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ENVIRONMENTAL SCIENCE

Influence of Sewage Sludge Dose on Physicochemical Characteristics of Soil and Productivity of Radish (Raphanus sativus L.)

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ABSTRACT

Sewage sludge, a byproduct of wastewater treatment, is a rich source of plant nutrients like nitrogen, phosphorus, potassium, magnesium, and iron. This makes it a potential fertilizer for agricultural use. However, sewage sludge also contains high concentrations of heavy metals that can accumulate in soil and potentially be taken up by plants. Additionally, it may harbor pathogens, posing health risks. This experiment, conducted at the College of Forestry SHUATS nursery in Allahabad, aimed to assess the impact of sewage sludge application on soil properties. The study involved applying varying rates of sewage sludge (9 kg/plot) to plots where the tuber crop radish (Raphanus sativus) was grown. A randomized complete block design with four replicates was used for the experiment. Soil samples were collected from a depth of 0-15 cm to analyze pH, electrical conductivity, organic carbon content, available nitrogen, available phosphorus, and available potassium. The results indicated a significant effect of sewage sludge on most soil properties. Notably, the application of sewage sludge increased soil nitrogen and phosphorus content. For example, soil nitrogen content rose from 127.4 kg/ha to 281.11 kg/ha with sewage sludge application, and soil phosphorus content increased from 15.3 kg/ha to 24.84 kg/ha. The study suggests that sewage sludge application in agriculture could be beneficial due to its ability to improve soil nutrient content and potentially enhance plant growth and yield. However, further research is needed to determine the long-term effects of heavy metal accumulation and potential pathogen contamination in the soil and harvested crops. A comprehensive risk assessment is crucial before widespread adoption of sewage sludge as a fertilizer.

تأثير جرعة حمأة الصرف الصحي على الخصائص الفيزيائية والكيميائية للتربة و إنتاجية الفجل

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الكلمات المفتاحية :

حمأة المجاري
التربة
الفجل
العناصر الغذائية
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الملخص

تعد حمأة الصرف الصحي، وهي نتيجة ثانوية لمعالجة مياه الصرف الصحي، مصدرًا غنيًا بالمغذيات النباتية مثل النيتروجين والفوسفور والبوتاسيوم والمغنيسيوم والحديد. وهذا يجعله سمادًا محتملاً للاستخدام الزراعي. ومع ذلك، تحتوي حمأة الصرف الصحي أيضًا على تركيزات عالية من المعادن الثقيلة التي يمكن أن تتراكم في التربة ومن المحتمل أن تمتصها النباتات. بالإضافة إلى ذلك، قد تحتوي على مسببات الأمراض، مما يشكل مخاطر صحية. تهدف هذه التجربة، التي أجريت في مشتل كلية الغابات شواتس في الله أباد، إلى تقييم تأثير تطبيق حمأة الصرف الصحي على خصائص التربة. تضمنت الدراسة تطبيق معدلات متفاوتة من حمأة مياه الصرف الصحي (9 كجم/قطعة أرض) على قطع الأراضي التي يزرع فيها محصول الفجل الدرني (Raphanus sativus). تم استخدام تصميم القطاعات العشوائية الكاملة بأربعة مكررات للتجربة. تم جمع عينات التربة من عمق 0-15 سم لتحليل الرقم الهيدروجيني، التوصيل الكهربائي، محتوى الكربون العضوي، النتروجين المتوفر، الفسفور المتوفر، والبوتاسيوم المتوفر. أشارت النتائج إلى وجود تأثير معنوي لحمأة الصرف الصحي على معظم خواص التربة. والجدير بالذكر أن استخدام حمأة الصرف الصحي أدى إلى زيادة محتوى التربة من النيتروجين والفوسفور. على سبيل المثال، ارتفع محتوى النيتروجين في التربة من 127.4 كجم/هكتار إلى 281.11 كجم/هكتار مع استخدام حمأة الصرف الصحي، وزاد محتوى الفوسفور في التربة من 15.3 كجم/هكتار إلى 24.84 كجم/هكتار. تشير الدراسة إلى أن استخدام حمأة الصرف الصحي في الزراعة يمكن أن يكون مفيدًا نظرًا لقدرته على تحسين محتوى مغذيات التربة وربما تعزيز نمو النبات وإنتاجيته. ومع ذلك، هناك حاجة إلى مزيد من البحوث لتحديد الآثار الطويلة الأجل لتراكم المعادن الثقيلة والتلوث المحتمل لمسببات الأمراض في التربة والمحاصيل المحصودة. يعد التقييم الشامل للمخاطر أمرًا بالغ الأهمية قبل اعتماد حمأة الصرف الصحي على نطاق واسع كسماد.

Introduction

Sewage sludge (SS) is formed as a product at a wastewater treatment plant and represents a heterogeneous mixture. This complex suspension consists of solid organic and inorganic substances and colloids, which have been separated from the wastewater during the treatment process [1]. The global production of SS is estimated at 45 million t of dry matter per year. India is home to 1.31 billion people, approximately 62,000 million liters sewage is generated, contains about

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120,000 tons of faecal sludge on a daily basis, but an estimated two-thirds of the country's households with access to sewerage network [2]. Many researchers have presented studies on how to benefit from sewage treatment plants. The treated water can be used in irrigate agricultural crops in arid areas. Also, electricity and heat can be generated from sludge through the process of anaerobically fermenting the sludge in the digester, thus obtaining biogas, which can be used to generate heat or electricity. Then use the final waste from the fermentation process as organic fertilizer to strengthen the poor desert lands [2-6] Thus, sewage sludge application (SSA) to soil enables the recycling of nutrients and may substitute the need for commercial fertilizers in cropland. Indiscriminate SSA in soil may, however, disturb the soil properties especially when it bears high concentrations of heavy metals such as Cd, Ni, Pb and Zn which may accumulate in plant tissues and cancause food chain contamination [7 - 12]. The physicochemical characteristics of sewage sludge, and the nutrients needed to enhance the properties of soil with a view to exploiting were potential for radish (Raphanus sativus) in Brazil. They found that the optimum dose is about 25 ton/ha of sewage sludge [13]. It had revealed that utilizing sewage sludge is an efficient way to improve saline–alkali soil and its physiochemical properties for plant productivity and improve soil's health and crop yield [14, 15]. The application of sewage sludge in Norway in combination with mineral fertilizers positively influenced crop growth and soil microbiological activity. An environmental impact of sewage sludge related to its disposal to agricultural areas has been analyzed in terms of global warming, ecotoxicity, and other internationally recognized issues [16, 17]. The utilization of sewage sludge is an efficient way to improve saline-alkali soil and its physiochemical properties for plant productivity and improve soil's health and crop yield [18]. The application of sewage sludge in Norway in combination with mineral fertilizers positively influenced crop growth and soil microbiological activity. The environmental impact of sewage sludge related to its disposal to agricultural areas has been analyzed in terms of global warming, ecotoxicity, and other internationally recognized issues [19, 20]. Radish (Raphanus sativus L.), is a popular root vegetable of the Brassicaceae family, thrives in India year-round despite its European and Asian origins [14, 21]. Its edible, tapered roots and vitamin-rich leaves are enjoyed raw or cooked, while immature pods (mongree) add variety to Indian cuisine. Renowned for its medicinal value, radish is prescribed for conditions like piles, liver issues, and jaundice. A significant contributor to Indian agriculture, particularly in Uttar Pradesh and Bihar, radish is primarily a cool-season crop sown during winter. Packing a nutritional punch with calcium, potassium, and vitamin C, radish's characteristic pungency comes from volatile isothiocyanates. Pink varieties boast higher vitamin C content, and optimal growth occurs at temperatures between 10-15°C [22]. Valued for its refreshing and diuretic properties, radish may also benefit those suffering from neurological headaches, sleeplessness, and chronic diarrhea [23]. While cultivation under cover allows for early production, large-scale farming typically utilizes open fields.

Materials and methods

This study evaluated the impact of sewage sludge dosage on soil chemical and physicochemical properties and on Radish (Raphanus sativus L.) productivity. The research was carried out during the zaid season of 2017 and 2018 at the Research Farm of the Department of Environmental Science and NRM, College of Forestry, Sam Higginbottom University of Agriculture, Technology, and Sciences in Prayagraj, India.

Treatment combination details

The recommended dosage of N.P.K fertilizers for Radish (Raphanus sativus L.) is 50:100:50 kg of nitrogen, phosphorus, and potassium per hectare. Table 1 outlines the treatments of different fertilizer.

Table 1. The treatments of different fertilizers

Treatments	Treatment explanation
T_1	Control
T_2	RSS 100% (Raw Sewage Sludge)
T_3	LTSS 100% (Lime Treated Sewage Sludge)
T_4	CDM 100% (Cow Dung Manure)
T_5	RSS 50% + CDM 50%

Soil analysis

Representative of soil samples were analysed for its physico-chemical properties and nutrient status and the data is given in the Table 1. The pH of soil was determined in 1:2.5 soil-water suspension after half an hour equilibration, with a glass electrode pH meter [24]. The electrical conductivity was determined in 1:2 soil-water suspension by using conductivity bridge [25] and expressed in dS m^{-1}. Organic carbon content of the soil was estimated by the wet digestion method [26]. Available nitrogen content of the soil was estimated by alkaline permanganate method [27]. Available phosphorus was extracted from soil by using Olsen's extractant (0.5 N $NaHCO_3$ with pH 8.5). The readings were recorded with spectrophotometer at 420 nm and were expressed in kg P_2O_5 ha^{-1} [28]. Available potassium was extracted from the soil using neutral normal ammonium acetate in 1:5 ratio and the readings were recorded using flame photometer. The quantity was calculated and expressed as kg K_2O, ha^{-1} [29].

Soil bulk density (mg.m^{-3})

Bulk density was determined as described by [30]. However, a natural undisturbed core soil sample was taken from 0-15 and 15-30 cm depth. The soil's density was calculated by recording the soil's oven-dry weight and the soil core's volume. Bulk density was calculated using the following eq.1.

$$Bulk\ density\ (m.g^{-3}) = \frac{weight\ of\ the\ dried\ soil\ (mg)}{volume\ of\ the\ soil\ (m^{-3})} \quad (1)$$

Particle density (mg. m^{-3})

Particle density of a soil sample is calculated from two measured quantities namely mass of the soil solid and its volume using pycnometer [30]. Particle density was calculated by the following formula, eq.2

$$Parical\ density\ (m.g^{-3}) = \frac{Mass\ of\ soil\ solid\ (g)}{Volume\ of\ solids\ (m3)}\ x\ 100\% \quad (2)$$

Water Holding Capacity (%) and Percent pore space

Water Holding Capacity of soil was measured as mentioned by [31]. whereas porosity was calculated from the particle density and bulk density of the soil using the eq.3 [30].

$$\%\ pore\ space = 1 - \frac{\text{Bulk Density}}{Partical\ Density}\ x\ 100\% \quad (3)$$

Principal component analysis

Principal Component Analysis (PCA) is a powerful statistical technique for simplifying complex datasets with many interrelated variables [32]. It achieves this by creating a new set of uncorrelated variables, called principal components (PCs), that capture most of the data's variance. These PCs are derived from linear combinations of the original variables. When variables are measured in different units, their scales can influence the composition of the resulting components. To mitigate this issue, it's crucial to standardize the data before analysis. In this study, the correlation matrix, which is unaffected by units, was used to extract the principal components.

Results and discussion

The results of the field experiment entitled "Effects of lime treated sewage sludge and soil management practices on soil microfauna and yield of radish" was conducted during Zaid season of 2017 and 2018 at Research Farm of the Department of Environmental Science & amp; NRM, College of Forestry, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj, are obtainable in this chapter. The data pertaining to the result of different levels of lime treated sewage sludge and soil management on yield and physiochemical analysis of soil were statistically analyze for test of significance of the outcome.

Root yield per plot (kg)

The data pertaining to effect of lime treated sewage sludge and soil management practices on root yield per plot (kg) of radish are presented in Table 1 during 2016-2017 and 2017-2018 with pooled data respectively. The result for the root yield per plot (kg) showed significant different for the various treatment applied soil application of lime treated sewage sludge during 2016-2017 and 2017-18 with pooled data respectively. However, the maximum root yield per plot (kg) (39.58, 40.62, 40.10) was recorded for the treatment T6 LTSS 50% + CDM 50%. The lowest root yield per plot (kg) (30.79, 30.60 and 30.69) was found in treatment T1 Control during 2016-2017 and 2017-2018 with pooled data respectively.

Root yield per t ha^{-1}

The data pertaining to effect of lime treated sewage sludge and soil management practices on Root yield per t ha^{-1} of radish are presented in Table 2 during 2016-2017 and 2017-2018 with pooled data respectively. The result for the Root yield per t ha^{-1} showed significant different for the various treatment applied soil application of lime treated sewage sludge during 2016-2017 and 2017-18 with pooled data respectively. However, the maximum Root yield per t ha^{-1} (43.98, 45.13 and 44.56) was recorded for the treatment T_6 LTSS 50% + CDM 50%. Whereas the minimum Root yield per t ha^{-1} (34.21, 34.00 and 34.10) was found in treatment T_1 Control during 2016-17 and 2017-2018 with pooled data respectively.

Bulk Density (mg.m^{-3})

The data pertaining to effect of lime treated sewage sludge and soil management practices on bulk density (Mgm^{-3}) of radish are presented in Table 3 during 2016-2017 and 2017-2018 with pooled data respectively. The result for the bulk density (Mgm^{-3}) showed significant different for the various treatment applied soil application of lime treated sewage sludge during 2016-2017 and 2017-18 with pooled data respectively. However, the maximum bulk density (m.gm^{-3}) (1.45, 1.49 and 1.47) was recorded for the treatment T_6 LTSS 50% + CDM 50%. Whereas the minimum bulk density (Mgm^{-3}) (1.66, 1.68 and 1.67) was found in treatment T_1 Control during 2016-17 and 2017-18 with pooled data respectively. A further review of table also revealed that treatment T_5 RSS 50% + CDM 50% as found to be statistically at par to treatment T_6 LTSS 50% + CDM 50% during 2016-17 and 2017-18 with pooled data respectively.

Particle density (mg.m^{-3})

The data pertaining to effect of lime treated sewage sludge and soil management practices on particle density (mgm^{-3}) of radish are presented in Table 4 during 2016-2017 and 2017-2018 with pooled data respectively. The result for the particle density (mgm$^{-3)}$ showed significant different for the various treatment applied soil application of lime treated sewage sludge during 2016-2017 and 2017-2018 with pooled data respectively. However, the maximum particle density (mgm^{-3}) (1.64, 1.78 and 1.71) was recorded for the treatment T_6

Table 1: Effects of Sewage sludge and soil management practices on root yield per plot (kg)

Treatments	Treatment explanation	Root yield per plot (kg)		
		2016-2017	2017-2018	Pooled
T_1	Control	30.79	30.60	30.69
T_2	RSS 100% (Raw Sewage Sludge)	31.59	33.28	32.43
T_3	LTSS 100% (Lime Treated Sewage Sludge)	33.13	35.23	34.18
T_4	CDM 100% (Cow Dung Manure)	34.84	36.36	35.60
T_5	RSS 50% + CDM 50%	35.98	38.24	37.11
T_6	LTSS 50% + CDM 50%	39.58	40.62	40.10
	F-Test	S	S	S
	C.D at 0.5%	2.033	1.561	0.846
	S. Ed	0.912	0.700	0.380

Table 2: Effects of Sewage sludge and soil management practices on Root yield per t ha^{-1}

Treatments	Treatment explanation	Root yield per t ha-1		
		2016-2017	2017-2018	Pooled
T1	Control	34.21	34.00	34.10
T2	RSS 100% (Raw Sewage Sludge)	35.10	36.98	36.04
T3	LTSS 100% (Lime Treated Sewage Sludge)	36.81	39.15	37.98
T4	CDM 100% (Cow Dung Manure)	38.71	40.40	39.55
T5	RSS 50% + CDM 50%	39.98	42.49	41.23
T6	LTSS 50% + CDM 50%	43.98	45.13	44.56
	F-Test	S	S	S
	C.D at 0.5%	2.259	1.734	0.940
	S. Ed	1.014	0.778	0.422

Table 3: Effects of Sewage sludge and soil management practices on Bulk density (mg.m^{-3})

Treatments	Treatment explanation	bulk density (Mgm^{-3}) 2016-2017	2017-2018	Pooled
T_1	Control	1.66	1.68	1.67
T_2	RSS 100% (Raw Sewage Sludge)	1.59	1.62	1.61
T_3	LTSS 100% (Lime Treated Sewage Sludge)	1.55	1.62	1.59
T_4	CDM 100% (Cow Dung Manure)	1.54	1.59	1.57
T_5	RSS 50% + CDM 50%	1.51	1.55	1.53
T_6	LTSS 50% + CDM 50%	1.45	1.49	1.47
	F-Test	S	S	S
	C.D at 0.5%	0.049	0.047	0.025
	S. Ed	0.022	0.021	0.011

LTSS 50% + CDM 50%. Whereas the minimum particle density (mg. m^{-3}) (1.36, 1.41 and 1.38) was found in treatment T_1 Control during 2016-2017 and 2017-2018 with pooled data respectively. A further review of table also revealed that treatment T_5 RSS 50% + CDM 50% as found to be statistically at par to treatment T_6 LTSS 50% + CDM 50% during 2016-2017 and 2017-18 with pooled data respectively.

Pore space (%)

The data pertaining to effect of lime treated sewage sludge and soil management practices on pore space (%) of radish are presented in Table 5 during 2016-2017 and 2017-2018 with pooled data respectively. The result for the pore space (%) showed significant different for the various treatment applied soil application of lime treated sewage sludge during 2016-2017 and 2017-2018 with pooled data respectively. However, the maximum pore space (%) (45.66, 45.75 and 45.71) was recorded for the treatment T_6 LTSS 50% + CDM 50%. Whereas the minimum pore space (%) (42.61, 42.78 and 42.70) was found in treatment T_1 Control during 2016-17 and 2017-18 with pooled data respectively. A further review of table also revealed that treatment T_5 RSS 50% + CDM 50% as found to be statistically at par to treatment T_6 LTSS 50% + CDM 50% during 2016-2017 and 2017-2018 with pooled data respectively.

Organic carbon (%)

The data pertaining to effect of lime treated sewage sludge and soil management practices on organic carbon (%) of radish are presented in Table 6 during 2016-2017 and 2017-2018 with pooled data respectively. The result for the organic carbon (%) showed significant different for the various treatment applied soil application of lime treated sewage sludge during 2016-2017 and 2017-2018 with pooled data respectively. However, the maximum organic carbon (%) (0.22, 0.25 and 0.24) was recorded for the treatment T_6 LTSS 50% + CDM 50%. Whereas the minimum organic carbon (%) (0.14, 0.14 0.14) was found in treatment T_1 Control during 2016-17 and 2017-18 with pooled data respectively. A further review of table also revealed that treatment T_5 RSS 50% + CDM 50% as found to be statistically at par to treatment T_6 LTSS 50% + CDM 50% during 2016-2017 and 2017-2018 with pooled data respective.

Soil Management Practices on pH

The data pertaining to effect of lime Treated Sewage sludge and soil management practices on pH of radish are presented in table7 during 2016-2017 and 2017-2018 with pooled data respectively. The result for the pH showed significant different for the various treatment applied soil application of lime treated sewage sludge during 2016-2017 and 2017-2018 with pooled data respectively.

However, the maximum pH (7.14, 7.18 and 0.716) was recorded for the treatment T_6 LTSS 50% + CDM 50%. Whereas the minimum pH (7.43, 7.50 and 7.46) was found in treatment T_1 Control during 2016-2017 and 2017-2018 with pooled data respectively. A further review of table also revealed that treatment T_5 RSS 50% + CDM 50% as found to be statistically at par to treatment T_6 LTSS 50% + CDM 50% during 2016-2017 and 2017-2018 with pooled data respectively.

Table 4: Effects of Sewage sludge and soil management practices on particle density (mg. m^{-3})

Treatments	Treatment explanation	particle density (mgm^{-3}) 2016-2017	2017-2018	Pooled
T_1	Control	1.36	1.41	1.38
T_2	RSS 100% (Raw Sewage Sludge)	1.46	1.53	1.49
T_3	LTSS 100% (Lime Treated Sewage Sludge)	1.54	1.58	1.56
T_4	CDM 100% (Cow Dung Manure)	1.56	1.63	1.60
T_5	RSS 50% + CDM 50%	1.62	1.76	1.69
T_6	LTSS 50% + CDM 50%	1.64	1.78	1.71
	F-Test	S	S	S
	C.D at 0.5%	0.069	0.057	0.035
	S. Ed	0.031	0.025	0.016

Table 5: Effects of Sewage sludge and soil management practices on pore space (%)

Treatments	Treatment explanation	Pore space (%)		
		2016-2017	2017-2018	Pooled
T_1	Control	42.61	42.78	42.70
T_2	RSS 100% (Raw Sewage Sludge)	44.90	44.89	44.90
T_3	LTSS 100% (Lime Treated Sewage Sludge)	45.23	45.31	45.27
T_4	CDM 100% (Cow Dung Manure)	45.28	45.39	45.33
T_5	RSS 50% + CDM 50%	45.35	45.42	45.39
T_6	LTSS 50% + CDM 50%	45.66	45.75	45.71
	F-Test	S	S	S
	C.D at 0.5%	0.552	0.144	0.287
	S. Ed	0.248	0.065	0.129

Table 6: Effects of Sewage sludge and soil management practices on organic carbon (%)

Treatments	Treatment explanation	organic carbon (%)		
		2016-2017	2017-2018	Pooled
T_1	Control	0.14	0.14	0.14
T_2	RSS 100% (Raw Sewage Sludge)	0.16	0.17	0.17
T_3	LTSS 100% (Lime Treated Sewage Sludge)	0.17	0.20	0.19
T_4	CDM 100% (Cow Dung Manure)	0.18	0.23	0.20
T_5	RSS 50% + CDM 50%	0.19	0.24	0.21
T_6	LTSS 50% + CDM 50%	0.22	0.25	0.24
	F-Test	S	S	S
	C.D at 0.5%	0.028	0.044	0.029
	S. Ed	0.012	0.020	0.013

Soil management Practices on EC

The data pertaining to effect of lime treated sewage sludge and soil management practices on pH of radish are presented in table 8 during 2016-2017 and 2017-2018 with pooled data respectively. The result for the pH showed significant different for the various treatment applied soil application of lime treated sewage sludge during 2016-2017 and 2017-2018 with pooled data respectively. However, the maximum pH (0.78, 0.80 and 0.79) was recorded for the treatment T_6 LTSS 50% + CDM 50%. Whereas the minimum pH (0.64, 0.69 and 0.67) was found in treatment T_1 Control during 2016-2017 and 2017-2018 with pooled data respectively. A further review of table also revealed that treatment T_5 RSS 50% + CDM 50% as found to be statistically at par to treatment T_6 LTSS 50% + CDM 50% during 2016-2017 and 2017-2018 with pooled data respectively.

Soil Management Practices on Available Nitrogen (kg ha^{-1})

The effects of lime-treated sewage sludge and various soil management practices on the available nitrogen (kg ha^{-1}) content in radish are presented in Table 9. During 2016-2017 and 2017-2018 with pooled data respectively. The result for the available nitrogen (kg ha^{-1}) showed significant different for the various treatment applied soil application of lime treated sewage sludge during 2016-2017 and 2017-2018 with pooled data respectively. However, the maximum available nitrogen (kg/ha^{-1}) (288.18, 297 and 292.73) was recorded for the treatment T_6 LTSS 50% + CDM 50%. Whereas the minimum available nitrogen (kg ha^{-1}) (176.13, 181.41 and 178.77) was found in treatment T_1 Control during 2016-2017 and 2017-2018 with pooled data respectively. A further review of table also revealed that treatment T_5 RSS 50% + CDM 50% as found to be statistically at par to treatment T_6 LTSS 50% + CDM 50% during 2016-17 and 2017-18 with pooled data respectively.

Soil management practices on available phosphorus (kg/ ha^{-1})

The data pertaining to effect of lime treated sewage sludge and soil management practices on available phosphorus (kg/ha^{-1}) of radish are presented in table10 during 2016-2017 and with pooled data respectively. The result for the available phosphorus (kg/ha^{-1}) showed significant different for the various treatment applied soil application of lime treated sewage sludge during 2016-2017 and 2017-2018 with pooled data respectively. However, the maximum available phosphorus (kg/ha^{-1}) (25.94, 26.29 and 26.12) was recorded for the treatment T_6 LTSS 50% + CDM 50%. Whereas the minimum available phosphorus (kg/ha^{-1}) (18.95, 19.32 and 19.14) was found in treatment T_1 Control during 2016-2017 and 2017-2018 with pooled data respectively. A further review of table also revealed that treatment T_5 RSS 50% + CDM 50% as found to be statistically at par to treatment T_6 LTSS 50% + CDM 50% during 2016-2017 and 2017-2018 with pooled data respectively.

Soil management practices on available potassium (kg ha^{-1})

The data pertaining to effect of lime treated sewage sludge and soil management practices on available potassium (kg ha^{-1}) of radish are presented in Table.11 during 2016-2017 and 2017-2018 with pooled data respectively. The result for the available potassium (kg/ha^{-1}) showed significant different for the various treatment applied soil application of lime treated sewage sludge during 2016-2017 and 2017-2018 with pooled data respectively. However, the maximum available potassium (kg/ha^{-1}) (131.58, 133.38 and 132.48) was recorded for the treatment T_6 LTSS 50% + CDM 50%. Whereas the minimum available potassium (kg/ ha^{-1}) (115.93, 119.05 and 117.49) was found in treatment T_1 Control during 2016-2017 and 2017-2018 with pooled data respectively. A further review of table also revealed that treatment T_5 RSS 50% + CDM 50% as found to be statistically at par to treatment T_6 LTSS 50% + CDM 50% during 2016-2017 and 2017-2018 with pooled data respectively.

Principal component analysis

Principal component analysis (PCA) was employed to identify the most important variables and treatment effects influencing our data. This technique condenses numerous correlated variables into a smaller number of independent principal components (PCs) that capture most of the data's variation and retained PCs with eigenvalues exceeding 1.

Eigenvalues indicate the amount of variance explained by each PC, with the sum of all eigenvalues equaling the original variable number.

Our analysis identified five PCs with eigenvalues greater than 1 during both 2016-2017 and 2017-2018 (Tables 13 and 14).

Table 7: Effects of Sewage sludge and soil management practices on pH

Treatments	Treatment explanation	pH		
		2016-2017	2017-2018	Pooled
T_1	Control	7.43	7.50	7.46
T_2	RSS 100% (Raw Sewage Sludge)	7.32	7.38	7.35
T_3	LTSS 100% (Lime Treated Sewage Sludge)	7.25	7.30	7.28
T_4	CDM 100% (Cow Dung Manure)	7.20	7.28	7.24
T_5	RSS 50% + CDM 50%	7.18	7.23	7.21
T_6	LTSS 50% + CDM 50%	7.14	7.18	7.16
	F-Test	S	S	S
	C.D at 0.5%	0.035	0.060	0.025
	S. Ed	0.016	0.027	0.011

Table 8: Effects of Sewage sludge and soil management practices on EC.

Treatments	Treatment explanation	EC (Sdm^{-1})		
		2016-2017	2017-2018	Pooled
T_1	Control	0.64	0.69	0.67
T_2	RSS 100% (Raw Sewage Sludge)	0.68	0.71	0.70
T_3	LTSS 100% (Lime Treated Sewage Sludge)	0.71	0.72	0.72
T_4	CDM 100% (Cow Dung Manure)	0.72	0.73	0.73
T_5	RSS 50% + CDM 50%	0.75	0.76	0.75
T_6	LTSS 50% + CDM 50%	0.78	0.80	0.79
	F-Test	S	S	S
	C.D at 0.5%	0.024	0.021	0.018
	S. Ed	0.011	0.009	0.008

Table 9: Effects of Sewage sludge and soil management practices on available Nitrogen (kg ha^{-1})

Treatments	Treatment explanation	Available Nitrogen (kg ha^{-1})		
		2016-2017	2017-2018	Pooled
T_1	Control	176.13	181.41	178.77
T_2	RSS 100% (Raw Sewage Sludge)	215.25	220.95	218.10
T_3	LTSS 100% (Lime Treated Sewage Sludge)	275.35	280.02	277.68
T_4	CDM 100% (Cow Dung Manure)	278.25	282.50	280.38
T_5	RSS 50% + CDM 50%	283.31	289.92	286.61
T_6	LTSS 50% + CDM 50%	288.18	297.27	292.73
	F-Test	S	S	S
	C.D at 0.5%	4.031	2.952	2.260
	S. Ed	1.809	1.325	1.014

Table 10: Effects of Sewage sludge and soil management practices on available phosphorus (kg/ha^{-1})

Treatments	Treatment explanation	Available phosphorus (kg ha^{-1})		
		2016-2017	2017-2018	Pooled
T_1	Control	18.95	19.32	19.14
T_2	RSS 100% (Raw Sewage Sludge)	21.28	22.40	21.84
T_3	LTSS 100% (Lime Treated Sewage Sludge)	22.43	23.33	22.88
T_4	CDM 100% (Cow Dung Manure)	23.23	25.11	24.17
T_5	RSS 50% + CDM 50%	24.68	24.82	24.75
T_6	LTSS 50% + CDM 50%	25.94	26.29	26.12
	F-Test	S	S	S
	C.D at 0.5%	0.965	0.710	0.536
	S. Ed	0.433	0.319	0.240

Table 11: Effects of Sewage sludge and soil management practices on available potassium (kg/ha^{-1})

Treatments	Treatment explanation	Available potassium (kg/ha-1)		
		2016-2017	2017-2018	Pooled
T_1	Control	115.93	119.05	117.49
T_2	RSS 100% (Raw Sewage Sludge)	119.79	123.29	121.54
T_3	LTSS 100% (Lime Treated Sewage Sludge)	123.00	126.21	124.60
T_4	CDM 100% (Cow Dung Manure)	125.17	128.71	126.94
T_5	RSS 50% + CDM 50%	128.98	131.63	130.31
T_6	LTSS 50% + CDM 50%	131.58	133.38	132.48
	F-Test	S	S	S
	C.D at 0.5%	3.041	2.698	2.202
	S. Ed	1.365	1.211	0.988

Table 12: Total variance explained by different principal components in radish during 2016-2017

	Principal Components				
	F1	F2	F3	F4	F5
Eigenvalue	16.792	2.518	1.663	0.807	0.220
Variability (%)	76.327	11.445	7.558	3.668	1.001
Cumulative %	76.327	87.772	95.330	98.999	100.000

Table 13: Factor loadings during (2016-2017)

	F1	**F2**	**F3**	**F4**	**F5**
Root yield per plot (kg)	0.954	-0.024	-0.225	0.193	0.033
Root yield per t ha^{-1}	0.954	-0.024	-0.225	0.193	0.033
pH	-0.992	0.099	0.064	0.037	0.011
EC	0.985	-0.001	0.123	-0.052	-0.113
Organic Carbon	0.866	-0.205	0.294	-0.346	0.036
Pore space	0.969	-0.063	-0.212	0.065	0.091
Partical density	-0.988	0.051	-0.147	0.017	0.007
bulk density	0.997	-0.011	-0.057	0.015	-0.042
N	0.916	-0.139	0.314	0.009	-0.206
P	0.999	0.009	-0.015	-0.031	-0.023
K	0.995	0.058	-0.041	0.042	-0.054
Penicillium	-0.664	0.495	-0.348	0.408	-0.161
Aspergillus trius	0.290	0.907	0.278	0.044	-0.119
Aspergillus sp.	0.065	0.941	0.096	-0.319	-0.006

Aspergillus niger	0.319	0.344	0.754	0.385	0.252
Total Bacteria	0.432	0.586	-0.610	-0.257	0.175

Table 14: Factor loadings during (2017-2018)

	F1	F2	F3	F4	F5
Root yield per plot (kg)	0.989	-0.070	0.130	-0.030	-0.009
Root yield per t ha^{-1}	0.989	-0.070	0.130	-0.030	-0.009
pH	-0.948	0.091	-0.244	-0.021	0.183
EC	-0.963	-0.002	0.192	-0.185	-0.035
organic carbon	0.906	-0.106	-0.315	0.259	0.032
Pore space	0.990	0.034	-0.022	-0.112	0.080
Partical density	-0.994	0.063	0.027	-0.025	-0.078
Bulk density	0.934	-0.142	0.302	-0.032	-0.124
Nitrogen	0.949	-0.051	-0.178	-0.025	0.254
Phosphorus	0.985	-0.033	-0.156	-0.016	-0.070
Potassium	0.996	0.037	0.072	-0.023	0.027
Penicillium	-0.695	0.330	0.549	-0.317	0.083
Aspergillus trius	0.314	0.901	0.221	0.039	0.196
Aspergillus sp.	0.042	0.840	0.317	0.438	-0.006
Aspergillus niger	0.370	0.677	-0.501	-0.391	-0.018
Total bacteria	-0.003	0.926	-0.308	0.009	-0.219

These five PCs cumulatively accounted for 100% of the total variation in the dataset. The first PC explained a significant portion of the variability, contributing 76.327% and 76.6632% in 2016-2017 and 2017-2018, respectively. The remaining PCs explained progressively smaller proportions of the variance (second PC: 11.45% & 13.8%, third PC: 7.55% & 5.71%, fourth PC: 3.66% & 2.77%, fifth PC: 1.001% & 1.093%).

Factor loadings

This principal component showed the strongest positive correlations with factors related to **soil properties and plant growth**, including root yield (kg/plot & t/ha), electrical conductivity (EC), pore space, bulk density, nitrogen, phosphorus, and potassium. Conversely, it exhibited a high negative correlation with pH and particle density. This component displayed positive correlations with fresh weight and the presence of specific fungi (penicillium, aspergillus trius, aspergillus sp., and aspergillus niger) and total bacteria. However, it showed negative correlations with root length, root weight, and other growth parameters (like root yield and EC). This component highlighted positive associations with soil properties and some fungal species. EC, organic carbon (OC), nitrogen, aspergillus trius, aspergillus niger, and aspergillus sp. had positive loadings, while number of leaves per plant, root weight, pore space, penicillium, and total bacteria had negative loadings. This component primarily linked aspergillus niger, penicillium, and root yield (both kg/plot and t/ha). However, it showed negative correlations with aspergillus sp., total bacteria, and OC. This component associated aspergillus niger and total bacteria with positive loadings, while nitrogen, EC, and aspergillus trius exhibited negative loadings.

Factor loadings

Further principal component analysis of carried out using varimax rotation to check character association with respective principal components. Correlation value of greater than 0.5 was considered to select relevant characters in different principal factor. Factor loading for different characters with varimax rotation have been represented in Table.14 during 2017-2018 is clear that first principal showed highest positive loading for root yield per plot (kg), root yield per t ha^{-1}, organic carbon , pore space, bulk density, nitrogen , phosphorus and potassium, whereas it showed high negative loading for Partical density, Penicillium and pH. Principal factor two enable high positive loading for Aspergillus trius, Aspergillus sp., Aspergillus niger and Total bacteria, whereas it showed high negative loading for organic carbon and Bulk density. Principal factor three enable high positive loading for Penicillium, Aspergillus trius and Bulk density, whereas it showed high negative loading for Total bacteria, Aspergillus niger, organic carbon and Ph. Principal factor fourth enable high positive loading for Aspergillus trius and Aspergillus sp., whereas it showed high negative loading for Aspergillus niger and Penicillium Principal factor fifth enable high positive loading for Nitrogen, whereas it showed high negative loading for Total bacteria.

Conclusion

The current study investigates the influence of sewage sludge dose on soil chemical and physicochemical characteristics and Radish (Raphanus sativus L.) productivity. It was carried out at the Research Farm of the Department of Environmental Science & NRM, College of Forestry, Sam Higginbottom University of Agriculture, Technology and Sciences, Prayagraj, during 2016-2017 and 2017-2018. The maximum root yield per plot (kg) (39.58, 40.62, 40.10) was recorded for the treatment T6LTSS 50% + CDM 50%. At the same time, the minimum root yield per plot (kg) (30.79, 30.60 and 30.69) was found in treatment T1 Control during 2016-2017 and 2017-2018 with pooled data, respectively. The maximum Root yield per t ha^{-1} (43.98, 45.13 and 44.56) was recorded for the treatment T_6 LTSS 50% + CDM 50%. Whereas the minimum Root yield per t ha^{-1} (34.21, 34.00 and 34.10) was found in treatment T_1 Control during 2016-17 and 2017-18 with pooled data respectively. The maximum bulk density (mg. m^{-3}) (1.45, 1.49 and 1.47) was recorded for the treatment T_6 LTSS 50% + CDM 50%. Whereas, the minimum bulk density (Mgm^{-3}) (1.66, 1.68 and 1.67) was found in treatment T_1 Control during 2016-2017 and 2017-2018 with pooled data respectively. The maximum particle density (mg.m^{-3}) (1.64, 1.78 and 1.71) was recorded for the treatment T_6 LTSS 50% + CDM 50%. Whereas the minimum particle density (mg. m^{-3}) (1.36, 1.41 and 1.38) was found in Whereas the minimum pH (7.43, 7.50 and 7.46) was found in treatment T_1 Control during 2016-2017 and 2017-2018 with pooled data respectively. The maximum pH (0.78, 0.80 and 0.79) was recorded for the treatment T_6 LTSS 50% + CDM 50%. Whereas the minimum pH (0.64, 0.69 and 0.67) was found in treatment T_1 Control during 2016-17 and 2017-18 with pooled data respectively. The maximum available nitrogen (kg ha-1) (288.18, 297 and 292.73) was recorded for the treatment T_6 LTSS 50% + CDM 50%. Whereas the minimum available nitrogen (kg ha^{-1}) (176.13, 181.41 and 178.77) was found in treatment T_1 Control during 2016-1207 and 2017-2018 with pooled data respectively.

The maximum available phosphorus (kg/ha^{-1}) (25.94, 26.29 and 26.12) was recorded for the treatment T_6 LTSS 50% + CDM 50%. Whereas the minimum available phosphorus (kg/ha^{-1}) (18.95, 19.32 and 19.14) was found in treatment T_1 Control during 2016-2017 and 2017-2018 with pooled data respectively. The maximum available potassium (kg/ha^{-1}) (131.58, 133.38 and 132.48) was recorded for the treatment T_6 LTSS 50% + CDM 50%. Whereas the minimum available potassium (kg/ha^{-1}) (115.93, 119.05 and 117.49) was found in treatment T_1 Control during 2016-2017 and 2017-2018 with pooled data respectively.

The first principal component explained 76.327 & 76.6632 per cent of the total variability. The second, third, fourth, fifth principal components explained (11.45 & 13.8), (7.55 & 5.71), (3.66 &2.77) and (1.001 & 1.093) per cent of the total variability, respectively during 2016-2017 & 2017-2018. First principal showed highest positive loading for plant height (cm), number of leaves per plant, root length (cm), root weight (g), fresh weight of plant (g), root diameter (cm), root yield per plot (kg), root yield per t ha^{-1}, EC, pore space, bulk density, nitrogen, phosphorus and potassium, whereas it showed high negative loading for pH and Partical Density. Principal factor two enable high positive loading for fresh weight of plant (g), penicillium, aspergillus trius, aspergillus sp., aspergillus niger and total bacteria, whereas it showed high negative loading for root length (cm), root weight (g), root yield per plot (kg), root yield per t ha^{-1}, EC, pore space, bulk density and nitrogen during 2016-2017. Principal factor three enable high positive loading for EC, OC, nitrogen, aspergillus trius, aspergillus niger and aspergillus sp., whereas it showed high negative loading root yield per plot (kg), root yield per t ha^{-1}, pore space, penicillium and total bacteria during 2016-2017. Principal factor fourth enable high positive loading for aspergillus niger, penicillium, root yield per t ha^{-1} and root yield per plot (kg), whereas it showed high negative loading for Aspergillus sp., Total Bacteria and OC during 2016-2017. Principal factor fifth enable high positive loading for Aspergillus niger and Total Bacteria, whereas it showed high negative loading for Nitrogen, EC and Aspergillus trius. First principal showed highest positive treatment T_1 Control during 2016-17 and 2017-2018 with pooled data respectively.

The maximum pore space (%) (45.66, 45.75 and 45.71) was recorded for the treatment T_6 LTSS 50% + CDM 50%. Whereas the minimum pore space (%) (42.61, 42.78 and 42.70) was found in treatment T_1 Control during 2016-17 and 2017-18 with pooled data respectively. The maximum organic carbon (%) (0.22, 0.25 and 0.24) was recorded for the treatment T_6 LTSS 50% + CDM 50%. Whereas the minimum organic carbon (%) (0.14, 0.14 0.14) was found in treatment T_1 Control during 2016-2017 and 2017-2018 with pooled data respectively. The maximum pH (7.14, 7.18 and 0.716) was recorded for the treatment T_6 LTSS 50% + CDM 50%. loading root yield per plot (kg), root yield per t ha^{-1}, organic carbon, pore space, bulk density, nitrogen, phosphorus and potassium, whereas it showed high negative loading for Partical density, Penicillium and pH during 2017-2018. Principal factor two enable high positive loading for Aspergillus trius, Aspergillus sp., Aspergillus niger and Total bacteria, whereas it showed high negative loading for organic carbon and Bulk density during 2017-2018. Principal factor three enable high positive loading for Penicillium, Aspergillus trius and Bulk density, whereas it showed high negative loading for Total bacteria, Aspergillus niger, organic carbon and pH during 2017-2018. Principal factor fourth enable high positive loading for Aspergillus trius and Aspergillus sp., whereas it showed high negative loading for Aspergillus niger and Penicillium during 2017-2018. Principal factor fifth enable high positive loading for Nitrogen, whereas it showed high negative loading for Total bacteria during 2017-2018.

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