its impact on soil fertility and groundwater quality; 2008. http://hdl.handle.net/10603/235561
18. HR S, Ca S, SS P, GC S. Studies on different dilutions of distillery spent wash for foliar application and its effect on soil properties, growth, yield and quality of tomato. Commun in Soil Sci and Plant Analysis. 2022;53(3):364–75. https://doi.org/10.1080/00103624.2021.2016807
19. Satisha GC. Bioconversion of sugar and distillery industrial wastes into enriched compost and its effects on soil and crops. Doctoral Dissertation, Tamil Nadu Agricultural University, Coimbatore; 2000. http://krishikosh.egranth.ac.in/handle/1/5810007769
20. Sivaloganathan P, Murugaiyan B, Appavou S, Dharmaraj L. Effect of dilution of treated distillery effluent (TDE) on soil properties and yield of sugarcane. American J Plant Sci. 2013;4(9):1811.
21. Mallika K. Ecofriendly utilization of distillery spent wash for enhancing soil fertility and crop productivity. Doctoral Dissertation, Tamil Nadu Agricultural University, Coimbatore; 2001. https://krishikosh.egranth.ac.in/handle/1/5810157790
22. Murugaragavan R. Distillery spent wash on crop production in dryland soils. Doctoral Dissertation, Tamil Nadu Agricultural University, India; 2002. https://krishikosh.egranth.ac.in/server/api/core/bitstreams/645107
23. Pattanayak SK, Mishra KN, Jena MK, Nayak RK. Evaluation of green manure crops fertilized with various phosphorus sources and their effect on subsequent rice crop. J Ind Society of Soil Sci. 2001;49(2):285–91. https://www.indianjournals.com/ijor.aspx?target=ijor:jisss&volume=49&issue=2&article=011
24. Parmar DK, Sharma V. Studies on long-term application of fertilizers and manure on yield of maize-wheat rotation and soil properties under rainfed conditions in Western-Himalayas. J Ind Society of Soil Sci. 2002;50(3):311–12. https://www.indianjournals.com/ijor.aspx?target=ijor:jisss&volume=50&issue=3&article=020&type=pdf
25. Singh S, Singh RN, Prasad J, Kumar B. Effect of green manuring, FYM and biofertilizer in relation to fertilizer nitrogen on yield and major nutrient uptake by upland rice. J Ind Society of Soil Sci. 2002;50(3):313–14. https://www.indianjournals.com/ijor.aspx?target=ijor:jisss&volume=50&issue=3&article=021&type=pdf
26. Seshadri B, Kunhikrishnan A, Bolan N, Naidu R. Effect of industrial waste products on phosphorus mobilisation and biomass production in abattoir wastewater irrigated soil. Environ Sci and Pollution Res. 2014;21:10013–21. https://doi.org/10.1007/s11356-014-3030-5
27. Mahimairaja S, Bolan NS, Hedley MJ. Dissolution of phosphate rock during the composting of poultry manure: an incubation experiment. Fertilizer Res. 1994;40:93–104. https://doi.org/10.1007/BF00750093
28. Singh P, Tiwari AK, editors. Sustainable sugarcane production. CRC Press; 2018 Mar 21. https://doi.org/10.1201/9781351047760
29. Khatik SK, Dikshit PR. Integrated use of organic manures and inorganic fertilizers on yield, quality, economics and nutrition of sunflower grown in Haplustert clay soil. Agric Sci Digest. 2001;21(2):87–90. https://www.indianjournals.com/ijor.aspx?target=ijor:asd&volume=21&issue
30. Khoshgoftarmanesh AH, Kalbasi M. Effect of municipal waste leachate on soil properties and growth and yield of rice. Commun in Soil Sci and Plant Analysis. 2002;33(13-14):2011–20. https://doi.org/10.1081/CSS-120005745
31. Verma TS, Suri VK, Paul J. Prescription-based fertilizer recommendations for rice, maize and wheat in different agro-climatic zones of Himachal Pradesh. J Ind Society of Soil Sci. 2002;50(3): pp. 272–77. https://www.indianjournals.com/ijor.aspx?target=ijor:jisss&volume=50&issue=3
32. Prabu PC. Bioremediation of paper mill effluent polluted habitat; 2003 http://hdl.handle.net/10603/245916
33. Sebastian SP, Udayasoorian C, Jayabalakrishnan RM. Influence of amendments on soil fertility status of sugarcane with poor quality

irrigation water. Sugar Tech. 2009;11:338–46. https://doi.org/10.1007/s12355-009-0059-8

34. Kumari KK, Singaram P. Relationship among soil chemical, biochemical properties and enzyme activities. Madras Agric J. 1995;82(1):69–70. https://www.cabidigitallibrary.org/doi/full/10.5555/19961906279

35. Madejon E, Burgos P, Lopez R, Cabrera F. Agricultural use of three organic residues: effect on orange production and on properties of a soil of the 'Comarca Costa de Huelva' (SW Spain). Nutrient Cycling in Agroecosystems. 2003;65. https://doi.org/10.1023/A:1022608828694

36. Ramana S, Biswas AK, Kundu S, Saha JK, Yadava RB. Effect of distillery effluent on seed germination in some vegetable crops. Bioresourc Technol. 2002;82(3):273–75. https://doi.org/10.1016/S0960-8524(01)00184-5

Additional information

Peer review: Publisher thanks Sectional Editor and the other anonymous reviewers for their contribution to the peer review of this work.

Reprints & permissions information is available at https://horizonepublishing.com/journals/index.php/PST/open_access_policy

Publisher's Note: Horizon e-Publishing Group remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

Indexing: Plant Science Today, published by Horizon e-Publishing Group, is covered by Scopus, Web of Science, BIOSIS Previews, Clarivate Analytics, NAAS, UGC Care, etc
See https://horizonepublishing.com/journals/index.php/PST/indexing_abstracting

Publisher information: Plant Science Today is published by HORIZON e-Publishing Group with support from Empirion Publishers Private Limited, Thiruvananthapuram, India.