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Feasibility of sewage sludge application in rice-wheat cropping system

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Abstract

A field experiment was conducted to find out the effect of the conjoint application of sewage sludge (SS) and fertilizers on the yield of rice-wheat cropping system using a randomized block design. The grain yield ranged between 24.99 ± 4.24 to 66.32 ± 2.58 q ha^{-1} and 22.50 ± 0.55 to 50.37 ± 1.07 q ha^{-1} in Ist year grown rice and wheat, respectively. Among all the treatments, T_3 (100% recommended dose of fertilizer (RDF) + 30 t ha^{-1} SS) recorded a significantly highest grain yield of rice crop (66.32 and 63.37 q ha^{-1}) and wheat crop (50.37 and 46.91 q ha^{-1}) during 2015-16 and 2016-17 years, respectively. The straw yield in Ist rice and Ist wheat ranged between 55.11 to 81.22 q ha^{-1} and 35.86 to 56.62 q ha^{-1}, whereas straw yield in IInd rice and IInd wheat were noticed between 48.42 to 79.31 q ha^{-1} and 30.45 to 52.32 q ha^{-1}, respectively. The finding clearly shows that the application of SS significantly enhances the yield of rice-wheat crops, and could be an option to a sustainable use of SS. However, the precautionary measure should be followed before use. In addition, the application of SS also indicates the improvement in soil health and sustainability.

Keywords: Heavy metals, nutrient status, microbial community, organic matter, sewage treatment plants.

Introduction

Sewage sludge (SS) consists of multi-element along with a good amount of organic matter (OM). It has the capacity to improve the physico-chemical characteristics and biological properties of the soil, and is beneficial for plant growth and development (Ye et al., 2019). However, SS also contains some amount of heavy metals and organic pollutants that can adversely affect soil micro-organisms (Seleiman et al., 2020). Furthermore, the toxic elements move through the food chain due to their uptake and accumulation by crops, posing a possible threat to human health as well (Jatav et al., 2016; Singh and Singh, 2020; Chaplygin et al., 2020; 2021). The worlds' population is increasing and concentrating in urban areas. This trend is particularly intense in developing countries, and an additional 2.1 billion people are expected to be living in cities by 2030 (Jatav et al., 2018a; Egidi et al., 2020).

Sewage sludge production is increasing at a faster rate as more and more wastewater treatment facilities are being developed. It is a product of sewage treatment plants (STPs) and results from the removal of solids and organic matter from the sewage (Agoro et al., 2020). On average about 38,354 million liters of sewage

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with an equivalent amount of sludge per day generated in India (Saha et al., 2018). It is a mixture of water, inorganic and organic materials removed from wastewater releases from various sources such as domestic and industrial sewage, stormwater, runoff from roads and other paved areas, through physical, biological, and chemical treatments (Jatav et al., 2018b; Wang et al., 2020). The solid material remaining after sewage treatment is referred to as 'bio-solids' or 'SS'. Often these materials can be obtained at little or no cost to farmers or landowners (Kidder, 2001).

The utilization of SS in agriculture is gaining popularity as a source of waste disposal. It has been widely used in many countries around the world, in the European community; over 40% of SS (10.13 Mt) is used as fertilizer in agriculture (Bouwen, 2009). The high nutrients and the OM contents of SS make it an excellent fertilizer to enhance soil fertility and crop production. However, the presence of heavy metals is a major concern for utilizing the SS in agriculture, moreover, its utilization in a proper manner could make it suitable to fulfill the nutritional requirement of the crops (Smith, 2009; Latare et al., 2014; Cieślik et al., 2015; Kumar et al., 2020). As the rice-wheat cropping system is the dominant cropping system, therefore, its suitability was judged to use as a test crop (Jatav et al., 2018a). Seeking its suitability for agriculture purposes to buildup soil fertility, SS was used to investigate the feasibility in the rice-wheat cropping system. The main objective to conduct the study is to find out a possible sustainable way to use the SS in the cropping system without impairing the grain and straw quality.

Material and Methods

The experiment was conducted in a randomized block design (RBD) during the years 2015-16 and 2016-17, using 10 treatments (Table 1) in triplicate on rice (*Oryza sativa,* L.) and wheat (*Triticum aestivum.* L) as test crop (Variety Hybrid Rice -Arize-6444; Wheat- HD-3086 Pusa Gautmi) at Agriculture Research Farm, Banaras Hindu University, Varanasi, U.P. (India). The recommended dose of fertilizer (RDF) was applied 150:60:60 kg $N:P_2O_5:K_2O$ ha^{-1} for rice crop and 120:60:60 kg $N:P_2O_5:K_2O$ ha^{-1} for the wheat crop. The SS was applied only in the first year of during rice crop.

Table 1. Treatment details of the experiment

Treatments	**2015-16**		**2016-17**	
	I^st^ Rice	**I^st^ Wheat**	**II^nd^ Rice**	**II^nd^ Wheat**
T_0	Without fertilizer, Control	Control	Control	Control
T_1	100% RDF	100% RDF	100% RDF	100% RDF
T_2	100% RDF + 20 t ha^{-1} SS	100% RDF	100% RDF	100% RDF
T_3	100% RDF + 30 t ha^{-1} SS	100% RDF	100% RDF	100% RDF
T_4	50% RDF + 20 t ha^{-1} SS	50% RDF	50% RDF	50% RDF
T_5	60% RDF + 20 t ha^{-1} SS	60% RDF	60% RDF	60% RDF
T_6	70% RDF + 20 t ha^{-1} SS	70% RDF	70% RDF	70% RDF
T_7	50% RDF + 30 t ha^{-1} SS	50% RDF	50% RDF	50% RDF
T_8	60% RDF + 30 t ha^{-1} SS	60% RDF	60% RDF	60% RDF
T_9	70% RDF + 30 t ha^{-1} SS	70% RDF	70% RDF	70% RDF

The samples of SS were collected from the Bhagwanpur STPs plant (Varanasi, U.P., India) and processed for different laboratory analyses, i.e., physical, chemical, and biological properties. The analysis of initial soil and SS has been presented in Table 2. Sewage sludge in the tank of Bhagwanpur STPs and final processing of SS by 2 mm manual sieving has been shown in Figure 1. The location of Bhagwanpur STPs and their different component of process have been depicted in Figure 2. The various analysis of SS was done as per standard methods. The bulk density (Piper, 1966); water holding capacity (Piper, 1966); moisture percent by moisture box; pH and EC (Jackson, 1973); Organic carbon (Walkley and Black, 1934); available nitrogen (Subbiah and Asija, 1956); available phosphorus (Olsen et al., 1954); available potassium (Hanway and Heidel, 1952); available sulphur (Chesnin and Yien, 1951); total micronutrients and heavy metals (Nieuwenhuize et al., 1991); micronutrients (Fe, Cu, Mn and Zn) and heavy metals (Cd, Cr, Ni and Pb) (Agilent FS-240; Lindsay and Norvell, 1978).

The bacteria, fungi, and actinomycetes colonies were observed by serial dilution on Asparagine-Mannitol agar medium (Thornton, 1922), rose Bengal streptomycin agar medium (Martin, 1950), and Ken Knight and Munaier's medium by pour plate method (Chhonkar et al., 2002). The enzymatic activities such as urease by urea hydrolyzed method (Tabatabai and Bremner, 1972); alkaline phosphatase and dehydrogenase by triphenyl tetrazolium chloride (TTC) method were also determined (Page et al., 1982).

Table 2. Physico- bio-chemical properties of experimental site (0-15 cm depth) and sewage sludge after final processing by 2 mm sieve

Properties	Parameter	Initial Soil	Sewage sludge
Physical	Bulk Density (mg m^{-3})	1.40 ± 0.12	1.21 ± 0.09
	WHC (%)	40.15 ± 2.18	51.24 ± 2.26
	Moisture (%)	7.21 ± 0.95	9.53 ± 1.14
Chemical	pH (soil:water, 1:2.5)	8.24 ± 0.51	6.58 ± 0.62
	EC (dS m^{-1})	0.15 ± 0.01	2.49 ± 0.02
	Organic Carbon (%)	0.46 ± 0.04	8.19 ± 0.59
	Available content	(kg ha^{-1})	(mg kg^{-1})
	N	141.72 ± 5.01	155.43 ± 4.23
	P	17.42 ± 0.26	68.56 ± 3.15
	K	132.74 ± 5.06	174.19 ± 5.85
	S (mg kg^{-1})	14.65 ± 0.92	49.82 ± 3.06
	Total content (%)		
	N	-	1.72 ± 0.11
	P	-	1.34 ± 0.08
	K	-	0.97 ± 0.04
	S	-	1.14 ± 0.07
	DTPA extractable (mg kg^{-1})		
	Fe	42.65 ± 2.47	87.64 ± 5.12
	Cu	2.17 ± 0.04	27.18 ± 2.48
	Zn	1.02 ± 0.05	29.52 ± 2.59
	Mn	11.41 ± 0.12	34.78 ± 3.11
	Cd	0.21 ± 0.03	4.22 ± 0.14
	Cr	0.34 ± 0.04	9.42 ± 0.85
	Ni	2.71 ± 0.07	12.39 ± 1.14
	Pb	0.11 ± 0.01	9.24 ± 0.94
	Total (mg kg^{-1})		
	Fe	188.40 ± 6.21	482.54 ± 14.60
	Cu	32.42 ± 2.14	234.91 ± 11.80
	Zn	88.92 ± 4.28	152.85 ± 7.81
	Mn	119.31 ± 5.42	258.45 ± 9.48
	Cd	0.55 ± 0.09	22.51 ± 3.45
	Cr	2.12 ± 0.12	49.31 ± 4.65
	Ni	9.24 ± 1.04	62.39 ± 5.25
	Pb	6.79 ± 0.08	41.58 ± 2.87
Biological	Bacteria (10^{-6}cfu g^{-1} soil)	14.50 ± 0.29	38.65 ± 2.54
	Fungi (10^{-4}cfu g^{-1} soil)	7.20 ± 0.21	24.55 ± 3.65
	Actinomycetes (10^{-5}cfu g^{-1} soil)	17.25 ± 0.35	39.20 ± 2.84
	Dehydrogenase (µg TPF released g^{-1} soil day^{-1})	22.35 ± 2.75	72.56 ± 4.26
	Urease (µg urea hydrolysed g^{-1} soil h^{-1})	112.54 ± 4.18	288.20 ± 6.41
	Phosphatase (µg p-PNP formed g^{-1} soil day^{-1})	48.28 ± 2.14	212.59 ± 3.85

Data represent mean of three samples with standard error (±)

Figure 1. Sewage sludge in tank of Bhagwanpur STPs and sewage sludge in final processing by 2 mm sieve (Jatav et al., 2018b)

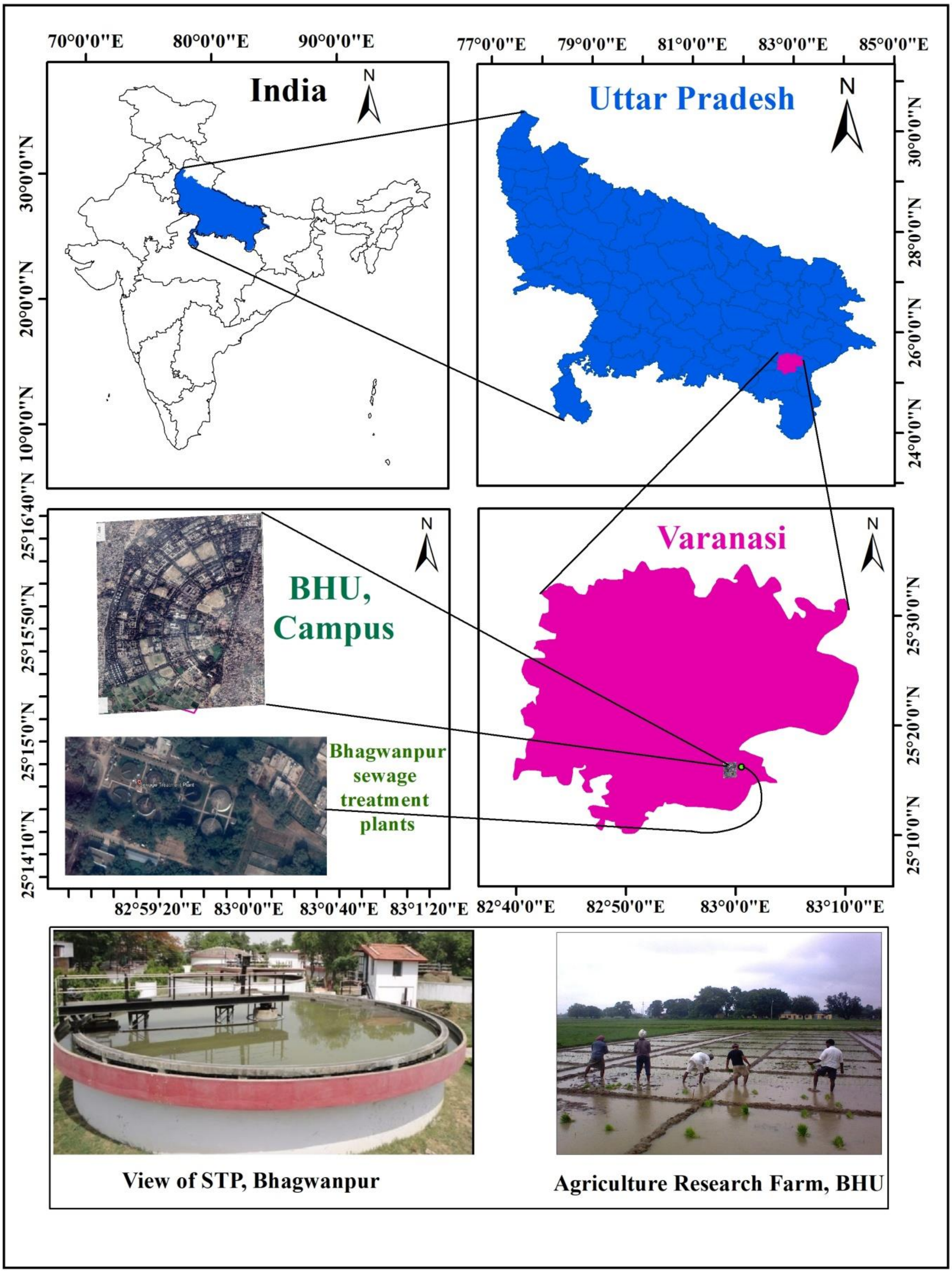

Figure 2. Location of Bhagwanpur sewage treatment plant (STPs) and experimental trial

Results and Discussion

The initial soil properties are depicted in the Table 2. The physical properties of experimental soils are as bulk density- 1.40±0.12; WHC- 40.15±2.18; Moisture- 7.21±0.95, and chemical properties are as pH- 8.24±0.51; EC- 0.15±0.01, Organic Carbon- 0.46 ± 0.04, available N, P, K S content 141.72±5.01, 17.42±0.26, 132.74±5.06, 14.65±0.92, respectively. The available content of Fe, Cu, Zn, Mn, Cd, Cr, Ni and Pb are 42.65±2.47, 2.17±0.04, 1.02±0.05, 11.41±0.12, 0.21±0.03, 0.34±0.04, 2.71±0.07, 0.11±0.01, respectively. Whereas the total content of Fe, Cu, Zn, Mn, Cd, Cr, Ni and Pb are 188.40±6.21, 32.42±0.14, 88.92±4.28, 119.31±5.42, 0.55±0.09, 2.12±0.12, 9.24±1.04, 6.79±0.08. The biological properties of experimental soil were observed as bacterial (14.5±0.29), fungal (7.2±0.21), and actinomycetes (22.35±2.75) colonies. The enzymatic activities were recorded as dehydrogenase (22.35±2.75), Urease (112.54±4.18) and Phosphatase (48.28±2.14).

Grain yield

A critical examination of data presented in Table 3 and Figure 3 showed that significantly higher grain yield was recorded with all combined treatments of SS as compared to treatments without fertilization. The grain yield ranged between 24.99 to 66.32 q ha^{-1} and 22.50 to 50.37 q ha^{-1} in Ist rice and Ist wheat, respectively. Treatment, T_3 (100% RDF + 30 t ha^{-1} SS) showed the highest grain yield of rice crop (66.32 and 63.37 q ha^{-1}) and in wheat crop (50.37 and 46.91 q ha^{-1}) during 2015-16 and 2016-17 years. The lower grain yield was recorded with the application of (T_0) control (24.99 and 17.87 q ha^{-1}) of the rice crop and (22.50 and 16.46 q ha^{-1}). The treatment, T_1 (100% RDF) was found at par with T_6 (20 t ha^{-1} SS+70% RDF), T_7 (30 t ha^{-1} SS+50% RDF), and T_8 (30 t ha^{-1} SS+60% RDF) where SS was applied along with fertilizer in Ist rice crop.

Table 3 Effect of conjoint application of sewage sludge and fertilizers on grain yield

	2015-16		2016-17	
	I- Rice	I- Wheat	II- Rice	II- Wheat
T_0 (WF)	24.99 ± 4.24^{d}	22.50 ± 0.55^{e}	17.87 ± 3.14^{f}	16.46 ± 1.09^{e}
T_1 (RDF 100)	58.28 ± 2.80^{abc}	40.60 ± 2.62^{bcd}	59.26 ± 1.90^{abc}	42.44 ± 1.83^{abc}
T_2 (RDF 100+SS 20)	64.47 ± 3.69^{ab}	47.87 ± 2.02^{ab}	62.00 ± 1.69^{ab}	45.95 ± 2.16^{ab}
T_3 (RDF 100+SS 30)	66.32 ± 2.58^{a}	50.37 ± 1.07^{a}	63.37 ± 0.63^{a}	46.92 ± 0.22^{a}
T_4 (RDF 50+SS 20)	52.13 ± 2.44^{c}	35.94 ± 3.44^{d}	48.56 ± 2.65^{e}	35.12 ± 3.44^{d}
T_5 (RDF 60+SS 20)	54.70 ± 2.61^{bc}	37.59 ± 2.62^{cd}	50.75 ± 2.34^{de}	36.90 ± 0.73^{cd}
T_6 (RDF 70+SS 20)	58.62 ± 1.59^{abc}	41.15 ± 2.07^{bcd}	55.28 ± 0.69^{cd}	40.52 ± 0.92^{bcd}
T_7 (RDF 50+SS 30)	59.80 ± 2.35^{abc}	42.25 ± 3.09^{bcd}	55.83 ± 1.55^{bcd}	40.91 ± 2.85^{abcd}
T_8 (RDF 60+SS 30)	61.46 ± 2.74^{abc}	43.35 ± 3.34^{abcd}	56.93 ± 0.96^{bc}	41.02 ± 0.76^{abcd}
T_9 (RDF 70+SS 30)	63.65 ± 2.62^{ab}	44.72 ± 0.73^{abc}	59.12 ± 0.99^{abc}	42.09 ± 0.57^{abc}

(Mean of 3 replicates ± standard error. Values with the same letter differ nonsignificantly ($p > 0.05$). Different letters for each parameter show a significant difference at $p < 0.05$)

In IInd rice the treatment, T_1 (100% RDF) was at par with T_9 where 30 t ha^{-1} SS+70% RDF was applied. In Ist wheat, the treatment T_1 (100% RDF) was found at par with T_6, T_7, and T_8 where SS was applied with reducing doses of fertilizer. During the IInd wheat crop T_1 (100% RDF) was found at par with T_6, T_7, T_8, and T_9 where 20 t ha^{-1} SS+70% RDF, 30 t ha^{-1} SS+50% RDF, 30 t ha^{-1} SS+60% RDF and 30 t ha^{-1} SS+60% RDF were applied, respectively. In Ist rice crop treatment T_2, T_3, T_8 andT_9 were 10.62%; 13.80% 5.46% and 9.21%, respectively higher as compared to treatment T_1 where 100% RDF was applied. In the case of IInd rice the treatment T_2, T_3, T_7, T_8 and T_9 were 17.91%; 24.06% 4.06% 6.53% and 10.15%, respectively were higher as compared to treatment T_1. During the Ist wheat crop experiment, grain yield of treatment T_2 (20 t ha^{-1} SS+100% RDF) and T_3 (30 t ha^{-1} SS+60% RDF) showed 4.62% and 6.94% increases over 100% RDF (T_1). In the case of IInd wheat the treatment T_2 (20 t ha^{-1} SS+100% RDF) and T_3 (30 t ha^{-1} SS+60% RDF) showed 8.27% and 10.56% yield increment over 100 % RDF (T_1).

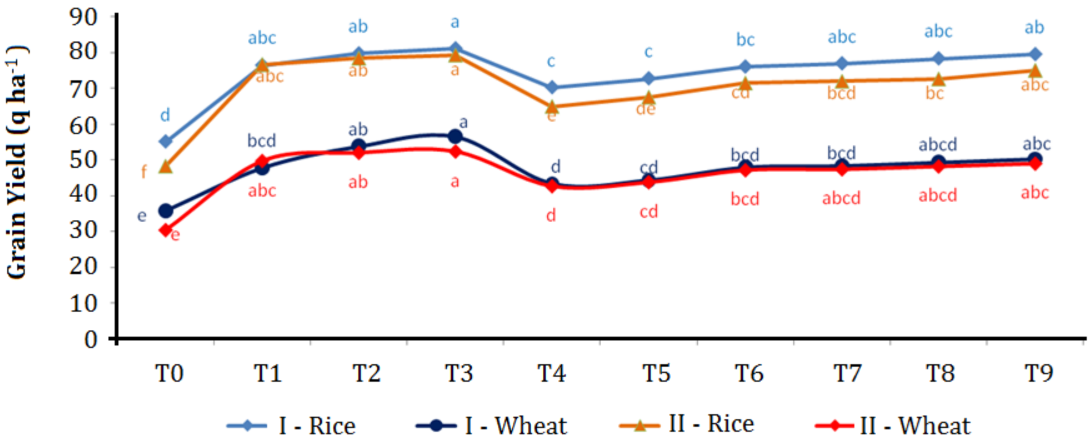

Figure 3. Effect of conjoint application of sewage sludge and fertilizers on grain yield of rice wheat cropping system

Generally, crop yield is considered to be the weight of grain or any other economic product on which crop is harvested. It has been reported by the scientist that the regular supply of crop nutrition has resulted in the optimum yield of the crop (Ali et al., 2008). The SS is found to be a good source for the nutrient that can properly supply nutrients. The optimum availability of nutrient will be helpful to the plant to enhance its potential yield. The SS was a feasible source to provide the all-necessary nutrient for the proper growth development in both years (Latare et al., 2014; Delibacak et al., 2020; Kumar et al., 2020).

Straw yield

The data presented in Table 4 on straw yield showed a significantly higher yield was recorded with all combined treatments of fertilizers and SS as compared to without fertilized treatment (T_1). The straw yield in Ist rice and Ist wheat ranged between 55.11 to 81.22 q ha^{-1} and 35.86 to 56.62 q ha^{-1}, respectively. The straw yield in IInd rice and IInd wheat ranged between 48.42 to 79.31 q ha^{-1} and 30.45 to 52.32 q ha^{-1}, respectively. The treatment, T_3 (100% RDF + 30 t ha^{-1} SS) recorded a significantly highest straw yield of rice crop (81.20 and 79.31 q ha^{-1}) and in wheat crop (56.62 and 52.32 q ha^{-1}) during 2015-16 and 2016-17 years, respectively than the other treatments. The treatment T_1 (100% RDF) show at par results with treatment T_2, T_5, T_6, T_7, T_8, and T_9 in the Ist rice crop. In the case of the Ist wheat crop, the treatment T_1 (100% RDF) was found at par with treatment T_2, T_6, T_7, T_8 and T_9. During the IInd rice experiment, the treatment T_2 (100% RDF + 20 t ha^{-1} SS) and T_3 (100% RDF + 20 t ha^{-1} SS) were found at par whereas, in the case of IInd wheat treatment, T_1(100% RDF) was found at par with T_2, T_5, T_6, T_7, T_8 and T_9. The significantly lower straw yield was recorded with the application of (T_0) control (55.1 and 48.42 q ha^{-1}) of the rice crop, and (35.86 and 30.45 q ha^{-1}) of the wheat crop during both years, respectively. In Ist rice crop treatment T_2, T_3, T_7, T_8 and T_9 were 4.30%, 6.11%, 0.61%, 2.42% and 3.95%, respectively higher as compared to treatment T_1 where 100% RDF was applied. In the case of IInd rice, the treatment T_2 and T_3 were 2.32% and 3.43%, respectively, higher as compared to treatment T_1. During the Ist wheat crop experiment on straw yield of treatment T_2 (20 t ha^{-1} SS+100% RDF), T_3 (30 t ha^{-1} SS+60% RDF), T_7 (30 t ha^{-1} SS+50% RDF), T_8 (30 t ha^{-1} SS+60% RDF) and T_9 (30 t ha^{-1} SS+70% RDF) showed 12.53%, 18.25%, 1.13%, 3.13% and 5.14% higher over 100 % RDF (T_1). Whereas, in the case of IInd wheat only treatment T_2 (20 t ha^{-1} SS+100% RDF) and T_3 (30 t ha^{-1} SS+60% RDF) showed 4.59% and 5.31% straw yield increment over 100 % RDF (T_1) respectively.

Table 4. Effect of conjoint application of sewage sludge and fertilizers on straw yield

2015-16		2016-17	
I- Rice	I- Wheat	II- Rice	II- Wheat
55.11 ± 3.80^{c}	35.86 ± 1.70^{c}	48.42 ± 2.86^{f}	30.45 ± 2.03^{c}
76.54 ± 5.23^{ab}	47.88 ± 2.97^{ab}	76.68 ± 0.55^{ab}	49.68 ± 2.12^{ab}
79.83 ± 1.76^{ab}	53.88 ± 2.90^{ab}	78.46 ± 1.67^{a}	51.96 ± 2.22^{ab}
81.22 ± 2.85^{a}	56.62 ± 3.69^{a}	79.31 ± 1.17^{a}	52.32 ± 2.15^{a}
70.33 ± 3.25^{b}	43.48 ± 4.04^{bc}	65.02 ± 1.32^{e}	42.66 ± 4.04^{b}
72.85 ± 3.93^{ab}	44.44 ± 2.14^{bc}	67.63 ± 1.55^{de}	43.76 ± 2.54^{ab}
76.12 ± 2.24^{ab}	48.01 ± 2.47^{ab}	71.55 ± 0.85^{cd}	47.11 ± 0.44^{ab}
77.01 ± 2.53^{ab}	48.42 ± 4.52^{ab}	72.02 ± 1.66^{bcd}	47.35 ± 4.52^{ab}
78.39 ± 2.20^{ab}	49.38 ± 3.69^{ab}	72.70 ± 0.60^{bc}	48.15 ± 3.69^{ab}
79.56 ± 1.86^{ab}	50.34 ± 1.17^{ab}	75.07 ± 1.15^{abc}	48.94 ± 1.17^{ab}

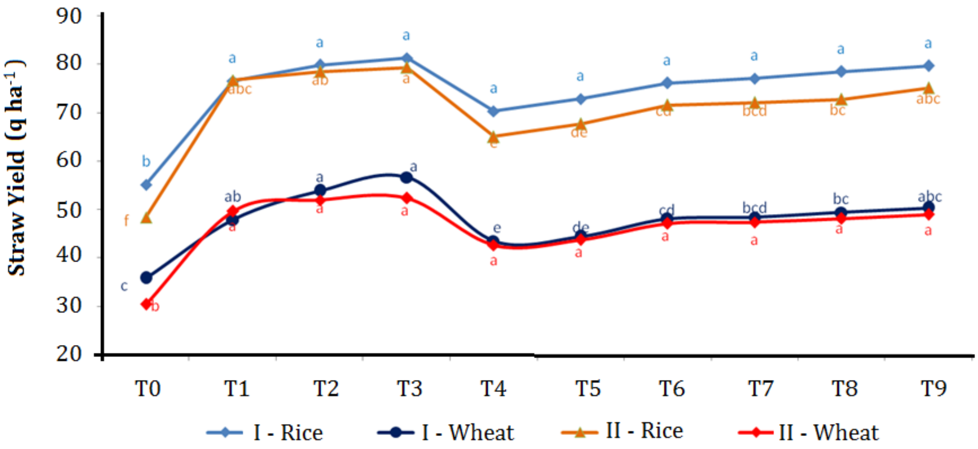

Figure 4. Effect of conjoint application of sewage sludge and fertilizers on straw yield of rice wheat cropping system

An increase in the chlorophyll concentration of leaf is responsible for increased photosynthetic rate and ultimately photosynthetic products resulting in higher straw yield (Basu et al., 1998). Adequate N nutrition accelerates the mining capacity of the plant and resulted in better root development, increased the number of tillers, length and width of leaves, plant height as well as the dry matter that will responsible for an increase in straw yield (Latare et al., 2017). A significant increase in straw yield might be due to the availability of all essential elements to the rice and wheat crop in sufficient amounts by the application of SS. Similar results were reported by Latare et al. (2017) and concluded that the crop yield enhanced with the application of SS, and stated the maximum straw yield of rice in treatment where 40 t ha^{-1} SS (S_{40}) was applied (52.57 g pot^{-1}) followed by RDF (49.37 g pot^{-1}). It was higher than the control. In wheat, it was maximum with RDF (34.08 g pot^{-1}) followed by S_{40} (30.34 g pot^{-1}) increased 43 and 36% over without SS application (S_0).

The SS application enhances the availability of nutrient in soil which is helpful for proper plant growth and development. The enhancement in the yield is resulted due to the application of SS which remains available till prolong time as its decomposition rate is slow.

Conclusion

The possible application of sewage sludge along with fertilizer enhances the grain and straw yield of both rice and wheat crops. Sewage sludge consists of multi-elements along with a good amount of organic matter. Therefore, it could be a good source of nutrients and precaution should be followed to use the sewage sludge. Current findings supported safe and sustainable application SS; however further long-term experiments are required in realistic conditions. The application of 70% RDF + 20 t ha-1 SS is more feasible and safer to use for batter yield.

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