UTILIZATION OF DISTILLERY WASTES FOR SUSTAINING SOIL HEALTH IN PADDY FIELDS

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Abstract. Sugarcane based industries like distilleries produce a large amount of byproducts like Raw Spent Wash (RSW), Treated Distillery Effluent (TDE) and Bio-compost (BC). The Treated Distillery Effluent is waste water, which could be recycled in agriculture both as irrigation water and as a source of plant nutrients. The beneficial effect of organic matter for enhancing the soil fertility and thereby improving the crop productivity is well established. Thus, the soil application of TDE could offer the double benefit of safe disposal of wastes and its effective utilization for agricultural production. Keeping this fact in view, a field experiment was conducted to study the effect of Treated Distillery Effluent (TDE) and bio-compost on soil chemical and biological properties using paddy as a test crop (ADT- 43). Based on the increase in soil chemical and biological properties, it can be concluded that TDE @ 0.1 million L ha^{-1}(M3) or TDE @ 0.15 million L ha^{-1} (M4) along with 37.5% N as urea + 37.5% N as bio-compost (S7) can be recommended as a nutrient source for paddy crop.
Keywords: *treated distillery effluent, dehydrogenase, phosphatase, urease, bio-compost*

Introduction

Beneficial utilization of industrial effluents, particularly the treated distillery effluent, has been thought of extensively as it contains all the essential nutrients such as nitrogen, phosphorus and potassium besides micronutrients (Manickam, 1996; Umair et al., 2021). Nutrient application in the form of effluent irrigation may be effective in respect of bioavailability of nutrients to plants. Moreover, application of TDE on soils is one of the most economical resources for the soil fertility amelioration due to improvement in soil water holding capacity, texture, structure and nutrients retention. The available nutrient status of the soil is an important property which supports the crop growth while, the crop growth and dry matter accumulation depends upon the ability of the soil to supply nutrients; the nutrients release from the soil in turn depends upon the demands of the growing plants (Valliappan, 1998; Mohamed Haroon and Subash Chandra Bose, 2004; Mishra et al., 2021). Therefore, the main objective of the present study was to

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evaluate the effect of different application rates of distillery wastes, on soil chemical and biological properties in paddy field.

Materials and methods

The experimental site lies geographically in between 10°15’ and 11°2’ North Latitude and 78°10’ and 79°5’ East Longitude and at an altitude of 90 m above mean sea level. Field experiment was conducted using paddy as a test crop (ADT- 43). The experiment was conducted in a split plot design with four main plots *viz*., control; TDE @ 0.05 million L ha^{-1}; TDE @ 0.1 million L ha^{-1}; TDE @ 0.15 million L ha^{-1}. Different levels of N fertilizers *viz.,* 100% N as urea, 75% N as urea, 100% N as bio-compost, 75% N as bio-compost, 75% N as urea and 25% N as bio-compost, 37.5% N as urea and 37.5% N as bio-compost and control were imposed as seven subplot treatments and the treatments were replicated twice. TDE was uniformly applied to each plot as per the treatment schedule at 45 days before planting.

The soil of the experimental field belongs to *Typic haplustert*, neutral in pH (pH 7.58) and low in EC (0.30 dSm^{-1}). The organic carbon content (4.00 g kg^{-1}) and the alkaline $KMnO_4$-N (162 kg ha^{-1}) were found to be low. The Olsen-P level (16 kg ha^{-1}) and the NH_4OAc-K (205 kg ha^{-1}) were medium. The bacterial, fungal and actinomycetes population were found to be 10.2×10^6 CFU g^{-1} of soil, 14×10^4 CFU g^{-1} of soil, 5.1×10^3 CFU g^{-1} of soil respectively. The urease, phosphatase and dehydrogenase activity were found to be 4.5 µg NH_4-N g^{-1} dry soil h^{-1}, 10.1 µg p-nitrophenol g^{-1} of soil h^{-1} and 2.5 µg TPF g^{-1} dry soil h^{-1} respectively. The enzymes viz., Dehydrogenase and urease activities were estimated by Chendrayan et al. (1980), Bremner and Mulvany (1978) and Silva et al. (2013) respectively. The data on various characters studied during the investigation were statistically analyzed by the method given by Gomez and Gomez (1984). The critical difference was worked out at 5% (0.05) probability levels (*Table 1*).

Bio-compost is prepared by utilizing the pressmud (an organic solid material obtained as by-product from sugar industries) as a raw material and the composting process is being carried out by mechanized open window system with the use of treated distillery effluent and bio-inoculants for about 70–80 days (Dinesh et al., 2020). The product is then sun dried, ground and sieved by mechanical separator and finally enriched with bio-fertilizers. The results of bio-compost analysis indicated that it was neutral in reaction (pH 7.56) with considerable amount of salt (EC 6.74 dSm^{-1}). It was rich in organic carbon (21.86%), N (1.58%), P (2.32%), K (4.56%), Ca (2.78%), Mg (1.62%), Na (1.76%) and had traces of micronutrients *viz*., Zn, Fe, Cu and Mn with a favorable C:N ratio of 20.4 and considerable amount of enzyme activity and microbial population. Hunsigi (2000) and Singh (2008) also reported that bio-compost prepared from distillery effluent have a neutral pH 6.5 to7.5 (*Table 2*).

The TDE was dark brown in color imparted by melanoidin and had unpleasant odor which may be due to skatole, indole and other sulphur compounds. It was neutral in reaction (pH 7.71), but loaded with high organic and inorganic salts recording high EC (34.6 dS m^{-1}). The total solids, suspended solids and dissolved solids content of the TDE were 51200, 5610 and 45590 mg L^{-1}, respectively. Being originated from plant sources, the TDE was rich in organic carbon (28,500 mg L^{-1}), K (12,650 mg L^{-1} as K_2O), Ca (2,250 mg L^{-1}), Mg (1,560 mg L^{-1}) with considerable amount of N (2,000 mg L^{-1}), low in P (246 mg L^{-1}), and had relatively small amounts of micronutrients in the order of Fe > Mn > Zn > Cu. The TDE contained large amounts of bases, whose concentration

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followed the order of Ca > Mg > Na. The BOD and COD of TDE used for land application were 7,890 and 38,562 mg L^{-1}, respectively. The TDE had appreciable counts of fungi, bacteria and actinomycetes. Sodium adsorption ratio, residual sodium carbonate and soluble sodium percentage were below the critical limits, whereas the potential salinity exceeded the critical level as per the irrigation water quality standards (*Table 3*).

Table 1. *Characteristics of initial soil*

Parameters	Values
1. Mechanical composition	
Clay (%)	26.75
Silt (%)	6.50
Fine sand (%)	38.88
Coarse sand (%)	25.89
Textural class	Sandy clay
Soil series	Poovalur series
Soil taxonomy	*Typic haplustert*
2. Physical composition	
Bulk density (Mg m^{-3})	1.35
Particle density (Mg m^{-3})	2.24
Pore space (%)	47.1
Water holding capacity (%)	22.2
3. Chemical composition	
pH (1: 2.5 soil water suspension)	7.58
EC (dSm^{-1}) (1: 2.5 soil water extract)	0.30
CEC [c.mol.(p^+) kg^{-1}]	16.40
ESP	9.75
Organic carbon (g kg^{-1})	4.00
Organic matter (g kg^{-1})	6.89
$KMnO_4$ - N (kg ha^{-1})	162
Olsen - P (kg ha^{-1})	16
NH_4OAc - K (kg ha^{-1})	205
Exchangeable Ca (cmol (p^+) kg^{-1})	9.00
Exchangeable Mg (cmol (p^+) kg^{-1})	5.50
Exchangeable Na (cmol (p^+) kg^{-1})	1.60
Exchangeable K (cmol (p^+) kg^{-1})	0.30
DTPA- Zn (mg kg^{-1})	0.95
DTPA-Cu (mg kg^{-1})	0.68
DTPA-Fe (mg kg^{-1})	11.74
DTPA-Mn (mg kg^{-1})	6.05
4. Biological properties	
Bacteria (× 10^6 CFU g^{-1} of soil)	10.2
Fungi (× 10^4 CFU g^{-1} of soil)	14.0
Actinomycetes (× 10^3 CFU g^{-1} of soil)	5.1
Dehydrogenase activity (µg TPF g^{-1} of soil h^{-1})	2.5
Phosphatase activity (µg p-nitrophenol g^{-1} of soil h^{-1})	10.1
Urease activity (µg NH_4-N g^{-1} of soil h^{-1})	4.5

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Table 2. *Characteristics of bio-compost*

Sl. No.	Parameters	Values
1	pH	7.56
2	Electrical conductivity (1:2.5) dS m^{-1}	6.74
3	Organic carbon (%)	21.9
4	Total nitrogen (%)	1.58
5	Total phosphorus (%)	2.32
6	Total potassium (%)	4.56
7	C:N ratio	20.37
8	Total calcium (%)	3.68
9	Total magnesium (%)	2.29
10	Total sodium (%)	1.56
11	Total iron (mg kg^{-1})	396
12	Total zinc (mg kg^{-1})	87
13	Total copper (mg kg^{-1})	41
14	Manganese (mg kg^{-1})	410
15	Bacteria (× 10^6 CFU g^{-1} of soil)	9.9
16	Fungi (× 10^4 CFU g^{-1} of soil)	33.5
17	Actinomycetes (× 10^2 CFU g^{-1} of soil)	8.8
18	Dehydrogenase activity (µg of TPF g^{-1} of soil h^{-1})	10.3
19	Phosphatase activity (µg of PNPP g^{-1} of soil h^{-1})	18.9
20	Urease activity (µg NH_4-N g^{-1} of soil h^{-1})	8.4

The experimental fields were thoroughly ploughed with tractor drawn iron plough to bring it to a fine tilth. The field was divided into four strips for imposing main plot treatments and each main plot was divided in to 14 sub plots of 20 m^2 to accommodate seven subplot treatments replicated twice. As per the layout, 22 days aged seedlings are transplanted in to the main field from the nursery.

The soil was ploughed well and calculated quantities of Treated Distillery Effluent (TDE) and Bio-compost (BC) were uniformly applied to the concerned plots as per the treatment schedule 45 days before planting and allowed for natural oxidation.

The treatments were allotted randomly using random principle. The buffer channels were provided around each plot. Calculated quantities of TDE and bio-compost were applied to the main and sub plots as per the treatment schedule.

After 30 days, surface of the treated plots were inverted manually with spade to facilitate aeration and oxidation. Then the plots were formed and a fertilizer schedule of 100:50:50 kg N, P_2O5, K_2O ha^{-1} was adopted as the 100% recommended dose. Calculated quantities of fertilizers were applied in each treatment as per the treatment schedule. Entire phosphorus dose was applied as basal while nitrogen and potassium were applied in two splits at 25-30, 45-50 days after sowing.

Collection and processing of soil samples

Initial surface (0-25 cm) soil samples were collected prior to the layout of field experiment to assess the initial fertility status of experimental fields. Soil samples were also drawn at 30^{th} (Active tillering stage), 60^{th} (Panicle initiation stage) day and at

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harvest stage. The collected soil samples were air dried under shade, powdered with wooden mallet and then sieved through 2 mm sieve and used for chemical analysis. To study microbial population and soil enzymes activity, fresh soil samples were collected separately (*Table 4*).

Table 3. *Characteristics of treated distillery effluent (TDE)*

Sl. No.	Parameters	Values
1	Color	Dark brown
2	Specific gravity (g cm^{-3})	1.18
3	pH	7.68
4	EC (dSm^{-1})	36.4
5	BOD (mg L^{-1})	7,890
6	COD (mg L^{-1})	38,562
7	Total solids (mg L^{-1})	51,200
8	Total volatile solids (mg L^{-1})	23,320
9	Total suspended solids (mg L^{-1})	5,610
10	Total dissolved solids (mg L^{-1})	45,590
11	Organic carbon (mg L^{-1}) (dry weight basis)	28,500
12	Total N (mg L^{-1})	2000
13	Total P (mg L^{-1})	246
14	Total K (mg L^{-1})	12,650
15	Total Ca (mg L^{-1})	2250
16	Total Mg (mg L^{-1})	1560
17	Total Na (mg L^{-1})	730
18	Total Zn (mg L^{-1})	15.7
19	Total Fe (mg L^{-1})	87.5
20	Total Cu (mg L^{-1})	4.95
21	Total Mn (mg L^{-1})	10.5
22	Soluble anions (mg L^{-1})	
	Cl^-	7348.5
	SO_4^{2-}	3580.8
	HCO_3^-	3525.8
	CO_3^-	Absent
23	Soluble cations (meq.L^{-1})	
	K^+	226
	Na^+	27.2
	Ca^{2+}	48.3
	Mg^{2+}	50.8
	SAR	3.86
24	RSC (meq.L^{-1})	-41.3
25	SSP	7.71
26	PS (meq.L^{-1})	245
27	Bacteria (× 10^6 CFU ml^{-1})	3.5
28	Fungi (× 10^4 CFU ml^{-1})	12.2
29	Actinomycetes (× 10^2 CFU ml^{-1})	3.5

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Table 4. *Standard methods followed for the analysis of soil and organic amendments*

S.No	Parameter	Method	Reference
1.	Bulk density	Cylinder method	Piper (1966)
2.	Particle density	Cylinder method	Piper (1966)
3.	pH	pH meter, 1:2.5 (soil: water)	Jackson (1973)
4.	EC	Conductivity meter 1:2.5 (soil: water)	Jackson (1973)
5.	Organic carbon	Wet digestion method	Walkley and Black (1934)
6.	Total N	Macrokjeldahl's method	Piper (1966)
7.	Total P	Vanadomolybdate phosphoric yellow color method	Jackson (1973)
8.	Total K	Flame photometric method	Jackson (1973)
9.	Available N	Alkaline permanganate method	Subbiah and Asija (1956)
10.	Available P	$NaHCO_3$ extract-colorimetric method	Olsen et al. (1954)
11.	Available K	Flame photometer	Jackson (1973)
12.	CEC	Neutral normal ammonium acetate	Jackson (1973)
13.	Exchangeable Ca	Neutral normal ammonium acetate (Versenate method)	Jackson (1973)
14.	Exchangeable Mg	Neutral normal ammonium acetate (Versenate method)	Jackson (1973)
15.	Exchangeable Na	Flame photometry (neutral normal ammonium acetate)	Jackson (1973)
16.	Exchangeable K	Flame photometry (neutral normal ammonium acetate)	Jackson (1973)
17.	Free $CaCO_3$	Volumetric method	Piper (1966)
18.	Available Zn, Cu, Fe and Mn	Atomic absorption spectrophotometry (DTPA extractant)	Lindsay and Norvell (1978)
19.	Microbial population	Serial dilution plate technique	Aneja (2005)

Soil enzyme activity

Dehydrogenase: Fresh composite soil sample (5 g) was taken in a boiling tube along with 1 ml of 3% 2, 3, 5-Triphenyl tetrazolium chloride and 1 ml of 1% 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 color. The color 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 (Chendrayan et al., 1980).

$$\text{Dehydrogenase activity of the sample } (\mu\text{g of TPF/g}) = X/5$$

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 1 h. 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 color intensity was read at 420 nm and the concentration of phosphatase (X) in the sample was obtained from the standard graph (Tabatabai and Bremner, 1969).

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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 min. Then 10 ml of 10% urea solution and 20 ml of citrate buffer were added, mixed thoroughly, stoppered and incubated for 3 h at 37°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 1 ml 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 min. The volume was made up to 50 ml and mixed well. The bluish green color 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 (Bremner and Mulvany, 1978).

Results

Soil available nitrogen as influenced by different levels of TDE and biocompost

Available nitrogen content was found to be significantly influenced by the TDE and bio-compost application. The available nitrogen content ranged from 142 kg ha^{-1} in M1S1 at post-harvest stage to 288 kg ha^{-1} in M3S7 at active tillering stage (*Table 5*). The available nitrogen content of the soil showed marked decline at post-harvest stage (225 kg ha^{-1}) compared to panicle initiation stage (231 kg ha^{-1}) and active tillering stage (235 kg ha^{-1}).

Among the main plot treatments, application of TDE @ 0.15 million L ha^{-1} (M4) registered higher available N status of 267 kg ha^{-1} which was on par with M3 (262 kg ha^{-1}). The control (M1) recorded the lowest value of 168 kg ha^{-1}.

Among the subplot treatments, S6 (application of 75% N as urea + 25% N as compost) recorded higher available N status of 239 kg ha^{-1} which was being comparable with S7 (37.5%N as urea + 37.5% N as bio-compost) registering 238 kg ha^{-1}. This was followed by100% N as urea being comparable among themselves with 75% N as urea registering high available nitrogen status of 234 kg ha^{-1} and 233 kg ha^{-1} respectively in the soil over rest of the treatments. This was followed by the application of 100% N as bio-compost (227 kg ha^{-1}) which in turn being on par with 75% N as bio-compost (224 kg ha^{-1}) and control recorded the lowest of 215 kg ha^{-1}.

Table 5. *Soil available nitrogen (kg ha^{-1}) as influenced by different levels of TDE and bio-compost in paddy*

Treatments	Active tillering stage (stage 1)					Panicle initiation stage (stage 2)					Post harvest stage (stage 3)				
	M1	M2	M3	M4	Mean	M1	M2	M3	M4	Mean	M1	M2	M3	M4	Mean
S1	160	221	248	259	**222**	154	215	244	257	**217**	142	201	238	249	**207**
S2	177	232	270	275	**238**	173	231	268	268	**235**	170	226	266	260	**231**
S3	175	234	267	277	**238**	171	230	265	270	**234**	168	225	262	264	**229**
S4	171	227	258	269	**231**	167	226	256	265	**228**	163	219	253	256	**222**
S5	169	225	254	265	**228**	163	225	252	262	**225**	162	216	250	253	**220**
S6	179	240	275	279	**243**	177	233	273	275	**239**	175	228	270	268	**235**
S7	173	229	288	283	**243**	169	228	282	280	**240**	165	223	276	273	**234**
Mean	**172**	**230**	**265**	**272**	235	**168**	**227**	**263**	**268**	231	**163**	**219**	**259**	**260**	225

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Treatments	Pooled mean				
	M1	M2	M3	M4	Mean
S1	152	212	243	255	**215**
S2	173	230	268	267	**234**
S3	171	230	264	270	**233**
S4	167	224	255	263	**227**
S5	165	222	252	260	**224**
S6	177	234	273	274	**239**
S7	169	227	282	278	**238**
Mean	**168**	**225**	**262**	**267**	**230**

	Stage	M	S	M at St	S at M	S at St	S at St × M
SEd	3	4	5	6	9	8	16
CD (5%)	6	7	9	12	18	NS	NS

Interaction of main × subplot treatment was found to be significant. Application of TDE @ 0.1 million L ha^{-1} (M3) along with 37.5% N as urea + 37.5% N as bio-compost (S7) registered high available nitrogen content of 282 kg ha^{-1} which was found to be comparable with the application of TDE @ 0.15 million L ha^{-1} (M4) along with 37.5% N as urea + 37.5% N as bio-compost (S7) recording 278 kg ha^{-1}.

Soil available phosphorus as influenced by different levels of TDE and bio-compost

The available P content of the soil showed a progressive decline over stages of crop growth from 19.48 kg ha^{-1} of tillering stage to 19.05 kg ha^{-1} at post-harvest stage. Among the main plot treatments, M4 (application of TDE @ 0.15 million L ha^{-1}) registered higher phosphorus availability of 21.36 kg ha^{-1} which was followed by M3 (application of TDE@ 0.1 million L ha^{-1}) registering 21.19 kg ha^{-1} while the lower doses of TDE and the control plot recorded low values for M2 (18.52 kg ha^{-1}) and M1 (16.23 kg ha^{-1}) respectively. The above the trend of result was observed at all the stages of the crop growth (*Table 6*).

Among the sub plot treatments, application of 75% N as urea + 25% N as bio-compost (S6) recorded higher phosphorus availability of 20.19 kg ha^{-1} which was being comparable with 37.5% N as urea + 37.5% N as bio-compost (S7) which registered 20.05 kg ha^{-1}. This was followed by application of 100% N as urea (S2) which was on par with 75% N as urea (S3) both of which were found superior over the application of 100% N a bio-compost (S4) and 75% N as bio-compost (S5) and control (S1) recorded the lowest (17.97 kg ha^{-1}). The above trend of results was found at all stages of crop growth.

Table 6. *Soil available phosphorus (kg ha^{-1}) as influenced by different levels of TDE and bio-compost in paddy*

Treatments	Active tillering stage (stage 1)					Panicle initiation stage (stage 2)					Post harvest stage (stage 3)				
	M1	M2	M3	M4	Mean	M1	M2	M3	M4	Mean	M1	M2	M3	M4	Mean
S1	15.35	17.55	20.30	19.90	**18.28**	15.17	17.16	20.20	20.00	**18.13**	14.11	16.38	19.90	19.60	**17.50**
S2	17.20	19.30	21.30	21.40	**19.80**	16.89	19.11	21.09	22.28	**19.84**	16.70	18.91	21.00	21.28	**19.48**
S3	16.70	19.20	21.70	21.20	**19.70**	16.51	19.01	21.59	22.07	**19.80**	16.41	18.82	21.40	21.09	**19.43**
S4	16.15	18.80	20.80	20.60	**19.09**	15.93	18.43	20.69	21.68	**19.19**	15.74	18.13	20.50	20.40	**18.69**
S5	15.95	18.60	20.50	20.40	**18.86**	15.74	17.94	20.40	21.48	**18.89**	15.45	17.65	20.30	20.20	**18.40**
S6	17.45	19.40	22.20	22.30	**20.34**	17.28	19.21	21.89	22.47	**20.21**	17.09	19.01	21.79	22.18	**20.02**
S7	16.50	19.00	22.70	22.85	**20.26**	16.32	18.72	22.39	22.67	**20.02**	16.13	18.52	22.29	22.48	**19.86**
Mean	**16.47**	**18.84**	**21.36**	**21.24**	**19.48**	**16.27**	**18.51**	**21.18**	**21.81**	**19.44**	**15.95**	**18.21**	**21.02**	**21.03**	**19.05**

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Treatments	Pooled mean (stages)				
	M1	M2	M3	M4	Mean
S1	14.88	17.03	20.13	19.83	**17.97**
S2	16.93	19.11	21.13	21.65	**19.71**
S3	16.54	19.01	21.56	21.45	**19.64**
S4	15.94	18.46	20.66	20.89	**18.99**
S5	15.72	18.06	20.40	20.69	**18.72**
S6	17.27	19.21	21.96	22.32	**20.19**
S7	16.32	18.75	22.46	22.67	**20.05**
Mean	**16.23**	**18.52**	**21.19**	**21.36**	**19.32**

	Stage	M	S	M at St	S at M	S at St	S at St × M
SEd	0.06	0.07	0.09	0.12	0.18	0.16	0.32
CD (5%)	0.12	0.14	0.18	0.24	0.37	NS	NS

Interaction of main plot × subplot treatment was found to be significant. Application of TDE @ 1.5 lakh L ha^{-1} (M4) along with 37.5% N as urea + 37.5% N as bio-compost (S7) registered high available phosphorus of 22.67 kg ha^{-1}. This combination was on par with the application of TDE @ 1.0 lakh L ha^{-1} (M3) along with 37.5% N as urea + 37.5% N as bio-compost (S7) registering 22.46 kg ha^{-1}.

Soil available potassium as influenced by different levels of TDE and bio-compost

Available potassium content of the soil showed a marked decline over the stages of crop growth. The available potassium content ranged from 137 kg ha^{-1} in M1S1 at post-harvest stage to 428 kg ha^{-1} in M3S7 at active tillering stage.

Among the main plot treatments, application of TDE @ 0.15 million L ha^{-1} registered higher potassium availability (404 kg ha^{-1}) which is comparable with the application of TDE @ 0.1 million L ha^{-1} registering 400 kg ha^{-1} and the above trend of result was observed at all stages of the growth (*Table 7*).

Among the subplot treatments, application of 75% N as urea + 25% N as compost, 37.5%N as urea + 37.5% N as bio-compost, 100% N as urea and 75% N as urea being comparable among themselves registering higher available potassium of 337 kg ha^{-1}, 333 kg ha^{-1}, 331 kg ha^{-1} and 329 kg ha^{-1} respectively in the soil over the rest of the treatments. Interaction of main plot × subplot treatments was found to be significant. Application of TDE @ 0.15 million L ha^{-1} (M4) along with 37.5% N as urea + 37.5% N as bio-compost (S7) registered high available potassium (417 kg ha^{-1}). This combination was on par with the application of TDE @ 0.1 million L ha^{-1} (M3) along with 37.5% N as urea + 37.5% N as bio-compost (S7) registering 416 kg ha^{-1}.

Table 7. *Soil available potassium (kg ha^{-1}) as influenced by different levels of TDE and bio-compost in paddy*

Treatments	Active tillering stage (stage 1)					Panicle initiation stage (stage 2)					Post harvest stage (stage 3)				
	M1	M2	M3	M4	Mean	M1	M2	M3	M4	Mean	M1	M2	M3	M4	Mean
S1	200	322	392	385	**324**	182	294	374	370	**305**	137	263	350	355	**276**
S2	209	336	409	421	**344**	198	326	401	415	**335**	178	296	395	394	**316**
S3	206	333	413	419	**343**	194	322	403	412	**333**	173	293	390	396	**313**
S4	204	328	408	416	**339**	190	312	408	408	**330**	157	279	385	389	**303**
S5	202	326	403	414	**336**	187	310	405	405	**327**	154	273	382	386	**299**
S6	211	339	424	425	**350**	200	328	418	418	**341**	182	302	400	401	**321**
S7	205	332	427	428	**348**	192	316	420	420	**337**	165	288	402	403	**314**
Mean	**205**	**331**	**411**	**415**	**341**	**192**	**315**	**404**	**407**	**330**	**164**	**285**	**386**	**389**	**306**

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Treatments	Pooled mean (stages)				
	M1	M2	M3	M4	Mean
S1	173	293	372	370	**302**
S2	195	319	402	410	**331**
S3	191	316	402	409	**329**
S4	184	306	400	404	**324**
S5	181	303	397	402	**321**
S6	198	323	414	415	**337**
S7	188	312	416	417	**333**
Mean	**187**	**310**	**400**	**404**	**325**

	Stage	M	S	M at St	S at M	S at St	S at St × M
SEd	6	7	9	12	19	16	32
CD (5%)	12	14	19	24	37	NS	NS

Soil phosphatase activity as influenced by different levels of TDE and bio-compost

Application of TDE and bio-compost significantly increased the soil phosphatase activity. Among the main plot treatments, application of TDE @ 0.15 million L ha^{-1} (M4) recorded highest phosphatase activity of 2.31 µg p-nitrophenol g^{-1} dry soil h^{-1} being on par with the application of TDE @ 0.1 million L ha^{-1} (M3) recording 2.27 µg p-nitrophenol g^{-1} dry soil h^{-1}. The control (S1) recorded lowest phosphatase activity of 1.40 µg p-nitrophenol g^{-1} dry soil h^{-1}.

Among the N fertilizer levels, S6 (75% N as urea + 25% N as bio-compost) recorded higher phosphatase activity of 2.06 µg p-nitrophenol g^{-1} dry soil h^{-1} which was being comparable with S7 (37.5% N as urea + 37.5% N as bio-compost) recording 2.04 µg p-nitrophenol g^{-1} dry soil h^{-1} (*Table 8*).

Table 8. *Soil phosphatase activity as influenced by different levels of TDE and bio-compost*

Treatments	Phosphatase activity (µg p-nitrophenol g^{-1} soil h^{-1})							
	S1	S2	S3	S4	S5	S6	S7	Mean
M1	1.27	1.45	1.43	1.40	1.38	1.49	1.41	**1.40**
M2	1.81	1.95	1.95	1.90	1.88	1.99	1.93	**1.92**
M3	2.10	2.31	2.28	2.21	2.17	2.36	2.44	**2.27**
M4	2.21	2.32	2.34	2.28	2.25	2.38	2.40	**2.31**
Mean	**1.85**	**2.01**	**2.00**	**1.95**	**1.92**	**2.06**	**2.04**	**1.97**

	M	S	M at S	S at M
SEd	0.03	0.01	0.03	0.01
CD (5%)	0.10	0.02	0.10	0.02

The interaction effect of M × S treatment was found to be significant. Application of TDE @ 0.1 million L ha^{-1} along with 37.5% N as urea + 37.5% N as bio-compost (M3S7) recorded higher phosphatase activity of 2.44 µg p-nitrophenol g^{-1} dry soil h^{-1} followed by the application of TDE @ 0.15 million L ha^{-1} along with 37.5% N as urea + 37.5% N as bio-compost (M4S7) recording higher phosphatase activity of 2.40 µg p-nitrophenol g^{-1} dry soil h^{-1}.

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Soil urease activity as influenced by different levels of TDE and bio-compost

Application of TDE and bio-compost significantly increased the urease activity in soil. Among the main plot treatments, application of TDE @ 0.15 million L ha^{-1} (M4) recorded highest urease activity of 7.12 µg NH4-N g^{-1} dry soil h^{-1} being comparable with the application of TDE @ 0.1 million L ha^{-1} (M3) recording 6.98 µg NH4-N g^{-1} dry soil h^{-1}. The control recorded the lowest urease activity of 4.33 µg NH4-N g^{-1} dry soil h^{-1} (*Table 9*).

Table 9. *Soil urease activity as influenced by different levels of TDE and bio-compost*

Treatments	Urease activity (µg NH4-N g^{-1} soil h^{-1})							
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**Mean**
M1	3.91	4.47	4.42	4.31	4.25	4.60	4.36	**4.33**
M2	5.56	6.02	6.02	5.86	5.80	6.13	5.94	**5.90**
M3	6.46	7.12	7.03	6.79	6.69	7.25	7.50	**6.98**
M4	6.81	7.15	7.22	7.03	6.94	7.32	7.40	**7.12**
Mean	**5.68**	**6.19**	**6.17**	**6.00**	**5.92**	**6.32**	**6.30**	**6.08**

	M	**S**	**M at S**	**S at M**
SEd	0.10	0.01	0.10	0.01
CD (5%)	0.30	0.02	0.30	0.02

Among the N fertilizer levels, S6 (75% N as urea + 25% N as bio-compost) recorded high urease activity of 6.32 µg NH4-N g^{-1} dry soil h^{-1} which was being comparable with S7 (37.5% N as urea + 37.5% N as bio-compost) recording 6.30 µg NH4-N g^{-1} dry soil h^{-1}. The control (S1) recorded the lowest urease activity of 5.68 µg NH4-N g^{-1} dry soil h^{-1}.

The interaction effect of M × S treatment was found to be significant. Application of TDE @ 0.1 million L ha^{-1} along with 37.5% N as urea + 37.5% N as bio-compost (M3S7) recorded higher urease activity of 7.50 µg NH4-N g^{-1} dry soil h^{-1} followed by the application of TDE @ 0.15 million L ha^{-1} along with 37.5% N as urea + 37.5% N as bio-compost (M4S7) recording high urease activity of 7.40 µg NH4-N g^{-1} dry soil h^{-1}.

Soil dehydrogenase activity as influenced by different levels of TDE and bio-compost

Application of TDE and bio-compost significantly increased the soil dehydrogenase activity. Among the main plot treatments, application of TDE @ 0.15 million L ha^{-1} (M4) recorded higher dehydrogenase activity of 24.05 µg TPF g^{-1} dry soil h^{-1} being comparable with the application of TDE @ 0.1 million L ha^{-1} (M3) recording 23.54 µg TPF g^{-1} dry soil h^{-1}. The control recorded the lowest dehydrogenase activity of 14.59 µg TPF g^{-1} dry soil h^{-1} (*Table 10*).

Table 10. *Soil dehydrogenase activity as influenced by different levels of TDE and bio-compost*

Treatments	Dehydrogenase activity (µg TPF g^{-1} soil h^{-1})							
	S1	**S2**	**S3**	**S4**	**S5**	**S6**	**S7**	**Mean**
M1	13.20	15.07	14.90	14.54	14.33	15.39	14.71	**14.59**
M2	18.74	20.30	20.29	19.80	19.58	20.66	20.03	**19.91**
M3	21.80	24.01	23.71	22.91	22.57	24.47	25.30	**23.54**
M4	22.98	24.10	24.35	23.71	23.41	24.68	25.10	**24.05**
Mean	**19.18**	**20.87**	**20.81**	**20.24**	**19.97**	**21.30**	**21.28**	**20.52**

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	M	S	M at S	S at M
SEd	0.32	0.01	0.32	0.03
CD (5%)	1.03	0.02	1.03	0.05

Among the N fertilizer levels, S6 (75% N as urea + 25% N as bio-compost) recorded higher dehydrogenase activity of 21.30 µg TPF g^{-1} dry soil h^{-1} which was being comparable with S7 (37.5% N as urea + 37.5% N as bio-compost) recording 21.28 µg TPF g^{-1} dry soil h^{-1}.

The interaction effect of M × S treatment was found to be significant. Application of TDE @ 0.1 million L ha^{-1} along with 37.5% N as urea + 37.5% N as bio-compost (M3S7) recorded higher dehydrogenase activity of 25.30 µg TPF g^{-1} dry soil h^{-1} followed by the application of TDE @ 0.15 million L ha^{-1} along with 37.5% N as urea + 37.5% N as bio-compost (M4S7) recording higher dehydrogenase activity of 25.10 µg TPF g^{-1} dry soil h^{-1}.

Discussion

Soil available nitrogen

The available N content was significantly influenced by the application of TDE and BC. Among the different treatments, application of TDE @ 0.15 million L ha^{-1} (M4) recorded the highest available N to a tune of 267 kg ha^{-1} which contributed to an increase of 37% over the absolute control. The higher rate of mineralization and release of N from soil, fertilizers and TDE could have contributed for the increase in the available N in the soil.

Among the subplot treatments, S6 (application of 75% N as urea + 25% N as compost) recorded high available N status which contributed to an increase of 10% over check. It was being on par with S7 (37.5%N as urea + 37.5% N as bio-compost) contributing an increase of 9.6% increase over the control. 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 N upon sustained mineralization of organic manures (Rakkiyappan et al., 2005; Venkatakrishnan and Ravichandran, 2007; Sridharan, 2007; Suganya, 2008; Dinesh, 2011; Selvamurugan et al., 2024).

Among the treatment combinations, application of TDE @ 0.1 million L per hectare (M3) along with 37.5% N as urea + 37.5% N as bio-compost (S7) registered high available nitrogen and was found to be comparable with the application of TDE @ 0.15 million L ha^{-1} (M4) along with 37.5% N as urea + 37.5% N as bio-compost (S7) recording 278 kg ha^{-1}. Higher N 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 resulting in an enhanced availability of N in soil. Similar results were reported by Satisha (2000), Subash Chandra Bose et al. (2002b), Sridharan (2007) and Stephen et al. (2024). Significant and positive correlation observed between the available N and yield (r = 0.802**) also supported the above findings. A marked decline in the available N in the soil was observed with the advancement of crop growth which might be due to the continuous removal of N by the crop, losses due to transformation. However, during the crop growth the reduction in the soil available N could be due to the uptake by growing crop.

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Soil available phosphorus

Application of TDE and bio-compost remarkably increased the available P in soil. Among the different treatments, application of TDE @ 0.15 million L ha^{-1}(M4) had recorded the highest available P to the tune of 21.36 kg P ha^{-1} which contributed to an increase of 24% over the absolute control. The increase in available P may be due to the application of TDE applied as well as the consequent dissolution of soil mineral P (apatite P). Though TDE was not acidic, its decomposition released organic acids which might have solubilised the soil native P and thus increased the $NaHCO_3$-P. Similar results were reported by Mallika (2001), Murugaraghavan (2002), Maheswari (2011), Dinesh (2011) and Silva and Kardos (2024).

Among the sub plot treatments, application of 75% N as urea + 25% N as bio-compost (S6) recorded higher phosphorus availability of 20.19 kg ha^{-1} being comparable with 37.5% N as urea + 37.5% N as bio-compost (S7) registering 20.05 kg ha^{-1}, both of which contributed to an increase of 10.9% and 10.4% increase over the check.

Application of TDE @ 0.1 million L ha^{-1} along with 37.5% N as urea + 37.5% N as bio-compost (M3S7) or 75% N as urea + 25% N as bio-compost (M3S6) being on par with the application of TDE @ 0.15 million L ha^{-1} along with 37.5% N as urea + 37.5% N as bio-compost (M4S7). The effect of bio-compost almost at all the stages of observations was found superior to check. These results are in line with the findings of Parmer and Sharma (2002) and Singh et al. (2002). The decomposition processes of easily degradable organics might have reduced the binding energy and P sorption capacity of the soil, favoring higher P availability in the soil. Significant and positive correlation observed between the available P and yield ($r = 0.869^{**}$) 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.

Soil available potassium

The available K in the soils was significantly influenced by the application of TDE and bio-compost. Among the main plot treatments, application of TDE@ 0.15 million L ha^{-1} (M4) registered significantly higher K availability (404 kg ha^{-1}) compared to the other main plot treatments which contributed to an increase of 53.7% over control. The reason attributed to this was due to the high potassium content of TDE (12,650 ppm). Increase in the available K content of the surface soil was sustained even after the harvest. These results also agreed with the findings of Murugaragavan (2002), Janaki (2008), Gbadeyan et al. (2024) and Selvamurugan et al. (2024) who observed that the available K in the soil increased due to the application of effluent.

Among the subplot treatments, application of 75% N as urea + 25% N as compost, 37.5%N as urea + 37.5% N as bio-compost, 100% N as urea and 75% N as urea being comparable among themselves registered higher available potassium content of 337 kg ha^{-1}, 333 kg ha^{-1}, 331 kg ha^{-1} and 329 kg ha^{-1} respectively in the soil over the rest of the treatments which contributed an increase of 10.4%, 9.3% and 8.8% increase over control.

The interaction effect of M × S was also significant wherein the application of TDE @ 0.1 million L ha^{-1} along with 37.5% N as urea + 37.5% N as bio-compost (M3S7) or 75% N as urea + 25% N as bio-compost (M3S6) being on par with the application of

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TDE @ 0.15 million L ha^{-1} along with 37.5% N as urea + 37.5% N as bio-compost (M4S7). The increase may be attributed to the release of mineral K and addition of K rich manures led to the release of K into the soil solution. The present findings fall in line with that of Verma et al. (2002), Prabu (2003), Sivasamy (2004), Venkatakrishnan and Ravichandran (2007) and Dinesh (2011). Significant and positive correlation observed between the available K and yield ($r = 0.748^{**}$) also supported the above findings. The availability of K in the soil got decreased as the crop growth advanced which could be attributed to the uptake of K by the crop.

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 @ 0.1 million L ha^{-1} along with 37.5% N as urea + 37.5% N as bio-compost (M3S7) followed by the application of TDE @ 0.15 million L ha^{-1} along with 37.5% N as urea + 37.5% N as bio-compost (M4S7) was found to have greater 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 (Kamalakumari and Singaram, 1995; Tripathi et al., 2022).

Engracia Madejon et al. (2003) found a positive correlation between the organic residues and dehydrogenase, β-glucosidase, urease and protease activities of the soil. Ramana et al. (2002) and Kumar et al. (2019) also reported that the enzyme activities were increased due to the application of distillery effluent. Generally, organic manure addition was found to enhance the microbial activities which in turn favored the synthesis of various enzymes in soil. These three enzymes play a significant role in the bio-transformation of nutrients in soil, and thus influence the nutrients availability in soil and uptake by crops. The mineralization rate of organic P is relevant to both P nutrition of crops and phosphatase activity in soil. Therefore, higher enzyme activities in soil suggested that the mineralization of N and P was greater due to the application of spent wash. Similar result was reported by Dinesh (2020).

Conclusion

In conclusion, this study highlights the potential of 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. Thus, it can be concluded that application of TDE @ 0.1 million L ha^{-1}(M3) or TDE @ 0.15 million L ha^{-1} (M4) along with 37.5% N as urea + 37.5% N as bio-compost (S7) recorded the highest availability of soil available nutrients and enzymatic activity in the soil.

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