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# Impact of Sewage Sludge Application on Soil Fertility, Microbial Population and Enzyme Activities in Soil under Rice-Wheat System

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A field experiment was conducted at Agricultural Research Farm, Banaras Hindu University, Varanasi, India for two consecutive years taking two crops each of rice and wheat in a sequence to study the effect of one time application of sewage sludge (SS) on soil fertility, microbial population and enzyme activities. Graded levels of SS were applied along with 50 and 100% recommended dose of fertilizers (RDF). The experiment was conducted in randomized block design taking 10 treatments with three replications. The soil pH decreased, while electrical conductivity (EC) and organic carbon (OC) content increased due to addition of SS. Application of SS in first crop and its residual effect in subsequent crops increased the available N, P, K and S content in soil. Higher available P was recorded in the second crop of the experiment, whereas, available K was high in third crop. Microbial colony count (bacterial and fungal) and enzyme activities (urease, phosphatase and dehydrogenase) were significantly increased due to application of SS resulting in higher microbial activity in post-harvest soils with 45 t ha$^{-1}$ SS. Sewage sludge added during previous years had pronounced residual influence on soil fertility and microbial activity.

**Key words:** Sewage sludge, soil fertility, microbial population, urease, phosphatase, dehydrogenase, rice-wheat system

Sewage sludge (SS) is a semi-solid material produced as a byproduct during sewage treatment of industrial or municipal wastewater. The number of sewage treatment plants in India is increasing due to increased urbanization and industrialization. Total wastewater generation in the country is around 38.3 billion litres per day (BLD) while, the installed sewage treatment capacity is just 11.8 BLD thereby leading to a gap of 26.5 BLD in sewage treatment capacity. It is projected that by 2050, about132 BLD of wastewaters with a potential to meet 4.5% of the total irrigation water demand would be generated thereby further widening this gap (Bhardwaj 2005). The utilization of SS in agriculture is gaining popularity as a source of nutrients. It has been widely used in many countries around the world; in the European community, over 40% of SS out of 10.1 million tonnes (Mt) production is used in agriculture (European Commission 2008).

Rice-wheat cropping system (RWCS) is one of the most popular systems in India. It has played a major role for raising food grain production to make the country self sufficient. However, continuous cultivation of these crops caused decline in soil fertility, especially soil organic matter content. Rice-wheat being the cereal crops, the mining of nutrients is higher. Diagnostic surveys in the Indo-Gangetic Plains, however, revealed that farmers often apply greater than recommended rates of fertilize nitrogen (N) and phosphorus (P), but ignore the sufficient application of other limiting nutrients to the RWCS (Dwivedi *et al*. 2001; Singh *et al*. 2013). Unbalanced application of nutrients over the years has led to emergence of multinutrient deficiencies in soils under the RWCS, particularly in the Trans Gangetic Plains and Upper Gangetic Plains (Singh *et al*. 2005; Ladha *et al*. 2009; Singh *et al*. 2013).

Reduced availability of nutrients and organic matter in soil may limit the microbial population and

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their activities. In contrast to chemical fertilizers, SS is relatively inexpensive and provides organic matter to soil in addition to nutrients (European Commission 2001; Haynes *et al*. 2009; Latare *et al*. 2014). The nutrients contained in SS are organically bound which get mineralized to inorganic form upon subsequent decomposition, therefore, it is also considered as a slow-release fertilizer. The SS contains high amount of organic carbon (OC) (12.6%), 1.6% N, 1.3% P, 0.8% K and 2.1% S in addition to substantial quantities of micronutrients 232, 186, 260 and 161 mg $kg^{-1}$ of Fe, Cu, Mn and Zn, respectively (Latare *et al.* 2014).Application of SS on surface or incorporation into the soil improves its physical condition, availability of plant nutrients, soil water-holding capacity and organic matter leading to increase in crop productivity. Sewage sludge addition can increase nutrient availability and restore the degraded soils (Gomez-Rico *et al*. 2008).

Incorporation of organic materials, such as SS into soil promotes its biological activity (Saviozzi *et al.* 1999). Microbial activity and soil fertility are closely related because it is through the biomass that the mineralization of the important organic elements (C, N and P) occurs (Ros *et al*. 2003). Soil enzymes help to maintain soil ecology, physical and chemical processes including nutrient release. The decomposition of organic matter in soil is carried out by soil microorganisms with the help of different soil enzymes. Sewage sludge application provides the substrate for the action of microbe and thereby increase the soil enzyme activities (Stark *et al*. 2008; Fernandez *et al*. 2009; Sciubba *et al*. 2013).

The rapid declining in soil OC pool due to continuous intensive cultivation is one of the biggest challenges. The use of SS might prove a feasible proposition for the improvement and/or restoration of organic matter in soil. The studies reported hereunder aimed to determine the direct and residual effect of one time application of SS on soil fertility, microbial population and soil enzyme activities under rice-wheat sequence.

## Materials and Methods

### *Experimental site*

The field experiment was conducted at Agricultural Research Farm, Banaras Hindu University, Varanasi, Uttar Pradesh, India taking two crops each of rice and wheat in a sequence during 2011-12 and 2012-13. Varanasi is situated at an altitude of 80.71 m above mean sea level and located between 25°18' N latitude and 80°36' E longitude. The study area falls under semi-arid to sub-humid climate with moisture deficit index from 20-40. Mean annual precipitation is about 1100 mm. The annual maximum and the minimum temperature ranged between 20-42 °C and 9-28 °C, respectively. The mean relative humidity is about 68% which rises to 82% during wet season and goes down to 30% during dry season. The soil at the experimental site is alluvial representing an Inceptisol (Typic Ustochrept). The experimental soil (0–15 cm) had pH 8.49 (1:2.5), EC 0.149 dS $m^{-1}$, OC 4.78 g $kg^{-1}$ and available N, P and K as 132.7, 18.3 and 127.7 kg $ha^{-1}$, respectively. The DTPA-extractable Fe, Mn, Cu and Zn contents of soil were 44.5, 12.3, 2.3 and 1.06 mg $kg^{-1}$, respectively.

### *Experimental design and treatments*

The experiment was set up in randomized block design taking 10 treatments with three replications. Sewage sludge was applied on dry weight basis only in first rice crop and chemical fertilizers were applied in each crop as per treatment details (Table 1).

**Table 1.** Treatment details for two rice-wheat cropping cycle

| Treatments | 2011-12 | | 2012-13 | |
|---|---|---|---|---|
| | I<sup>st</sup> rice | I<sup>st</sup> wheat | II<sup>nd</sup> rice | II<sup>nd</sup> wheat |
| $T_1$ | 100% RDF*(Control) | 100% RDF | 100% RDF | 100% RDF |
| $T_2$ | 15 t SS** $ha^{-1}$ | - | - | - |
| $T_3$ | 30 t SS $ha^{-1}$ | - | - | - |
| $T_4$ | 45 t SS $ha^{-1}$ | - | - | - |
| $T_5$ | 100% RDF + 15 t SS $ha^{-1}$ | 100% RDF | 100% RDF | 100% RDF |
| $T_6$ | 100% RDF + 30 t SS $ha^{-1}$ | 100% RDF | 100% RDF | 100% RDF |
| $T_7$ | 100% RDF + 45 t SS $ha^{-1}$ | 100% RDF | 100% RDF | 100% RDF |
| $T_8$ | 50% RDF + 15 t SS $ha^{-1}$ | 50% RDF | 50% RDF | 50% RDF |
| $T_9$ | 50% RDF + 30 t SS $ha^{-1}$ | 50% RDF | 50% RDF | 50% RDF |
| $T_{10}$ | 50% RDF + 45 t SS $ha^{-1}$ | 50% RDF | 50% RDF | 50% RDF |

*Recommended dose of fertilizers,**Sewage sludge

Two cropping cycles of rice (var: PRH-10) and wheat (var. HUW-234) were completed during 2011-12 and 2012-13 without disturbing the experimental layout. Residual effect of SS was monitored up to fourth crop (second wheat) in sequence in conjunction with graded doses of RDF. Recommended dose of fertilizers ($N:P_2O_5:K_2O$) was 150:75:75 kg $ha^{-1}$ for rice and 120:60:60 kg $ha^{-1}$ for wheat.

*Collection and analysis of sewage sludge samples*

The SS was collected from Sewage Treatment Plant, Bhagwanpur, Varanasi, Uttar Pradesh in the month of May, 2011. The dry SS (20% moisture) was ground to get homogenous mass. The SS had pH 6.57, EC 2.57 dS $m^{-1}$, organic C 9.65%, total N, P, K and S content as 1.4, 1.2, 0.87 and 0.96%, respectively. Sewage sludge samples were analyzed using standard procedures (Peters *et al.* 2003).

*Collection and analysis of soil samples*

Initial soil sample was taken from experimental field before application of treatments and post-harvest soil (PHS) samples (0-15 cm) were collected from each plot after harvest of each crop. The soil samples were air-dried, powdered with wooden roller and sieved through 2-mm sieve. For chemical analysis, soil samples were further ground and sieved through 0.5 mm sieve to make them homogenous. For estimation of microbial properties, moist soil samples (0-15 cm) after harvest of each crop were stored in zipped polythene bags in refrigerator at 4 °C.

Soil pH was determined in a soil-water suspension (1:2.5) with the help of pH meter, the EC was measured in the supernatant of the same suspension (Sparks 1996). The OC was estimated employing wet oxidation method (Walkley and Black 1934); available N by alkaline potassium permanganate method (Subbiah and Asija 1956) using Kjeltec semi-auto nitrogen analyzer (Pelican Kjeltech); available P by Olsen's method (Olsen *et al*. 1954); available K in 1 *N* ammonium acetate extract using flame photometer (Hanway and Heidel 1952) and available S by turbidity method (Chesnin and Yein 1951).

Total bacterial and fungal populations were estimated by following the serial dilution and plate count techniques as described by Schimidt and Cadwell (1967) using Thornton's medium for bacteria and Czapek-Dox Agar medium for fungi. Urease activity in soils was estimated as per procedure outlined by Tabatabai and Bremner (1972). Alkaline phosphatase and dehydrogenase activity was measured employing the method given by Page *et al*. (1982). Dehydrogenase activity was determined by measuring the reduction of triphenyl tetrazolium chloride (TTC) to triphenyl formazan (TPF) and expressed as ìg TPF formed $h^{-1}$ $d^{-1}$.

*Statistical analysis*

The data were subjected to one-way analysis of variance (ANOVA) using SPSS version 16. Duncan's multiple range test (DMRT) was performed to test the significance of difference between the treatments at 95% level of confidence.

**Results and Discussion**

*Physicochemical properties of soil*

The pH of soil decreased significantly with graded levels of SS in first rice and also in succeeding crops (Table 2), although, SS was applied only in first rice crop. The maximum pH in first rice (8.50) was recorded both in $T_1$ (RDF) and $T_5$ (RDF+15 t SS $ha^{-1}$), and the minimum pH of 8.40 and 8.32 in first year rice and wheat was recorded due to application of RDF + 45 t SS $ha^{-1}$ ($T_7$) and 50% RDF + 45 t SS $ha^{-1}$ ($T_{10}$), respectively. It was noticed that pH decreased significantly in SS amended plots particularly with higher doses ($T_4$, $T_7$ and $T_{10}$) as compared to RDF. The gradual decrease in soil pH with the application of SS might be due to the degradation of organic matter and release of organic and inorganic acids such as carbonic, citric and malic acids as well as $H^+$ produced from mineralization of N in the organic matter (Brofas *et al*. 2000; Habteselassie *et al*. 2006). However, increase in pH of soil with application of SS was also reported by Latare *et al.* (2014).

There was a significant increase in EC of soil (Table 2) due to graded application of SS. The maximum EC during both the year was recorded with 50% RDF+45 t SS $ha^{-1}$ application ($T_7$), whereas the minimum was recorded with RDF ($T_1$). An increase in EC might be due to high salinity of the SS. At harvest, during both the years of study higher EC in soils of wheat was recorded compared to soils of rice. The lower values of EC after rice could be attributed to leaching of salts in flooded rice. The increase in EC with the addition of SS was also reported by Meena *et al.* (2013). Latare *et al.* (2014) also found significant increase in EC of the post-harvest rice and wheat soil over control due to addition of 30 and 40 t SS $ha^{-1}$ in rice crop only.

**Table 2.** Direct and residual effect of sewage sludge on pH, EC and OC of soil (mean of 3 replicates ± SE)

| Treatment | pH | | | | EC (dS m$^{-1}$) | | | | OC (g kg$^{-1}$) | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | 2011-12 | | 2012-13 | | 2011-12 | | 2012-13 | | 2011-12 | | 2012-13 | |
| | I$^{st}$ Rice | I$^{st}$ Wheat | II$^{nd}$ Rice | II$^{nd}$ Wheat | I$^{st}$ Rice | I$^{st}$ Wheat | II$^{nd}$ Rice | II$^{nd}$ Wheat | I$^{st}$ Rice | I$^{st}$ Wheat | II$^{nd}$ Rice | II$^{nd}$ Wheat |
| $T_1$ | 8.50±0.01b* | 8.51±0.01d | 8.47±0.01c | 8.49±0.02d | 0.16±0.02a | 0.30±0.01a | 0.12±0.01a | 0.33±0.05a | 4.34±0.04a | 4.21±0.04a | 3.72±0.06a | 3.47±0.06a |
| $T_2$ | 8.49±0.01b | 8.46±0.01cd | 8.41±0.01bc | 8.40±0.01c | 0.20±0.01ab | 0.35±0.02abc | 0.17±0.02b | 0.38±0.03a | 4.64±0.07a | 4.44±0.04a | 4.17±0.03ab | 3.91±0.03abc |
| $T_3$ | 8.45±0.02ab | 8.38±0.01ab | 8.32±0.02a | 8.23±0.01ab | 0.25±0.00ab | 0.35±0.06abc | 0.18±0.01b | 0.40±0.04a | 7.46±0.08b | 6.91±0.05b | 6.44±0.09cd | 5.55±0.12cde |
| $T_4$ | 8.43±0.01a | 8.35±0.02a | 8.28±0.03a | 8.19±0.02a | 0.28±0.01b | 0.44±0.02cd | 0.24±0.01cde | 0.42±0.02a | 9.22±0.08b | 9.25±0.11c | 8.42±0.05d | 7.34±0.07ef |
| $T_5$ | 8.50±0.01b | 8.47±0.01cd | 8.43±0.01bc | 8.41±0.01c | 0.19±0.01ab | 0.33±0.01ab | 0.18±0.00bc | 0.36±0.01a | 4.45±0.05a | 4.14±0.07a | 3.83±0.03a | 3.61±0.02ab |
| $T_6$ | 8.44±0.04ab | 8.36±0.01a | 8.31±0.02a | 8.25±0.01b | 0.23±0.01ab | 0.42±0.05bcd | 0.21±0.02bcd | 0.38±0.04a | 7.13±0.06b | 6.32±0.09b | 5.91±0.05bc | 5.42±0.04bcd |
| $T_7$ | 8.40±0.02a | 8.34±0.02a | 8.30±0.01a | 8.21±0.02ab | 0.26±0.02ab | 0.45±0.03d | 0.28±0.04e | 0.41±0.04a | 8.54±0.05b | 8.25±0.09bc | 8.17±0.10d | 7.32±0.07ef |
| $T_8$ | 8.44±0.02ab | 8.42±0.01bc | 8.40±0.01b | 8.42±0.01c | 0.18±0.05ab | 0.33±0.01a | 0.19±0.01bc | 0.34±0.06a | 4.62±0.07a | 4.31±0.05a | 4.28±0.02ab | 4.04±0.02abc |
| $T_9$ | 8.42±0.00a | 8.36±0.02a | 8.33±0.02a | 8.23±0.02ab | 0.21±0.04ab | 0.42±0.00bcd | 0.22±0.01bcd | 0.39±0.02a | 7.81±0.06b | 6.84±0.08b | 7.14±0.05cd | 6.61±0.04def |
| $T_{10}$ | 8.42±0.02a | 8.32±0.03a | 8.29±0.03a | 8.21±0.03ab | 0.26±0.07ab | 0.47±0.00d | 0.25±0.01de | 0.44±0.09a | 8.94±0.07b | 8.66±0.06bc | 8.42±0.09d | 7.83±0.06f |

*Values followed by different alphabets in a column are statistically significant (*P<0.05*) from each other.

Direct and residual effect of SS application on OC content was significant in both the years (Table 2). The OC content in soil at harvest of first rice was higher which progressively decreased in the subsequent cropping seasons. The maximum OC content (9.2 g kg$^{-1}$) at harvest of first rice and first wheat crops was recorded with 45 t SS ha$^{-1}$ application ($T_4$) while after second rice (8.4 g kg$^{-1}$) and wheat (7.8 g kg$^{-1}$), it was due to 50% RDF + 45 t SS ha$^{-1}$ ($T_{10}$). During both the years, treatments amended with SS resulted in higher soil OC content compared to control ($T_1$), however, the effect was significant only with 30 and 45 t SS ha$^{-1}$ application. The slow decomposition rate of added SS with high organic load contributed to build-up of OC. Similar findings were also reported by Singh and Agrawal (2010) and Orman *et al.* (2014). Increase in OC content of soil due to increase in fertilizer application might be attributed to higher root biomass production. In pot culture studies, Latare *et al.* (2014) found that application of 20, 30 and 40 t SS ha$^{-1}$ increased the OC content in soil at harvest of rice by 14, 18 and 35 per cent respectively over control. At harvest of wheat, soil OC increased by 52 and 51per cent over control due to residual effect of 40 and 30 t SS ha$^{-1}$, respectively. They attributed this to profuse root growth in rice which after decomposition increased the OC content in soil after wheat.

*Available N, P and K in soil*

The available soil N content at harvest significantly increased due to direct and residual effect of SS (Table 3). The maximum available soil N content during first year at harvest of rice (278 kg ha$^{-1}$) and wheat (261 kg ha$^{-1}$); and during second year after rice (237 kg ha$^{-1}$) and wheat (194 kg ha$^{-1}$) was recorded due to RDF + 45 t SS ha$^{-1}$ application ($T_7$), whereas, the minimum was due to 15 t SS ha$^{-1}$ ($T_2$). Sole application of 45 t SS ha$^{-1}$ showed 40, 35, 26 and 16 per cent increase in available soil N content after rice and wheat during first and second year, respectively over their respective RDF ($T_1$). The residual effect of 45 t SS ha$^{-1}$ with 50% RDF ($T_{10}$) had 43 per cent higher available soil N content over RDF at harvest of rice whereas it reduced to 18 per cent after wheat during first year. The increase in available soil N content as a result of SS application may be ascribed to its organic matter content. Most of the N present in soil is bound in organic form, which upon decomposition released in the soil over a period of time. Latare *et al.* (2014) also reported increase in available soil N in post harvest soils of

**Table 3.** Direct and residual effect of sewage sludge on available nitrogen and phosphorus in soil (mean of 3 replicates ± SE)

| Treatment | Available N (kg ha$^{-1}$) | | | | Available P (kg ha$^{-1}$) | | | |
|---|---|---|---|---|---|---|---|---|
| | 2011-12 | | 2012-13 | | 2011-12 | | 2012-13 | |
| | I$^{st}$ Rice | I$^{st}$ Wheat | II$^{nd}$ Rice | II$^{nd}$ Wheat | I$^{st}$ Rice | I$^{st}$ Wheat | II$^{nd}$ Rice | II$^{nd}$ Wheat |
| $T_1$ | 171±4.56ab | 169±8.30ab | 162±7.32abc | 159±4.56bc | 28.6±1.14ab | 37.3±1.45ab | 30.7±3.55a | 28.3±1.54c |
| $T_2$ | 163±8.30a | 160±8.30a | 142±5.82a | 131±6.36a | 24.0±1.19a | 27.6±2.23a | 25.4±2.27a | 15.8±2.16a |
| $T_3$ | 184±5.53bc | 173±7.62ab | 159±13.8abc | 147±3.62ab | 32.1±2.03bcde | 36.4±1.68ab | 27.1±3.38a | 16.6±0.85a |
| $T_4$ | 239±4.56e | 228±5.77d | 205±6.36e | 184±4.18de | 35.2±1.73cde | 41.5±1.16ab | 30.7±1.65a | 22.5±0.96b |
| $T_5$ | 193±2.77c | 189±3.77bc | 173±6.53bcd | 161±13.8bc | 35.8±2.62de | 35.6±1.25ab | 32.5±2.47ab | 28.2±1.03c |
| $T_6$ | 211±7.54d | 206±5.53c | 190±11.5de | 179±9.58cde | 36.6±0.43de | 39.7±2.59ab | 39.2±1.68b | 30.2±1.40c |
| $T_7$ | 278±6.36f | 261±6.09e | 237±12.8f | 194±15.8e | 37.5±1.42e | 50.8±3.89c | 39.7±1.76b | 30.9±2.31c |
| $T_8$ | 173±3.77ab | 169±7.62ab | 153±12.8ab | 141±14.8ab | 29.4±1.55abc | 34.6±1.25b | 26.5±1.90a | 16.3±0.37a |
| $T_9$ | 196±5.53cd | 188±7.24bc | 176±11.8cd | 164±4.18bc$^d$ | 31.1±1.50bcd | 37.7±0.89ab | 28.8±3.02a | 22.4±2.31b |
| $T_{10}$ | 253±5.82e | 246±13.1de | 232±8.30f | 187±6.85e | 35.1±2.80cde | 40.5±1.59ab | 33.7±2.45ab | 26.7±2.62ab |

*Values followed by different alphabets in a column are statistically significant (P<0.05) from each other.

rice and wheat with the addition of SS in rice. The maximum N content in post rice harvest soil was recorded due to amendment of 40 t SS ha$^{-1}$ (155 kg ha$^{-1}$) followed by 30 t SS ha$^{-1}$ (134 kg ha$^{-1}$), which accounted 39 and 30 per cent increase in available soil N over control, whereas its residual effect in wheat recorded 65 and 61 per cent increase over control, respectively.

Direct and residual effect of SS increased the soil available P significantly (Table 3). It increased at harvest of wheat of first year compared to rice and then it subsequently decreased after harvest of rice and wheat in second year. The maximum available soil P content at harvest of rice and wheat during both the years was recorded with RDF + 45 t SS ha$^{-1}$ ($T_7$), whereas the minimum was with 15 t SS ha$^{-1}$ ($T_2$). Sole application of 30 and 45 t SS ha$^{-1}$ ($T_3$ and $T_4$) showed 34 and 47 per cent increase in available soil P over 15 t SS ha$^{-1}$ ($T_2$) at harvest of rice during first year, whereas, its residual effect after wheat was 32 and 52 per cent, respectively. Application of 15, 30 and 45 t SS ha$^{-1}$ with RDF($T_5$, $T_6$ and $T_7$) had 25, 28 and 31 per cent increase in available soil P over RDF ($T_1$) at harvest of rice of first year. The residual effect of 30 and 45 t SS ha$^{-1}$ application along with 50% RDF ($T_9$ and $T_{10}$) were statistically at par with RDF at harvest of rice during second year. A significant build-up of available soil P with increase in graded dose of SS might be due to the higher content of phosphate compounds in sludge itself. Meena *et al.* (2013) reported that the available P content significantly increased in the soil amended with 10 t FYM+10 t SS ha$^{-1}$ in pearlmillet-mustard cropping system. They suggested that availability of P was governed by organic carbon build-up in the soil. Latare *et al.* (2014) also reported increase of available P in post harvest soil under rice and wheat with the addition of SS in rice. The P content increased significantly with 20 t ha$^{-1}$ or higher levels of sludge and was the maximum with 40 t SS ha$^{-1}$ followed by 30 t SS ha$^{-1}$ with respective increase of 45 and 44 per cent over control (no sludge). Vieira *et al.* (2014) reported that the P contents in the soils due to addition of SS were 82 per cent higher over previous agricultural year, which suggested that if the application is done every year, the content of P in the soil could reach environmentally unacceptable levels.

Available soil K content at harvest increased due to application of SS in first year rice till the second year rice then it decreased (Table 4). The maximum available soil K content post harvest soil of rice and wheat during both the years was recorded with RDF+45 t SS ha$^{-1}$ ($T_7$), whereas the minimum was with 15 t SS ha$^{-1}$ ($T_2$). Application of 15, 30 and 45 t SS ha$^{-1}$ with RDF ($T_5$, $T_6$ and $T_7$) showed 8, 20 and 37 per cent increase in available soil K at harvest of first year rice, while, its residual effect in first year wheat showed a respective increase of 18, 22 and 31 per cent, over RDF ($T_1$). Residual effect of sole application of 30 and 45 t SS ha$^{-1}$ in first rice increased the available soil K content by 10 and 26 per cent ; and 30 and 44 per cent at harvest of second year rice and wheat, respectively over 15 t SS ha$^{-1}$ ($T_2$). The SS used in the present study contained 0.87 per cent K which might have increased the available soil K content at harvest of rice and wheat. The straw and root residues of the previous crops left over in the field also significantly contributes to soil available K, this might also be a reason for its increase in the available soil K at harvest. Delibacak *et al.* (2009) reported significantly higher available K in soil amended with treated SS. Meena *et al.* (2013) reported

**Table 4.** Direct and residual effect of sewage sludge on available potassium and sulphur in soil (mean of 3 replicates ± SE)

| Treatment | Available K (kg ha$^{-1}$) | | | | Available S (mg kg$^{-1}$) | | | |
|---|---|---|---|---|---|---|---|---|
| | 2011-12 | | 2012-13 | | 2011-12 | | 2012-13 | |
| | I$^{st}$ Rice | I$^{st}$ Wheat | II$^{nd}$ Rice | II$^{nd}$ Wheat | I$^{st}$ Rice | I$^{st}$ Wheat | II$^{nd}$ Rice | II$^{nd}$ Wheat |
| $T_1$ | 164±5.87ab | 184±7.46b | 202±4.97ab | 181±8.14bc | 10.8±1.24a | 10.7±1.38a | 10.7±1.38a | 9.67±0.34a |
| $T_2$ | 159±6.73a | 168±2.91a | 195±5.83a | 142±5.50a | 18.5±2.01b | 21.6±2.24b | 21.6±2.24b | 13.3±1.86ab |
| $T_3$ | 162±2.34ab | 187±4.05b | 215±8.24bc | 184±44.6bcd | 23.3±1.49bc | 26.3±2.31bc | 26.3±2.31bc | 15.0±2.65abc |
| $T_4$ | 184±7.12bc | 217±5.11cd | 246±13.3de | 204±4.75de | 31.1±1.52ef | 31.9±1.34c | 31.8±1.34c | 20.1±2.83cde |
| $T_5$ | 178±4.41abc | 217±4.75cd | 262±5.90ef | 188±5.28cd | 23.2±1.44bc | 22.1±1.85b | 22.1±1.85b | 13.9±1.63abc |
| $T_6$ | 196±8.75c | 224±4.95de | 255±6.81ef | 202±6.37cde | 24.7±1.10cd | 21.9±1.82b | 21.9±1.82b | 14.1±1.34abc |
| $T_7$ | 226±5.98d | 241±9.53e | 268±6.81f | 209±2.47e | 24.0±2.37c | 21.9±1.55b | 21.9±1.55b | 21.7±1.01de |
| $T_8$ | 167±7.84ab | 190±3.93b | 204±14.1ab | 167±6.63b | 29.4±1.50de | 24.0±2.55b | 24.0±2.55b | 14.6±1.84abc |
| $T_9$ | 183±4.94bc | 199±8.41bc | 224±13.7c | 188±4.85cd | 32.4±1.82ef | 26.2±1.39bc | 26.2±1.39bc | 17.0±1.84bcd |
| $T_{10}$ | 192±10.7c | 224±7.44de | 230±15.9cd | 215±12.0e | 35.0±1.29f | 32.0±0.89c | 31.9±0.89c | 24.2±2.39e |

*Values followed by different alphabets in a column are statistically significant (*P<0.05*) from each other.

**Table 5.** Direct and residual effect of sewage sludge on bacterial and fungal populations in post- harvest soil (mean of 3 replicates ± SE)

| Treatment | Bacterial population (× 10$^5$ CFU g$^{-1}$ soil) | | | | Fungal population (× 10$^4$ CFU g$^{-1}$ soil) | | | |
|---|---|---|---|---|---|---|---|---|
| | 2011-12 | | 2012-13 | | 2011-12 | | 2012-13 | |
| | I$^{st}$ Rice | I$^{st}$ Wheat | II$^{nd}$ Rice | II$^{nd}$ Wheat | I$^{st}$ Rice | I$^{st}$ Wheat | II$^{nd}$ Rice | II$^{nd}$ Wheat |
| $T_1$ | 21.7±0.33a | 23.3±0.88a | 21.7±0.33a | 19.7±0.67a | 9.30±0.88a | 8.00±0.59a | 8.00±0.54a | 8.70±0.84a |
| $T_2$ | 24.7±0.88b | 26.0±0.58ab | 26.3±0.29b | 22.0±0.59ab | 14.0±±0.59bc | 10.3±0.84ab | 10.0±1.15a | 10.0±1.15a |
| $T_3$ | 32.0±0.58c | 33.0±1.15c | 26.0±1.53b | 25.7±0.33cd | 18.7±1.20d | 12.0±1.15b | 14.3±1.45b | 10.0±1.39a |
| $T_4$ | 35.0±0.51d | 34.3±1.67c | 32.3±0.48d | 29.3±1.76ef | 20.3±1.36de | 17.7±0.39c | 20.3±0.39c | 14.0±1.12bc |
| $T_5$ | 23.7±0.81ab | 27.0±0.46b | 29.0±1.00c | 23.3±1.20bc | 19.7±0.85de | 10.0±0.57ab | 20.3±1.20c | 10.3±0.88ab |
| $T_6$ | 32.7±0.74cd | 34.0±1.11c | 30.3±1.45cd | 30.7±0.67fg | 21.3±0.39de | 11.3±1.20b | 19.0±1.53c | 11.3±1.34abc |
| $T_7$ | 35.3±1.45d | 33.7±0.79c | 32.7±0.39d | 32.3±0.59g | 22.0±0.58c | 17.7±0.86c | 19.7±19.7c | 10.0±1.53a |
| $T_8$ | 24.7±0.87b | 26.3±0.84ab | 27.7±0.42bc | 24.3±0.48bc | 12.0±1.15ab | 9.3±0.84ab | 14.0±1.16b | 14.3±1.17c |
| $T_9$ | 31.3±1.20c | 28.7±1.20b | 30.0±0.58cd | 25.3±0.64cd | 15.3±1.45c | 16.7±0.86c | 19.3±1.20c | 12.0±1.13abc |
| $T_{10}$ | 33.0±0.53cd | 36.0±1.15c | 32.3±0.88d | 27.7±0.31de | 20.3±1.20de | 17.0±0.59c | 20.7±0.87c | 10.3±0.85ab |

*Values followed by different alphabets in a column are statistically significant (*P<0.05*) from each other.

that application of 10 t FYM+5.0 t SS ha$^{-1}$ to pearl millet significantly increased available K in soil. Latare *et al.* (2014) also reported a significant increase in K contents of post harvest soil under rice and wheat due to SS application in rice only.

The application of SS in first year rice and its residual effect in subsequent crops increased the available S content in soil at harvest (Table 4). All the SS amended treatments resulted in significantly higher available soil S at harvest of first three crops. The lowest values were recorded at harvest of second year wheat. The maximum available soil S content at harvest of rice and wheat during both the years was recorded with 50% RDF + 45 t SS ha$^{-1}$ ($T_{10}$) while the minimum was with RDF ($T_1$). Sole application of 30 and 45 t SS ha$^{-1}$ ($T_3$ and $T_4$) increased available soil S by 34 and 44; 26 and 68 and 22 and 48 per cent at harvest of first year rice, wheat and second year rice, respectively over 15 t SS ha$^{-1}$ ($T_2$). Increase in available S content might be attributed to application of S rich SS (0.96%). Deshmukh *et al.* (2004) also reported increase in N, P, and K in soil with increase in the rate of SS application. A significant increase in available S due to the direct and residual effect of SS on rice and wheat was also reported by Latare *et al.* (2014). They found maximum S content in post harvest soils due to amendment of 40 t SS ha$^{-1}$ followed by 30 t SS ha$^{-1}$, which accounted respective increase of 50 and 37 per cent over control in rice and 49 and 46 per cent in wheat.

*Microbial population*

Application of 30 and 45 t SS ha$^{-1}$ significantly increased the bacterial population (Table 5) over control (100% RDF) in soils during both the years of study. The maximum bacterial population in soils of post harvest rice and wheat during both the years was recorded in $T_7$ where 45 t SS ha$^{-1}$ was applied with

100% RDF (Table 5). Sole application of 15, 30 and 45 t SS $ha^{-1}$ ($T_2$, $T_3$ and $T_4$) significantly increased the bacterial population in soil by 14, 47, 61 and 12, 42 and 47 per cent at harvest of first year rice and wheat; and 21, 20 and 48 and 12, 30 and 49 per cent after second year of rice and wheat, respectively over control. Hence, a significant residual effect of SS on bacterial population was clearly noticeable up to the second year wheat over 100% RDF. The minimum bacterial population during all the cropping periods was recorded in control (100% RDF). Organic matter being the food of microorganisms provides the substrate for growth and activities of microorganisms. Hence, significant increase in bacterial count was recorded in the present study. Increase in bacterial population with application of SS was also reported by Singh *et al.* (2014). The treatment in which 75% RDF + 25% N through SS applied showed $36\times10^6$ cfu $g^{-1}$ soil bacterial population, whereas, in control it was $22\times10^6$ cfu $g^{-1}$ soil.

Application of SS significantly influenced the fungal population on soils of post harvest rice and wheat (Table 5). Similar to the bacterial population, the application of 30 and 45 t SS $ha^{-1}$ in first rice increased the fungal colony count during both the years of study, however the effect was significant only up to second year rice. The maximum fungal population in post harvest soils under rice and wheat during both the years was found in $T_7$ where 45 t $ha^{-1}$ SS was applied with 100% RDF except in second wheat where it was found in $T_8$ *i.e.* application of 15 t $ha^{-1}$ SS with 50% RDF (Table 5). Sole application of 15, 30 and 45 t SS $ha^{-1}$ ($T_2$, $T_3$ and $T_4$) increased the fungal population by 50, 100, 117 and 29, 50 and 121 per cent after first year rice, and wheat; and 25, 79 and 153 per cent after second year rice over control (100% RDF). The fungal population was higher in soil after rice as compared to wheat during both the years of study. Fungi generally prefers to grow in acidic conditions, in the present study increase in OM content coupled with decrease in pH of soil might be attributed to increased fungal population. The complex OM in SS provides substrate for proliferation of microbial and fungal colonies in soil. It provides favorable soil moisture and aeration conditions beneficial for the growth and development of fungal colonies. Increase in fungal population with application of SS was reported by Singh *et al.* (2014). They found fungal population of $33\times10^6$ cfu $g^{-1}$ soil due to 75% RDF + 25% N through SS applied, whereas, in control it was $18\times10^6$ cfu $g^{-1}$ soil. The population of soil bacteria and fungi were found to increase with application of FYM and vermicompost (Jadhav *et al.* 2016)

*Soil enzyme activities*

The urease activity in post harvest soils of rice and wheat increased significantly (Fig. 1) due to graded application of SS. The maximum urease activity after rice and wheat during both the years was recorded in $T_7$ where 45 t SS $ha^{-1}$ was applied with 100% RDF (Fig. 1). Sole application of 15, 30 and 45 t SS $ha^{-1}$ ($T_2$, $T_3$ and $T_4$) increased the urease activity by 16, 25, 41 and 19, 25 and 55 per cent at harvest of first year rice and wheat; and 5, 41 and 49 per cent in second year wheat, respectively over control (100% RDF). Urease is an enzyme that depends on Ni for its activity. Thus, high total content of Ni (65.8 mg $kg^{-1}$) in SS might be the probable reason for increased urease activity. Urease activity in soils is considered mainly of microbial origin which increases due to SS application (Klose and Tabatabai 2000). Increased urease activity as a result of SS application has also been registered in literature (Kakhki *et al.* 2008; Patel and Patra 2014; Jadhav *et al.* 2016).

Significant increase in the alkaline phosphatase activity in post-harvest soils was recorded due to direct and residual effect of SS both in rice and wheat (Fig. 1). Application of 15, 30 and 45 t SS $ha^{-1}$ along with 100% RDF ($T_5$, $T_6$ and $T_7$) increased soil alkaline phosphatase activity by 37, 38 ,41 and 6, 10, 36 per cent at harvest of first year rice and wheat; and 43, 69 and 75 per cent in second year wheat, respectively. Application of lower dose of SS (15 t SS $ha^{-1}$) resulted in low alkaline phosphatase activity, as compared to control (100% RDF), during both the years. Significant increase in phosphatase activity in soil after application of SS was also recorded by Criquet and Braud (2008).

The dehydrogenase activity significantly increased in soils due to the direct and residual effect of SS application. The maximum dehydrogenase activity (Fig. 1) in soils of first rice, first wheat, second rice and second wheat was 48.6, 53.3, 48.3 and 44.3 μg TPF released $g^{-1}$ soil $d^{-1}$. Sole application of 15, 30 and 45 t SS $ha^{-1}$ ($T_2$, $T_3$ and $T_4$) significantly increased the dehydrogenase activity by 33, 54 and 87 per cent in first rice, 49, 67 and 111 per cent in first wheat, 30, 43 and 49 per cent in second rice and 20, 56 and 56 per cent in second wheat, respectively over control ($T_1$). Similar effect was found for SS in combination with different doses of RDF in other treatments also. Significantly higher dehydrogenase

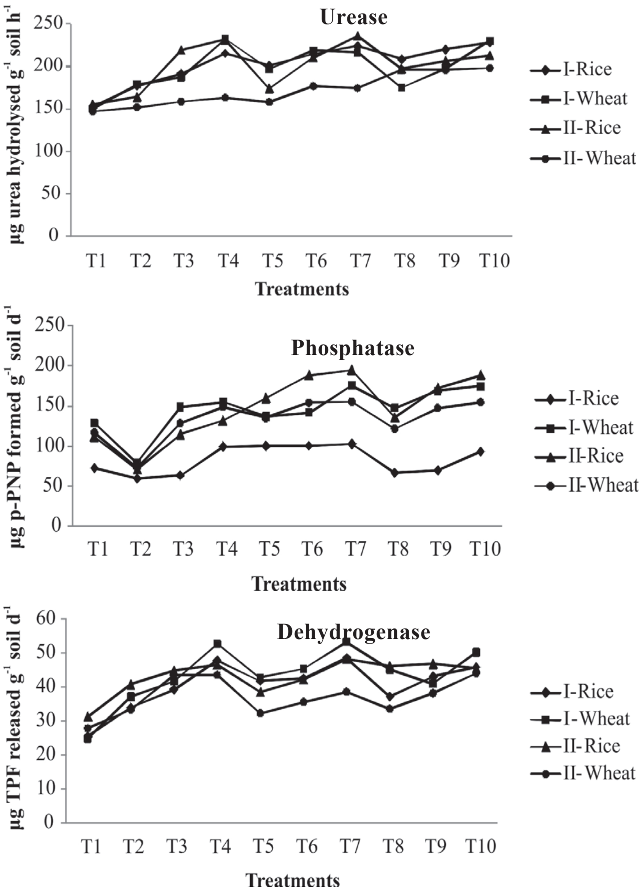


**Fig.1.** Direct and residual effect of sewage sludge on urease, phosphatase and dehydrogenase activities in post-harvest soil

activity in all sludge amended soil was recorded compared to control (100% RDF) in all four crops of the study. In general, the dehydrogenase activity in SS amended soil increased upto second crop (first wheat) of the sequence then it slightly decreased and was minimum in fourth crop (second wheat), though it was significantly higher in sludge amended treatments over control. The increase in dehydrogenase activity might be a result of addition of organic substrates in the form of SS and decrease might be related to advancement in decomposition of SS. The increase in dehydrogenase activity with increasing levels of tannery sludge (TS) was also reported by Patel and Patra (2014). They explained that dehydrogenase is known to oxidize soil organic matter; presumably this was the reason that in 100% TS treatment, dehydrogenase activity was the maximum. During oxidation, transfer of proton and electron from substrate to acceptors which is the part of respiration pathways of soil microorganism, may be the reason behind increasing of dehydrogenase activity with TS treatments. Jadhav *et al*. (2016) have also indicated higher dehydrogenase activity in soil treated with manure as a result of enhanced microbial population.

## Conclusions

The study inferred that conjoint application of SS along with inorganic fertilizers was effective for a significant enhancement of microbial population and enzymatic activity in the soil. Application of SS decreased pH while EC and OC content of soil increased. Further, available N, P, K and S content in soil also increased. Thus, SS improved soil fertility and helped in increasing the availability of nutrients for better crop productivity. We observed a pronounced residual effect of SS addition in soil. However, in order to address environmental concern, application of SS should be monitored for build-up of heavy metals in soil.

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