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Effect of Sewage Sludge Integration with Fertilizer on Growth Parameters of Rice-wheat Cropping System

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

A two-year field experiment was conducted at the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, India, in 2019–2021 to assess the growth attributes performance of rice-wheat cropping system (RWCS) as influenced by the concurrent application of sewage sludge (SSL) and chemical fertilizer. The treatments comprised of control, 100% RDF [recommended dose of nitrogen (N), phosphorus (P), and potassium (K)], 100% RDF +20 t ha^{-1}SSL, 100% RDF +30 t ha^{-1}SSL, 50% RDF +20 t ha^{-1}SSL, 60% RDF+20 t ha^{-1}SSL, 70% RDF +20 t ha^{-1}SSL, 50% RDF +30 t ha^{-1}SSL, 60% RDF +30 t ha^{-1}SSL, and 70% RDF +30 t ha^{-1}. The experiments used a randomized block design with three replications, the results revealed that when using 100% RDF with 20 and 30 t ha^{-1}SSL, rice and wheat growth and yield attributes were superior to when using 100% RDF alone. However, 70% RDF+ 30 t ha^{-1}SSL provided a comparable or better growth yield than 100% RDF in RWCS. In conclusion, the use of SSL in conjunction with chemical fertilizer, i.e., 70% RDF with 20 and 30 t ha^{-1}SSL, provided a higher yield advantage with no harmful or negative impact on the soil system and could be recommended as a potential organic amendment for a sustainable agricultural production system.

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Keywords: Plant height; greenness index; nutrient status; rice-wheat cropping system; sewage sludge.

1. INTRODUCTION

Sewage sludge (SSL) is a semi-solid residual material produced by sewage treatment plants as a by-product that possesses greater amounts of nutrients, pollutants, and biological activity, [1,2]. The solid wastes are separated as SSL when the wastewater entered the treatment plants and undergone multiple mechanical, biological, and chemical processes, [3]. There are different advantages to applying SSL to agricultural land, including increased nutrient availability and recycling in areas where nutrient supplies, particularly micronutrient resources, are running out, [4] and [5] and restoration of degraded soil fertility due to intensive cropping systems, [6]. Utilizing SSL might eventually result in a decrease in the demand for synthetic fertilizers, [7]. However, SSL includes heavy metals (HMs), which may have an impact on soil microbial populations and associated processes since they are essential for preserving healthy soil conditions and ecosystem functioning. Therefore, solid guiding principles and a monitoring system are needed for the agricultural use of SSL in order to reduce the danger of heavy metal contamination. Therefore, effective SSL usage necessitates an individual assessment of natural variances present in agricultural fields as a result of climate and soil type. Previous research on the use of SSL has demonstrated improved crop development and yield results with improved soil micronutrient and macronutrient status [8], [9], and [10] (13). According to some researchers, sludge is an alternative to inorganic fertilizer for amending degraded land since it enhances the physical characteristics of the soil, such as bulk density, macro aggregates, water retention, porosity, and hydraulic conductivity, [9] and [11]. However, sludge build-up has also resulted in unfavorable changes, including pH drop, increased salinity, and heavy metal concentration in soil [12]. Continuous and higher doses of SSL application may increase the build-up of hazardous heavy metals including lead (Pb), chromium (Cr), and mercury (Hg), which have a negative effect on the populations and activities of soil microbes. Thus, the purpose of the current study was to investigate the impact of SSL and fertilizer application on growth, yield characteristics, and yield of the rice-wheat cropping system.

2. MATERIALS AND METHODS

2.1 Experimental Site

An experiment with four cropping cycles of rice (Oryza sativa: Arize 6444)–wheat (*Triticum aestivum*: HD 2967) was completed during 2015–2016 (I- rice and I- wheat) 2016– 2017 (II-rice and II-wheat), 2017-2018 (III-rice and III-wheat) and 2018-19 (VI-rice and VI- wheat) (Table 1). The present investigation comprising the next two cycles of rice-wheat was set up during 2019–2020 (V-rice and V- wheat) and 2020–2021 (VI- rice and VI-wheat) without disturbing the field design of the previous experiment at the Agricultural Research Farm, Banaras Hindu University, Varanasi (UP), India.

This farm is situated in the Northern Gangetic Alluvial (Inceptisol) Plain (128.93 m asl; latitude 25°19 N, and longitude 83° E) (Fig. 1).

2.2 Soil Condition

The experimental soil has alkaline nature of (pH 8.24), with low salt concentration (EC 0.15 dS/m), and organic carbon (OC) content (4.60 g/kg), with low available N (141.72 kg/ha), medium available P (17.42 kg/ha), available K (132.74 kg/ha) and sulphur (14.65 mg/kg). In the initial soil iron (Fe), copper (Cu), zinc (Zn), and manganese (Mn) content were observed at 42.65, 2.17, 1.02, and 11.41 mg/kg, respectively. The SSL used in this experiment had pH: 6.6, EC: 3.17 dS/m, OC: 8.67%, total N: 1.76%, total P: 1.29%, and total K: 1.15%.

Table 1. Cropping history of the experimental field

Year	Kharif	Rabi
2014-2015	Rice	Wheat
2016- 2017	Rice	Wheat
2017-2018	Rice	Wheat
2018- 2019	Rice	Wheat
2019- 2020	Rice	Wheat
2020- 2021	Rice	Wheat

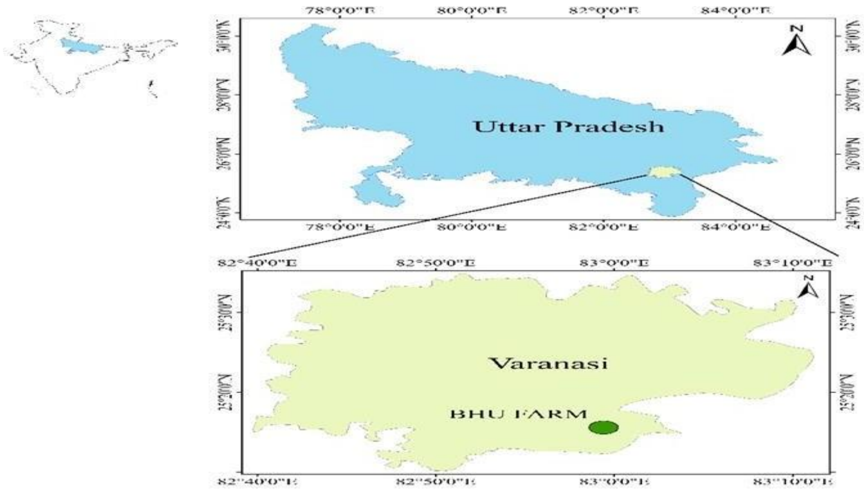

Fig. 1. Location of experimental trial

2.3 Characteristics of Sewage Sludge

Sewage sludge (SSL) of domestic origin was collected from a Sewage Treatment Plant (STP) in Bhagwanpur, Varanasi, in the month of May 2019. For further analysis, a composite sample was ground and passed through a 2 mm sieve and stored in a polythene bag. The SSL used in this experiment had pH: 6.6, EC: 3.17 dS/m, OC: 8.67%, total N: 1.76%, total P: 1.29%, and total K: 1.15%. While the total micronutrients and heavy metal content (mg/kg) in SSL were as follows Fe:490.27, Cu: 240.63, Zn: 184.27, Mn: 246.08, cadmium (Cd): 7.30, Cr: 49.20, nickel (Ni): 27.43 and Pb: 39.53. According to the Council of the European Communities [13], the maximum permissible limits (MPLs) for potentially toxic elements such as Zn, Cu, Cd, Pb, Ni, and Cr in sludge used in agricultural soils are 2500, 1000, 20, 750, 300 and 750 mg kg^{-1}, respectively. The sludge used for the study contained 200, 247, 8, 52, 17, and 44 mg kg^{-1} of Zn, Cu, Cd, Pb, Ni, and Cr, respectively. Thus, all the heavy metals were within the MPL.

2.4 Experimental Design and Treatments

The experiment was started as a part of a long-term field experiment that was initiated at Agricultural Researched Farm BHU during the year 2015–2016. Before conducting the present study, four cropping cycles of rice (var. Arize6444) and wheat (var. HD 2967) were already followed with the same treatment history. In the experiment, ten treatments were replicated thrice using a randomized block design. The SSL was applied only in the first year of the rice crop (Table 2).

The half dose of N and a full dose of P and K were applied during the sowing of the crop as basal dose while the remaining half dose of N was applied in two equal splits at 30 and 60 DAT/DAS.

Table 2. Treatment details of the experiment

Treatments Experiment - 2019-2020		Experiment -2020-21	
Rice (*Kharif*) Wheat (*Rabi*)		**Rice (*Kharif*)**	**Wheat(Rabi)**
T0 Control	Control	Control	Control
T1 100% RDF	100% RDF	100% RDF	100% RDF
T2100% RDF + 20 t ha^{-1}SSL	100% RDF	100% RDF	100% RDF
T3100% RDF + 30 t ha^{-1} SSL	100% RDF	100% RDF	100% RDF
T450% RDF + 20 t ha^{-1} SSL	50% RDF	50% RDF	50% RDF
T560% RDF + 20 t ha^{-1} SSL	60% RDF	60% RDF	60% RDF
T6 70% RDF + 20 t ha^{-1} SSL	70% RDF	70% RDF	70% RDF
T7 50% RDF + 30 t ha^{-1} SSL	50% RDF	50% RDF	50% RDF
T9 60% RDF + 30 t ha^{-1} SSL	60% RDF	60% RDF	60% RDF
T8 70% RDF + 30 t ha^{-1} SSL	70% RDF	70% RDF	70% RDF

2.5 Soil and Sewage Sludge Analyses

The pH and EC of soil and SS samples were determined in 1:2.5 soil: water suspension according to the method given by Jackson, [14], and Organic carbon was estimated according to Walkley and Black, [15] Further, and available nitrogen (N) was estimated by the 0.32% alkaline $KMnO_4$ method [16]. The available phosphorus (P) content was determined by the ascorbic acid method given by Olsen et al. [17]. The available potassium (K) content was determined by the 1N neutral ammonium acetate method [18]. The aqua regia digestion mixture was used to determine total micronutrients and heavy metals. Soil samples are digested on a heated plate with a 3:1 combination of HCl and HNO_3 in the traditional aqua regia digestion technique [19]. By using an atomic absorption spectrophotometer (Agilent FS-240), the DTPA extractable (available) micronutrients (Fe, Cu, Mn, and Zn) and heavy metals (Cd, Cr, Ni, and Pb) were determined according to Lindsay and Norvell, [20].

2.6 Statistical Data Analysis

The data were statistically analyzed using one-way analysis of variance (ANOVA) in Origin Pro 2022. Tukey test was used to test the significance of the difference between the treatments at the 5% level.

3. RESULTS AND DISCUSSION

3.1 Growth Parameters

Plant height and greenness index of rice and wheat responded positively to concurrent application of treated SSL and chemical fertilizer over T_1 in both years, while no such impact was evident in the greenness index (SPAD value) (Table 3), The greenness index was observed to be significantly superior to T1 (100% RDF) under only the treatment T_3 (100% + 30 t ha^{-1}) while the remaining treatments (T_2, T_4, T_5, T_6, T_7, T_8, and T_9) were statistically at par in rice and wheat crops during the experimentation. The plant height at harvest in V- rice significantly varied between 60.93 to 110.07 cm, whereas, in V - wheat it ranged from 60.93 to 102.93 cm. The maximum plant height at harvest time in V- rice (110.07 cm) as well as in V- wheat (102.93 cm) was recorded in treatment T_3 which was significantly superior to their respective 100% RDF (T1). The plant height in treatment T_3 and T_2 at harvest were observed 20.46 and 16.48% higher over T_1 in V- rice crop, while in V-wheat crop, the same treatments had a respective increase of 14.20 and10.76%. Treatments T_4, T_5, T_6, T_7, and T_8 were recorded statistically comparable with T_1 in V- rice, however in V-Wheat, treatments T_2, T_4, T_5, T_6, T_7, T_8, and T_9 were found at par respectively.

During the 2020–2021 experiment, the plant height at harvest ranged between 65.73 to 108.17 cm and 59.6 to 99.57 cm in VI-rice and VI-wheat, respectively. The maximum plant height at harvest in VI-rice (108.17 cm) and VI-wheat (99.57 cm) was also observed in T3 (RDF+30 t ha^{-1}SSL), which was significantly superior to their respective T1 (100% RDF). Treatments (T_2, T_6, T_7, T_8, and T_9) were found to be comparable to T1 in VI - rice, but in the case of VI – wheat, T_2, T_4, T_5, T_6, T_7, T_8, and T_9 were observed at par respectively. These findings were consistent with those reported by [9,21], and [10]. The higher plant height advantage with concurrent treatment might be explained by SSL's gradual release of nutrients in appropriate proportions.

3.2 Yield Components

The maximum number of tillers per running meter was found in treatment T_3 followed by T_2 in rice during both years of research (Table 4). The total number of tillers per running meter in V-rice and VI-rice ranged from 38.78 to 103.45 and 31.48 to 104.34. The maximum number of tillers was recorded at harvest stages 103.45 and 104.34 in T_3 (100%RDF+30 t ha^{-1}SSL) in both V-rice and VI-rice and the minimum was recorded in T_0 (control, without SSL or CF). In V-rice, the number of tillers per running meter in treatments T_2, T_3, T_4, T_5, T_6, T_7, T_8, and T_9 were observed to be statistically similar to T_1 except for T_0, however, in VI-rice, T_2 and T_3 were significantly increased by 14.15% and 23.24%, respectively, over T_1 (100% RDF) and the rest of the treatments were noticed at par while the total number of tillers per running meter in V-wheat and VI-wheat varied between 28.07 to 91.27 and 27.8 to 88.14. Among all treatments, T_3 recorded the maximum number of tillers per running meter at harvest stage 91.27 and 88.14 in both V-rice and VI-rice which was found significantly higher at 23.24% and 16.99% as compared to T_1 (100% RDF). However, a significant reduction in the number of tillers per running meter was recorded in T_0 (control, without SSL or CF).

Table 3. Effect of conjoint application of sewage sludge and fertilizer on growth attributesof rice and wheat

Treatment	Plant height (cm)				Greenness index (SPAD)			
	2019 V-rice	2019-20 V-wheat	2020 VI-rice	2020-2021 VI-wheat	2019 V-rice	2019-2020 V-wheat	2020 VI-rice	2020-2021 VI-wheat
T0	60.93±3.1d	65.73±1.6f	59.6±2.02e	60.93±3.1d	25.37±0.71d	23.48±0.62c	25.18±0.82d	23.12±0.72e
T1	90.13±0.54bc	96.03±0.33bcd	90.67±0.63bcd	90.13±0.54bc	31.6±0.64bcd	37.07±1.2b	34.87±2.06abc	35.7±0.23bcd
T2	99.83±1.91ab	104.77±2.94ab	97.27±3.07ab	99.83±1.91ab	37.8±0.87abc	39.08±0.67ab	36.57±1.29ab	38.16±1.14ab
T3	102.93±1.69a	108.17±1.18a	99.57±0.32a	102.93±1.69a	41.63±0.88a	42.17±0.49a	41.31±1.61a	40.34±0.65a
T4	83.7±2.35c	85.13±2.31e	82.96±2.24d	83.7±2.35c	34.83±0.86abc	36.78±0.74b	29.25±1.14cd	32.27±0.37d
T5	88.69±1.69c	88.3±1.55de	85.66±1.11cd	88.69±1.69c	30.74±2.17cd	37.04±0.87b	30.37±1.03bcd	33.28±0.58cd
T6	91.83±1.05bc	96.27±2.06bcd	90±1.75bcd	91.83±1.05bc	33.68±1.46bc	37.39±0.42ab	32.53±1.56bc	34.84±0.34bcd
T7	87.03±2.15c	89.9±1.56cde	86.27±1.26cd	87.03±2.15c	32.27±1.03bcd	35.11±0.86b	32.17±1.74bcd	32.36±1.11d
T8	88.83±1.51c	97.57±2.1bc	86.9±1.33cd	88.83±1.51c	35.2±2.81abc	38.09±2.03ab	34.36±1.12abc	34.97±0.57bcd
T9	93.22±3.48abc	102.9±1.48ab	92.13±1.84abc	93.22±3.48abc	38.32±1.77ab	39.34±0.61ab	35.77±1.3abc	36.96±1.19abc

Table 4. Effect of conjoint application of sewage sludge and fertilizer on yield attributes of rice and wheat

Treatment	Tillers per runningmeter				Tiller per hill in rice Tillers square per meter in wheat			
	2019 V-rice	2019-20 V-wheat	2020 VI-rice	2020-2021 VI-wheat	2019 V-rice	2019-2020 V-wheat	2020 VI-rice	2020-2021 VI-wheat
T0	38.78±1.24d	28.07±2.58f	31.48±0.7e	27.8±1.41f	5.15±0.2e	5.09±0.29e	178.4±11.47d	172.08±8.19f
T1	92.48±3.93abc	74.06±0.2bcde	93.36±1.73bcd	75.34±2.16bc	9.02±0.53d	10.88±0.35d	368.27±9.17b	360.21±10.41cd
T2	101.55±4.14a	84.54±1.16ab	101.34±2.62ab	83.46±2.57ab	15.48±0.68ab	14.79±0.67ab	423.77±4.4a	410.22±7.59ab
T3	103.45±3.4a	91.27±4.4a	104.59±0.94a	88.14±2.92a	16.93±0.75a	15.72±0.32a	446.2±3.83a	432.02±6.55a
T4	82.96±1.49c	63.82±1.18e	83.4±2.69d	62.54±0.76e	11.18±0.34cd	10.94±0.38d	331.2±4.78c	323.19±4.43e
T5	87.6±1.83bc	66.74±1.71de	88.77±1.73cd	65.83±0.59de	12.04±0.89c	11.52±0.23d	349.63±7.34bc	337.75±3.84de
T6	92.48±3.93abc	71.08±1.23cde	91.09±1.78cd	69.53±0.93cde	12.6±0.36bc	11.88±0.52cd	381.27±2.85b	370.45±4.14cd
T7	92.2±1.14abc	72.54±0.99cde	92±3.39bcd	70.79±0.79cde	11.81±0.38cd	11.33±0.31d	364.23±10.13bc	351.99±4.09de
T8	95.65±1.36abc	76.05±1.38bcd	93.8±1.45bc	73.77±1.09cd	12.26±0.61c	11.83±0.09cd	381.83±2.98b	369.2±9.43cd
T9	98.76±1.1ab	80.14±2.9bc	97.62±1.25abc	77.07±2.43bc	15.43±0.83ab	13.56±0.47bd	419.4±7.87a	394.36±8.09bc

The maximum number of tillers per hill was recorded at 16.93 and 15.72 under T_3 (RDF+30 t ha^{-1} SSL) at harvest in both V-rice and VI-rice, while the minimum was recorded in T_0 (control, without SSL and CF). Direct application of SSL in V-rice crop, number of tillers per hill in treatments T_2, T_3, T_5, T_6, T_8, and T_9 were found significantly increases over T_1 (100% RDF), respectively.

Mean values within the same column having alike alphabets differ non-significantly (p ≤ 0.05), while different alphabets show a significant difference (p ≤ 0.05). Mean (±SE) was taken from three replicates for each treatment.

Treatment T_2 and T_3 were found significantly superior to T_1 and the remaining treatments were observed statistically at par respectively in VI-rice. Similar results for the maximum number of tillers were also reported by Rahman et al. [22], Latare et al. [9], Latare et al. [23], Rehman et al. [24], and Jatav et al. [5]. Because the soil's nitrogen supply capability increased at this stage, cell division was aided by the application of sewage sludge in conjunction with fertilizers. The tillers/m^2 varied from 178.40-446.20 and 172.08–432.02 in the wheat crop during the first and second year, respectively (Table 4). In the V-wheat and VI- wheat, the maximum number of tillers per square meter was recorded in the treatments T_3 (446.20 and 432.02) followed by T_2 (423.77 & 410.22) which were (22.87% & 20.05%) and (20.88% & 19.05%) higher over T_1 (368.27 and 360.21) during the experiment. The number of tillers is the most important parameter for yield and increases in yield will result from increasing the number of tillers, especially efficient ones.

Mean values within the same column having alike alphabets differ non-significantly (p ≤ 0.05), while different alphabets show a significant difference (p ≤ 0.05). Mean (±SE) was taken from three replicates for each treatment.

Due to the significant amounts of N, P, and micronutrients in SSL that have a direct impact on many enzymes' mediated pathways, regulatory functions, auxin production, and synthesis, and transport of carbohydrates to the K, the application of SSL along with chemical fertilizer that enhances plant growth and the number of tillers has led to higher growth and development (number of tillers). [21] also reported an increase in the number of rice tillers and wheat application of SSL or fertilizer (CF). Similar results were also found by [25]. The results agreed with the finding of Latare et al. [9] who explained that a higher dose of sludge with chemical fertilizer increased tiller number, dry matter, tillering capacity, and plant height both in rice and wheat crops, due to the adequate amount of organic matter and nutrient availability N, P, S, and cationic micronutrients which has direct involvement in many enzymatic-mediated pathways, regulatory functions, and auxin production and synthesis and transport of carbohydrates to the sink.

4. CONCLUSION

In comparison to 100% RDF, the application of 20 or 30 t/ha SSL in combination with 100% RDF significantly boosted the rice-wheat system's growth yield. However, in light of environmental concerns, current data suggests the safe and sustainable use of SSL. However, more long-term tests in realistic situations are necessary. For better growth attribute yield, the application of 70% RDF + 20 t ha^{-1} SSL is more realistic and safer.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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