**Original Research Article**

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**Effect of Distillery Raw Spentwash on Soil Microbial Properties and Yield of Paddy in a Sodic Vertisol**

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**Abstract**

To evaluate the effect of distillery RSW on soil microbial properties and yield of paddy in a sodic Vertisol a field study was conducted at Agricultural Research Station, Gangavathi, Koppal, Karnataka. The treatment consists of five graded levels of RSW, viz., 1.0, 1.5, 2.0, 2.5 and 3.0 lakh L ha\(^{-1}\) (T\(_1\) to T\(_5\)), gypsum @ 50 and 100 per cent of gypsum requirement (GR) (T\(_6\) and T\(_7\)) and control (T\(_8\)). The RDF applied to these treatments was common. The surface soil samples collected at harvest of the crop were examined for changes in physico-chemical properties, bacteria, fungi, actinomycetes, soil microbial biomass carbon, dehydrogease, urease and phosphatase activities. The soil pH, Ex-Na and ESP decreased with the levels of RSW application and decrement was linear with the proportion of RSW application. Apart from decreasing soil ESP it also enhanced the soil microbial activity. In general, the bacteria, fungi, actinomycetes, urease and phosphatase activities increased with increase in RSW application only up to 2.5 lakh L ha\(^{-1}\). However, soil salinity build up was observed with the increased levels of RSW application. Paddy grain yield was significantly higher in T\(_4\) and T\(_3\) compared to other treatments, while significantly higher straw yield was recorded in T\(_5\) compared to other treatments except T\(_4\).

**Keywords**

Distillery raw spentwash, Microbial properties, Paddy grain yield, Sodic soil.

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**Introduction**

In India, salt affected soils are broadly classified into two groups: sodic (alkali) and saline soils. As per the recent reconciled estimate (CSSRI, Karnal, NRSA, NBSS&LUP, 2006) nearly 6.73 M ha area is found to be salt affected (sodic soils: 3.77 M
ha and saline soils: 2.96 M ha). In Karnataka state, nearly 4.14 L ha of land is being affected by salinity problem (Gupta et al., 1995). It is reported that sodic soils known to occupy an area of about more than 15000 ha in the districts of Koppal, Bellary and Raichur of Northern Karnataka and over 28000 ha in Karnataka. In arid and semi-arid areas, where good-quality water for irrigated agriculture is scarce, inadequate management of soil and water resources can lead to soil sodification (Assouline et al., 2015). Soil sodicity is characterized by a relatively high concentration of sodium in the exchange complex or in the soil water, causing adverse effects on the physical, chemical and biological properties of the soil. Among the soil microbial properties, the soil urease activity, acid and alkaline phosphatase activity in soils were reported to decrease with the increase in soil pH and ESP (Viraj Beri and Brar, 1978; Batra, 2010). Similarly, the soil microbial biomass, dehydrogenase activity and soil microbial biomass carbon observed to decrease due to a specific ion deficiencies and toxicities at high soil pH and ESP (Batra and Manna, 1997; Batra, 1998).

Distillery spentwash, a byproduct of alcohol industry is gaining its importance in the reclamation of non-saline sodic soils as it is highly acidic (pH=3.9-4.3) and contains fairly good amount of soluble organic matter, Ca (2050-7000 ppm), Mg and other essential plant nutrients. In India there are 400 distillery units with an average production of 3.80 × 10^9 L of alcohol generating 4.56 × 10^10 L of spentwash (Verma chhaya and Rajesh Kumar, 2014). Karnataka has 25 working distilleries with an installed capacity of 250 M L with the annual production of 125 M L of alcohol generating 1500 M L of spentwash. The number of sugarcane crushing industries in Karnataka is also increasing. Alcohol industry continue to face the challenges of disposal of huge quantity of effluent without causing air, water and soil pollution due to its high organic load (high COD and BOD) which otherwise can be made use for the reclamation of non-saline sodic soil. Thus, application of distillery raw spentwash (RSW) to a sodic soil as an organic amendment and a source of plant nutrients is a promising alternative method for its safe disposal.

A significant research in the last 3-4 decades was carried out mainly on the use of raw spentwash (RSW) or pre-treated spentwash (PTSW) at proper dilutions as a source of nutrient in enhancing production of crops like wheat, maize, sugarcane, cow pea, red gram and black gram etc. (Chidankumar and Chandraju, 2008; Rath et al., 2011). But, research on using RSW as an organic reclamation agent for sodic soil appears to be meager. Further, the research results from elsewhere reflect variation in the levels of dose of RSW applied depending on the soil and crop to be grown. The application rate varies as low as 1.5 lakh L ha^{-1} (sandy clay loam) to as high as 5.0 lakh L ha^{-1} (sandy loam). Information is lacking on using RSW as an organic amendment for sodic soils of the districts in Karnataka where heavy textured (clay/clay loam) soils are prominent. In a laboratory incubation study conducted by Saliha et al., (2005) revealed that application of RSW at 55 ml kg^{-1} soil recorded significantly higher bacterial, fungal and actinomycetes colonies, urease and phosphatase activity compared to control and other RSW treatments (110 and 225 ml kg^{-1} of soil). Further, increased concentration of spentwash in soil decreased the microbial population and enzyme activity. However, dehydrogenase activity (DHA) increased significantly with increased levels of RSW application. The indiscriminate use of RSW might adversely affect the soil microbial properties by increase in soil salinity. Therefore, the present study was aimed to examine the “Effect of distillery raw
spentwash on soil microbial properties and yield of paddy in a sodic Vertisol”.

Materials and Methods

A field experiment was conducted at the Agriculture Research Station (ARS), Gangavathi during Kharif 2014. The research site falls under the Northern Dry Zone of Karnataka state (semi-arid eco-subregion) lying between 15°35'07" N latitude and 76°15'47" E longitude at an altitude of 419 m above mean sea level with an average annual rainfall of around 542 mm. During the year 2014-2015 the rainfall received was about 29 per cent higher (763 mm) than the average rainfall of the station. Normally dry weather prevails over entire summer months with hottest period observed during April-May.

The mean maximum and minimum air temperature was ranged from 28.26 °C to 38.18 °C and 16.70 °C to 23.91 °C, respectively. The surface soil (0-15 cm) pH, ECE, bulk density, cation exchange capacity (CEC), Ex-Na and ESP before the start of the experimentation was 8.82, 1.32 dS m⁻¹, 1.35 Mg m⁻³, 36.2 cmol (p⁺) kg⁻¹, 7.1 cmol (p⁺) kg⁻¹ and 21.3%, respectively. The organic carbon content was medium (5.6 g kg⁻¹), soil microbial biomass carbon was 105.6 µg g⁻¹ of soil, DHA was 1.15 µg TPF g⁻¹ soil 24hr⁻¹, urease and alkaline phosphatase activities were 6.34 µg NH₄-N g⁻¹ soil hr⁻¹ and 60.83 µg p-nitrophenol g⁻¹ soil hr⁻¹, respectively. The soil microbial biomass like bacteria, fungi and actinomycetus populations were 10.59 CFU × 10⁶ g⁻¹ soil, 11.2 CFU × 10⁴ g⁻¹ soil and 19.08 CFU × 10³ g⁻¹ soil, respectively. The field experiment was laid out in a randomised complete block design with eight treatments consisting of five graded levels of RSW, viz., 1.0, 1.5, 2.0, 2.5 and 3.0 lakh L ha⁻¹ (T₁ to T₅), two levels of gypsum requirement (Gypsum @ 50 & 100% GR: T₆ & T₇) and control (T₈). All these treatments received RDF in common. During Kharif 2014, two months prior to transplanting of paddy, as one time application the required quantities of RSW and GR were applied manually to the plots (5m × 4m) as per treatments. The RSW was procured from “M/s. Vijayanagar Sugars Pvt. Ltd.”, Mundaragi, Gadag, Karnataka. The properties of which were analyzed and presented in Table 1. Transplanted paddy (var. BPT 5204) was grown as a test crop to study the effect of RSW on grain yield.

The surface soils (0-15 cm) collected after the harvest of the paddy were analyzed for physico-chemical properties, microbial properties and enzyme activities to know the effect of levels of RSW application. The pH and EC of the soil was estimated in 1:2.5 soil: water suspension. The EC (1:2.5) values were multiplied by a common derived factor of 2.66 for soils at ARS, Gangavathi to convert them to ECE (dS m⁻¹); saturation paste extract values. The ESP was determined by using a formula ESP = \frac{\text{Ex-Na}}{\text{CEC}} × 100 and expressed in per cent. The organic carbon content of the soil was determined by Walkley and Black method (Jackson, 1973).

The microbial population in moist surface soil was determined by serial dilution and plating technique as outlined by Waksman and Fred (1922). The soil microbial biomass carbon (SMBC) of the moist surface soil was determined by chloroform fumigation extraction method as outlined by Vance et al., (1987). Dehydrogenase activity (DHA) in these soils was assayed by the method of Casida et al., (1964) using 2,3,5-triphenyltetrazolium chloride (TTC) as the electron acceptor and expressing the results in µg TPF g⁻¹ soil 24hr⁻¹. The activity of urease was determined by NH₄-N distillation method as outlined by Bremner and Keeney (1966) and expressed in µg NH₄-N g⁻¹ soil hr⁻¹ and the phosphatase activity was determined by p-
nitrophenyl phosphate method given by Tabatabai and Bremner (1969) and expressed in µg p-nitrophenol g⁻¹ soil hr⁻¹.

Analysis of variance (ANOVA) was carried out using the randomised complete block design. Duncan’s multiple range test (DMRT) at 5% level of probability was used to test the differences between means of individual treatments (Gomez and Gomez, 1984).

Results and Discussion

Chemical properties

Soil pH and electrical conductivity (ECe)

At crop harvest, the surface soil (0-15 cm) pH decreased significantly with increase in the levels of RSW and it varied from 7.68 (T₅) to 8.72 (T₈), respectively (Table 2). Among the treatments, T₅ (RSW @ 3.0 lakh L ha⁻¹) recorded significantly lower soil pH than other treatments but at par with T₄ (RSW @ 2.5 lakh L ha⁻¹) (7.82). Similarly, the soils amended with gypsum also decreased from 8.72 to 8.44 with increase in dose of gypsum application with T₇ (Gypsum @ 100% GR). The treatment T₂ (RSW @ 1.5 lakh L ha⁻¹) had similar effect as that of T₇. Decreased soil pH may be attributed to the replacement of Na⁺ on the exchange complex by Ca²⁺ ions released into the soil and the acidic nature of RSW (pH 3.7). In addition, release of organic acids during the decomposition of organic matter (added through RSW) might have also solubilised the native lime and released free Ca²⁺ ions into the soil apart from high Ca content of RSW. In addition, increase in neutral soluble salts content of soils through application of RSW (EC 36.1 dS m⁻¹) also might have helped to decrease soil pH in RSW treated plots.

Unlike soil pH, the ECe increased significantly with increased levels RSW (Table 2). The soils treated with RSW recorded significantly higher ECe compared to control and gypsum treated plots. Among the treatments, significantly higher soil ECe (6.08 dS m⁻¹) was recorded under T₅ (RSW @ 3.0 lakh L ha⁻¹) compared to rest of the treatments which may be attributed to the contribution of salts from RSW which has high salt load in it (36.1 dS m⁻¹) (Table 2). Similar results were reported by Mahendra (2007), Bhagya Lakshmi (2009) and Hati et al., (2007). The extent of buildup of soluble salt concentration above the critical limit (4 dS m⁻¹ above which soils are classified as saline) particularly at higher rate of RSW application (3.0 lakh L ha⁻¹) is a cause of concern for increasing the rate of RSW application in such soils.

Soil exchangeable sodium (Ex-Na) and exchangeable sodium percentage (ESP)

In general, the soil Ex-Na and ESP decreased with the increased levels of RSW and the decrease was linear with the levels of RSW application. The decrease of Ex-Na and ESP at surface soil was significantly lower at the highest levels of RSW (T₅) application compared to T₁, T₂, T₆, T₇ and T₈ (Table 2). The per cent decrease in ESP over its initial levels was 75.2 (Table 2) in soils receiving RSW @ 3.0 lakh L ha⁻¹. Similarly, the application of gypsum @ 100% GR (T₇) has decreased the soil ESP from 21.58 to 16.38. However, the application of RSW @ 1.5 lakh L ha⁻¹ had the same effect of gypsum @ 100% GR on soil ESP and apart from enriching the soil with organic matter and available macro and micronutrients. The decrease in Ex-Na and hence ESP might be due to replacement of Ex-Na on the clay colloid from Ca and leaching of Na⁺ as soluble Na₂SO₄ as explained above. The results are in conformity with the findings of Bhagya Lakshmi (2009) who reported that the Ex-Na and ESP were decreased at harvest
with higher levels of RSW application (7.5 lakh L ha\(^{-1}\)) from 10.44 to 5.91 cmol (p\(^+\)) kg\(^{-1}\) and ESP from 37.2 to 22.3 respectively. Similarly, in a pot culture experiment with sunflower as a test crop Mahendra (2007) also noticed that application of RSW at 4.5 lakh L ha\(^{-1}\) reduced ESP from 19.41 to 10.47.

**Soil Microbial properties**

**Soil organic carbon (SOC), soil microbial biomass carbon and DHA**

In general, the soil organic carbon increased significantly with increased levels of RSW application (Table 2). The SOC increased significantly from its initial 5.6 to 12.0 g kg\(^{-1}\) where higher rate of RSW application was applied (RSW @ 3.0 lakh L ha\(^{-1}\)) compared to rest of the treatments except T\(_4\) (11.2) and T\(_3\) (10.7 g kg\(^{-1}\)). Whereas, the increase of SOC was also noticed in soils treated with the gypsum but it was marginal as compared to RSW treated soils. The addition of organic carbon (4.01%) through RSW and associated better crop growth with increase in root biomass could probable be the reason for increase in soil organic carbon content particularly in RSW treated soils (Hati et al., 2007). The results are also in line with the findings of Bhagyalakshmi, 2009 and Biswas et al., 2009.

**Table 1** Physico-chemical properties, chemical composition and biological properties of the distillery raw spentwash

| Parameter       | Spentwash | Parameter              | Spentwash |
|-----------------|-----------|------------------------|-----------|
| pH              | 3.7       | Total S (mg L\(^{-1}\)) | 2250      |
| EC (dS m\(^{-1}\)) | 31.6     | Bicarbonates (mg L\(^{-1}\)) | 13256     |
| OC (%)          | 4.01      | Zn (mg L\(^{-1}\))     | 7         |
| COD (mg L\(^{-1}\)) | 96500    | Fe (mg L\(^{-1}\))     | 85        |
| BOD (mg L\(^{-1}\)) | 38500    | Mn (mg L\(^{-1}\))     | 13.6      |
| Total N (mg L\(^{-1}\)) | 5850    | Cu (mg L\(^{-1}\))     | 5.8       |
| Total K (mg L\(^{-1}\)) | 210     | Cl (mg L\(^{-1}\))     | 9285      |
| Total Ca (mg L\(^{-1}\)) | 14700   | Bacteria (CFU)         | 20 × 10\(^6\) ml\(^{-1}\) |
| Total Mg (mg L\(^{-1}\)) | 6377    | Fungi (CFU)            | 7 × 10\(^4\) ml\(^{-1}\) |
| Total Na (mg L\(^{-1}\)) | 385     | Actinomycetus (CFU)    | 3 × 10\(^2\) ml\(^{-1}\) |

**Table 2** Effect of distillery raw spentwash on physico-chemical properties of the soil at harvest of the crop in a sodic Vertisol

| Treatment | pH   | ECe (dS m\(^{-1}\)) | Ex-Na (cmol (p\(^+\)) kg\(^{-1}\)) | ESP | OC (g kg\(^{-1}\)) |
|-----------|------|---------------------|----------------------------------|-----|------------------|
| T\(_1\)   | 8.34\(^{cd}\) | 3.08\(^{d}\)        | 6.16\(^{bc}\)                   | 17.02\(^{bc}\) | 8.16\(^{bc}\) |
| T\(_2\)   | 8.27\(^{c}\)  | 3.27\(^{d}\)        | 5.51\(^{b}\)                   | 15.28\(^{b}\) | 9.07\(^{b}\) |
| T\(_3\)   | 7.96\(^{a}\)  | 4.51\(^{c}\)        | 4.69\(^{a}\)                   | 12.96\(^{a}\) | 10.70\(^{a}\) |
| T\(_4\)   | 7.82\(^{ab}\) | 5.43\(^{b}\)        | 4.46\(^{a}\)                   | 12.32\(^{a}\) | 11.19\(^{a}\) |
| T\(_5\)   | 7.68\(^{a}\)  | 6.08\(^{a}\)        | 4.40\(^{a}\)                   | 12.15\(^{a}\) | 12.01\(^{a}\) |
| T\(_6\)   | 8.51\(^{d}\)  | 1.75\(^{el}\)       | 6.75\(^{c}\)                   | 18.65\(^{c}\) | 6.65\(^{d}\) |
| T\(_7\)   | 8.44\(^{cd}\) | 2.08\(^{c}\)        | 5.93\(^{bc}\)                  | 16.38\(^{b}\) | 6.86\(^{cd}\) |
| T\(_8\)   | 8.72\(^{c}\)  | 1.46\(^{l}\)        | 7.81\(^{d}\)                   | 21.58\(^{d}\) | 6.45\(^{d}\) |
Table 3 Effect of distillery raw spentwash on soil microbial population at harvest of the crop in a sodic Vertisol

| Treatment | Bacteria (CFU × 10^7 g^-1 soil) | Fungi (CFU × 10^4 g^-1 soil) | Actinomycetes CFU × 10^5 g^-1 soil |
|-----------|---------------------------------|-----------------------------|----------------------------------|
| T1        | 4.19^{cd}                       | 13.6^{cd}                  | 16.3^{cd}                        |
| T2        | 4.86^{c}                        | 15.3^{c}                   | 19.1^{c}                         |
| T3        | 6.16^{b}                        | 17.8^{b}                   | 23.8^{b}                         |
| T4        | 7.75^{a}                        | 22.3^{a}                   | 31.2^{a}                         |
| T5        | 7.11^{a}                        | 20.6^{a}                   | 28.4^{a}                         |
| T6        | 3.07^{ef}                       | 10.5^{ef}                  | 12.5^{ef}                        |
| T7        | 3.40^{d}                        | 11.8^{de}                  | 14.9^{de}                        |
| T8        | 2.33^{f}                        | 9.2^{e}                    | 11.3^{f}                         |

Table 4 Effect of distillery raw spentwash on soil enzyme activities at harvest of the crop in a sodic Vertisol

| Treatment | SMBC (µg g^-1 soil) | DHA (µg TPF g^-1 soil 24hr^-1) | Phosphatase (µg PNP g^-1 soil hr^-1) | Urease (µg NH_4-N g^-1 soil hr^-1) |
|-----------|---------------------|---------------------------------|-----------------------------------|----------------------------------|
| T1        | 209.9^{d}           | 3.25^{c}                        | 229.5^{d}                         | 23.42^{c}                       |
| T2        | 256.2^{c}           | 4.76^{b}                        | 312.3^{c}                         | 26.46^{c}                       |
| T3        | 268.7^{bc}          | 5.05^{ab}                       | 382.2^{b}                         | 31.33^{b}                       |
| T4        | 288.7^{ab}          | 5.70^{ab}                       | 475.9^{a}                         | 38.83^{a}                       |
| T5        | 301.9^{a}           | 5.89^{a}                        | 437.4^{a}                         | 36.13^{a}                       |
| T6        | 159.7^{e}           | 2.18^{d}                        | 148.9^{e}                         | 15.12^{d}                       |
| T7        | 165.1^{e}           | 2.67^{cd}                       | 170.7^{e}                         | 18.34^{d}                       |
| T8        | 148.0^{e}           | 1.87^{d}                        | 124.3^{e}                         | 9.28^{e}                        |

Table 5 Effect of distillery raw spentwash on yield of paddy in a sodic Vertisol

| Treatments | Plant height (cm) | Tiller hill^{-1} | Productive tillers hill^{-1} | Grain yield (kg ha^{-1}) | Straw yield (kg ha^{-1}) |
|------------|-------------------|------------------|-------------------------------|------------------------|-------------------------|
| T1 (RSW @ 1.0 lakh L ha^{-1}) | 86.6^{bc}         | 17.5^{c}         | 14.4^{bc}                     | 4198^{cd}              | 5284^{d}                |
| T2 (RSW @ 1.5 lakh L ha^{-1}) | 88.4^{b}          | 18.6^{bc}        | 16.4^{ab}                     | 4388^{c}               | 5593^{cd}               |
| T3 (RSW @ 2.0 lakh L ha^{-1}) | 98.6^{a}          | 21.1^{ab}        | 18.9^{a}                      | 4913^{ab}              | 6129^{bc}               |
| T4 (RSW @ 2.5 lakh L ha^{-1}) | 99.7^{a}          | 21.4^{ab}        | 19.0^{a}                      | 5006^{a}               | 6462^{ab}               |
| T5 (RSW @ 3.0 lakh L ha^{-1}) | 100.5^{a}         | 22.6^{a}         | 18.0^{a}                      | 4544^{bc}              | 6706^{a}                |
| T6 (Gypsum @ 50% GR)         | 79.2^{bc}         | 12.4^{de}        | 11.3^{dc}                     | 3622^{e}               | 4131^{ef}               |
| T7 (Gypsum @ 100% GR)        | 81.6^{bc}         | 14.1^{d}         | 13.0^{cd}                     | 3909^{de}              | 4526^{e}                |
| T8 (Control)                 | 76.8^{e}          | 10.6^{e}         | 9.6^{e}                       | 3481^{e}               | 3841^{f}                |

The SMBC increased with graded levels of RSW application. The SMBC increased from 105.6 to 301.9 µg g^-1 dry soil where the highest level of RSW was applied (Table 4). Among the treatments, T5 (RSW @ 3.0 lakh L ha^-1) recorded significantly higher SMBC (301.9 µg g^-1 dry soil) compared to rest of the treatments except T4. The distillery RSW
contains considerable amount of easily degradable organic matter which would stimulate soil microbial biomass, microbial activity and consequently the SMBC. The results are in agreement with the findings of Hati et al., (2007) who reported increase in SMBC from 130.5 (control) to 359.6 mg kg\(^{-1}\) (179\%) with the application of RSW at 7.5 lakh L ha\(^{-1}\). Similar to SMBC, the DHA increased with increased levels of RSW application (Table 4) with T\(5\) recording significantly higher DHA (5.89 µg g\(^{-1}\) dry soil 24hr\(^{-1}\)) compared to T\(1\), T\(2\), T\(3\), T\(6\), T\(7\) and T\(8\) but at par with the T\(4\) (RSW @ 2.5 lakh L ha\(^{-1}\)).

Soil microbial biomass and enzyme activity

The soil microbial population is concurrent with pH, EC, ESP and fertility of the soil. In accordance with the decrease in soil pH, ESP and increase in organic carbon content, the microbial population viz., bacteria, fungi and actinomycetes at rhizosphere soil (0-15 cm) increased significantly with increased levels RSW up to 2.5 lakh L ha\(^{-1}\) but decreased slightly at 3.0 lakh L ha\(^{-1}\) (Table 3). However, higher salt build up in soil (ECe 6.08 dS m\(^{-1}\)) at higher level of RSW (3.0 lakh L ha\(^{-1}\)) might have caused reduction in microbial population. In an incubation study, Saliha et al., (2005) reported that the microbial population in sodic soil was higher under lower levels of RSW application (55 ml kg\(^{-1}\) soil) as compared higher levels of RSW (225 ml kg\(^{-1}\) soil). The bacteria, fungi and actinomycetes population ranged from 2.33 to 7.75 CFU \times 10^7 g\(^{-1}\) soil, 9.2 to 22.3 CFU \times 10^4 g\(^{-1}\) soil and 11.3 to 31.2 CFU \times 10^5 g\(^{-1}\) soil, respectively. The lower and higher bacteria, fungi and actinomycetes populations were recorded in T\(8\) (Control+ RDF) and T\(4\) (RSW @ 2.5 lakh L ha\(^{-1}\)) respectively. As indicated by Baskar et al., (2013), high organic carbon content and nutrients of distillery RSW (Table 1) would serve as ready energy source for the growth, enzyme processes and multiplication of microbes.

The urease and alkaline phosphatase activity was significantly higher (38.83 µg NH\(_4\)N g\(^{-1}\) soil hr\(^{-1}\) & 475.9 µg PNP g\(^{-1}\) soil hr\(^{-1}\)) in soils receiving RSW at 2.5 lakh L ha\(^{-1}\) compared to other treatments except T\(5\) (RSW @ 3.0 lakh L ha\(^{-1}\)) where a marginal decrease was observed (Table 4). As discussed above, 2-3 folds increase in enzyme activity in RSW treated soils might be attributed to decrease in soil pH, increase in organic matter and microbial population. Similar to microbial biomass, decrease in these activities at higher levels (RSW @ 3.0 lakh L ha\(^{-1}\)) might be due to “Salting out” effect of Cl\(^{-}\) which might have modified the ionic confirmation of active centre of enzymes and subsequent specific ion toxicities caused by nutritional imbalance for the adequate synthesis of enzymes (Saliha et al., 2005). Saliha et al., (2005) also reported an increase in phosphatase (392\%) and urease (140\%) activity from 26 (control) to 128.1 g kg\(^{-1}\) hr\(^{-1}\) and 1.9 and 28.6 g kg\(^{-1}\) hr\(^{-1}\) respectively with the application of RSW at 55 ml kg\(^{-1}\) soil followed by RSW at 110 ml kg\(^{-1}\) soil at 60 days after incubation. Similar effect of RSW application on phosphatase and urease activity was also reported by Murugaragavan (2002).

Paddy yield

The plant height, number of tillers and productive tillers per hill, grain and straw yield increased significantly with increased levels of RSW application and the increase may be attributed to improvement in soil physico-chemical properties along with enhanced fertility status of the soil which in turn might have promoted better root development, nutrient content and its uptake by the crops and higher biomass production (Table 5). Among the treatments, T\(5\) recorded significantly higher plant height, number of
tillers per hill and straw yield compared T₁, T₂, T₆, T₇ and T₈ but at par with T₄ and T₃. However, the number of productive tillers per hill and grain yield were significantly higher in T₄ (RSW @ 2.5 lakh L ha⁻¹) compared to T₁, T₂, T₅, T₆, T₇ and T₈ but at par with T₃.

The results are in agreement with the findings of Saliha (2003) who reported that the application of RSW at the rate of 125 m³ ha⁻¹ recorded significantly higher rice grain yield than at 250 and 500 m³ ha⁻¹. Similar effect of RSW application on yield was also reported by Hati et al., (2007) and Biswas et al., (2009) for soybean and wheat; Balasubramanian et al., (2007) for rice crop, respectively.

It is evident from the above study that the application of RSW at about 2.0 lakh L ha⁻¹ appears to be ideal for increasing soil microbial population and enzyme activities of a sodic Vertisol. The buildup of soil salinity and thus increased ionic concentrations and toxicity of specific ions at higher rates of RSW application might have adversely affected the growth of soil microbial biomass and consequently reduced enzyme activity. The positive effects of one time application of RSW @ 2.0 lakh L ha⁻¹ on soil physico-chemical and biological properties reflected in improved plant growth and yield of paddy.

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