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Effect of Sewage Sludge Application on Growth Parameters and Uptake of Micronutrients by Poplar Nursery

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Abstract: Field study was conducted to study the effect of different doses of sewage sludge and its combination with chemical fertilizers on growth parameters and uptake of micronutrients by poplar nursery. Sixteen treatments were applied namely control, 50% RDF (recommended dose of fertilizers), 75% RDF, 100% RDF, 5 t/ha SS (sewage sludge), 10 t/ha SS, 15 t/ha SS, 50% RDF + 5 t/ha SS, 50% RDF + 10 t/ha SS, 50% RDF + 15 t/ha SS, 75% RDF + 5 t/ha SS, 75% RDF + 10 t/ha SS, 75% RDF + 15 t/ha SS, 100% RDF + 5 t/ha SS, 100% RDF + 10 t/ha SS and 100% RDF + 15 t/ha SS. The treatments were applied in randomized block design in three replications in the field having loamy sand soil texture. The growth parameters (height and collar diameter) differed significantly among various treatments. Concentration and uptake of micronutrients (Fe, Mn, Cu, Zn and Ni) by poplar nursery were analysed. In comparison to other treatments, concentration and uptake of micronutrients were significantly higher at 50% RDF + 15 t/ha SS and 75% RDF + 10 t/ha SS. Litterfall had the highest concentration of nutrients, followed by roots and shoots. The soil's micronutrient build-up peaked at 100% RDF + 15 t/ha SS. It is advised to use either 50% RDF + 15 t/ha SS or 75% RDF + 10 t/ha SS to ensure healthy poplar nursery growth and for saving of inorganic fertilizers.

Keywords: Micronutrients, Litterfall, Nutrient uptake, Sewage sludge

Pollution is a significant challenge for developing and underdeveloped countries, primarily due to increased urbanization and industrialization, along with the global issue of unsustainable population growth. This has led to the generation of large amounts of various types of solid waste, including sewage sludge (Singh et al 2015). Approximately three billion people living in urban areas around the world produce about 1.2 kg of solid waste per person each day. By 2025, it is projected that the urban population will grow to 4.3 billion, generating roughly 1.42 kg of solid waste per person daily (Hossain et al 2017). In India, major cities alone are reported to generate about 38,354 million liters of sewage daily, while the sewage treatment infrastructure can only process 11,786 million liters per day (Kaur et al 2012). On the other hand, excessive use of chemical fertilizers deteriorate the soil quality and contaminate groundwater and other water bodies through leaching and runoff losses. Therefore, a reliable source is required for fertilization. Hence, the use of sewage sludge can be considered as one of the reliable options for fertilization in agriculture to overcome these issues.

Sewage sludge is semi-solid residual material produced from the treatment of municipal or industrial wastewater. When sewage sludge is recycled through sludge treatment it is frequently referred as “biosolids”. Biosolids are organic wastewater sediments that can be recycled after stabilisation processes such as anaerobic digestion and composting. The amount of wastewater treated and the treatment method employed have an impact on the amount of sewage sludge produced. It contains 50-70% organic matter and 30-50% inorganic material, as well as diversity of microorganisms (Gul et al 2015, Raheem et al 2018). It contains a considerable amount of micronutrients which promotes the plant growth (Fytili and Zabaniotou 2008, Tyagi and Lo 2013, Samolada and Zabaniotou 2014).

Various methods have been developed to safely dispose sewage waste; the most common are application to soil, sea dumping and landfilling (Gude 2015, Zhang et al 2017). Most of the cities and towns along the riverbank dumped waste into the waterways. Many nations have implemented environment legislation that forbids the discharge of sewage and effluents into rivers (Singh and Agrawal 2008), which has led to the accumulation of larger volumes of sewage sludge than before. On the other hand, disposing of sewage sludge in landfills is associated with leachate issues and higher CO_2 emission into the environment (Barberio et al 2013). Land application is therefore among the best methods of disposing of sewage sludge. Efficient nutrient recycling is key requirement of sustainable agriculture over long term. By applying sewage sludge as soil amendments in arable fields, these nutrients can be recycled (Kirchmann et al 2017). Khanna (2019) suggested that sewage sludge can be regenerated by employing it as organic manure in agriculture. At present, there is a lot of interest in the use of sewage sludge for reclamation and soil amendment. Sludge use on agricultural land can improve the soil's physical, chemical, and biological properties (Singh and Agrawal 2008). About half of the solid sewage sludge is composed of organic matter, which is known to enhance the physical characteristics of soil, such as bulk density and water-holding capacity, as well as to form stable complexes of heavy organic metals and reduce the amount of heavy metals present in contaminated soil (Kominko et al 2017). Sludge application improves the physical and chemical characteristics of the soil and has a major favourable impact on plant growth which increases the nutritional value of crop plant (Singh and Agrawal 2008, Eid et al 2019, Guoqing et al 2019).

Application of sewage sludge in forestry is considered as more reliable and safest option of disposing of sewage sludge as forest products are not consumed directly. This practice will also not affect the quality of soil as trees are long lived and store trace elements in their aerial parts. Poplar (*Populus deltoides* Bartr.) is a quick growing tree with a wide range of hybrids and cultivars. It is well known for their ability to exhibit phytoremediation (Guoqing et al 2019). It is an economical way to handle solid waste. Trees are important for environmental purification because they detoxify soil by absorbing large amounts of toxic metals (Madiwalar et al 2023, Singh et al 2020). Absolutely, the use of sewage sludge in growing poplar seedlings presents a promising yet underexplored area. Poplar trees are favoured for their fast growth and adaptability, which makes them ideal for various applications, including biomass production and environmental remediation.

MATERIAL AND METHODS

Study area: The research was conducted in the Forestry Research Area at Punjab Agricultural University, Ludhiana in the year 2022-2023. Ludhiana is situated at 244 meters above sea level, at a latitude of 30° 56' North and a longitude of 75° 52' East. The area's climate ranges from subtropical to tropical. The average annual maximum temperature is 29.8°C, while the average minimum temperature is 16.8°C. The region receives about 760 mm of rainfall each year.

Experimental details: Sewage sludge was applied in poplar nursery under field conditions having loamy sand soil texture replicated thrice in randomized block design in February 2022. Sixteen treatments were applied consisting of different rates of chemical fertilizer and sewage sludge. These were control (T1), 50% RDF (recommended dose of fertilizers) (T2), 75% RDF (T3), 100% RDF (T4), 5 t/ha SS (T5), 10 t/ha SS (T6), 15 t/ha SS (T7), 50% RDF + 5 t/ha SS (T8), 50% RDF + 10 t/ha SS (T9), 50% RDF + 15 t/ha SS (T10), 75% RDF + 5 t/ha SS (T11), 75% RDF + 10 t/ha SS (T12), 75% RDF + 15 t/ha SS (T13), 100% RDF + 5 t/ha SS (T14), 100% RDF + 10 t/ha SS (T15) and 100% RDF + 15 t/ha SS (T16). The recommended dose of N, P_2O_5 and K_2O was 125, 150 and 75 kg/ha, respectively. Application of full dose of phosphorus, potassium and sewage sludge was done at planting. Application of nitrogen was done in two splits, one half in first week of July and remaining in first week of August. The plants were uprooted after one year of nursery growth in January 2023. Different plant parts (shoot and root) were separated and litterfall was collected separately from each plot.

Observations: The plant height was recorded in January 2023 using a measuring scale from base to apex of the shoots in centimetres. The collar diameter of plants was measured using digital calliper in millimetres. The concentration and uptake of micronutrients (Fe, Mn, Cu, Zn and Ni) by shoot, root and litterfall was determined. Standard analytical techniques were used to ascertain the physico-chemical characteristics of the experimental soil and sewage sludge (Table 1). Experimental soil had an alkaline pH and deficit in organic carbon and available nitrogen. Available phosphorus content was in medium range and available potassium and micronutrients were in sufficient range. Sewage sludge was rich in organic carbon content (32.9%) while Ni content was lowest (43.9 mg kg^{-1}) among different elements.

Plant and sewage sludge analysis: After harvesting of poplar nursery in January 2023, shoot, root and litterfall samples were collected from different plots and fresh weight was recorded after removing dust from samples. Then, they were oven dried at 65 ±2˚C until the constant weight was attained. Samples were stored in paper bags after proper

Table 1. Physico-chemical properties and nutrient status of the experimental soil and sewage sludge used in the study

Property	Soil	Property	Sewage sludge
Sand (%)	80.9	Organic carbon (%)	32.9
Silt (%)	10.5	Total nitrogen (%)	1.9
Clay (%)	8.6	Total phosphorus (%)	0.18
Soil texture	Loamy sand	Total potassium (%)	0.31
$pH_{1:2}$	8.48	Fe (mg/kg)	8457
EC (dS/m)	0.22	Mn (mg/kg)	223.8
Organic carbon (%)	0.35	Cu (mg/kg)	86.1
Fe (mg/kg)	3.80	Zn (mg/kg)	364.3
Mn (mg/kg)	1.27	Ni (mg/kg)	43.9
Cu (mg/k)	0.52		
Zn (mg/kg)	1.40		
Ni (mg/kg)	0.179		

grinding for further analysis. For organic carbon analysis of sewage sludge, it was heated in muffle furnace at a temperature of 550 ˚C for one hour and organic matter content was determined by difference in weight of sewage sludge before and after heating. Nitrogen analysis in sewage sludge was done using Kjeldahl method given by Jackson (1973), in which one gram of sewage sludge was digested with 10 g of catalyst mixture (20 g of $CuSO_4.6H_2O$, 1 g Se-powder and 3 g HgO with 480 g of potassium sulphate). P and K content in sewage sludge and micronutrients (Fe, Mn, Cu, Zn and Ni) in plants and sewage sludge were determined by digesting one gram sample of sewage sludge with 10-15 ml of diacid mixture (HNO_3 and $HClO_4$ in 3:1 ratio). After making the volume of digested extract with distilled water, readings were taken on inductively Coupled Plasma-Optical Emission Spectrometer (ICP-OES). The uptake of micronutrients by shoot, root and litterfall was determined by multiplying the concentration of nutrients with their dry biomass.

Soil sampling and analysis: Before initiating the experiment, a composite soil sample was collected from surface layer (0-15 cm) for basic physico-chemical properties of experimental soil. After the completion of experiment, post-harvest soil samples were collected from all replication of different treatments. Before chemical analysis, samples were properly air dried and grinded and then sieved through 2 mm sieve. International pipette method was adopted to determine the texture of soil. Soil pH and electrical conductivity was determined by method employed by Jackson (1973) using soil:water ratio of 1:2. Wet digestion method (Jackson 1973) was followed to assess the organic carbon content of soil. Build-up of micronutrients in soil after application of different doses of chemical fertilizer and sewage sludge was done using DTPA extractable method (Lindsay and Norvell 1978).

Statistical analysis: The data were analysed in randomized block design using CPCS-1 software.

RESULTS AND DISCUSSION

Growth parameters: The plant height and collar diameter of one year old poplar nursery were maximum (409.1 cm and 27.88 mm, respectively) when treated with 100% RDF + 10 t/ha SS (T15) which were statistically similar with T10, T12, T13 and T16. The treatments where there was no application of chemical fertilizers and sewage sludge showed the lower plant height and collar diameter (277.9 cm and 17.31 mm, respectively) as compared to other treatments. Maximum increment was observed where combination of chemical fertilizers and sewage sludge was applied which might be due to the better utilization and more availability of nutrients for plant growth (Jamil and Bayan 2004).

Concentration and uptake of micronutrients by shoot: The concentration and uptake of micronutrients by shoot showed significant increment when applied with sewage sludge and its combination with chemical fertilizer over control (Table 2, 3). Maximum content and uptake of micronutrients was recorded when combined doses of sewage sludge and chemical fertilizer were applied. Fe, Zn and Ni showed highest content (197.3, 19.34 and 0.877 mg/kg, respectively) in shoots when applied with 100% RDF + 15 t/ha SS which was statistically similar with different doses of sewage sludge except 5 t/ha SS, 50% RDF + 15 t/ha SS and 75% RDF + 10 t/ha SS. Mn showed the highest concentration (27.16 mg/kg) at 50% recommended dose of fertilizer + 15 t/ha of sewage sludge whereas its uptake was highest (460.4 g/ha) at 100% RDF + 10 t/ha SS which was at par with 50% RDF + 15 t/ha SS. The maximum (3727 g/ha and 16.35 g/ha, respectively) uptake of Fe and Ni was also at 100% RDF + 10 t/ha SS which was statistically similar with 75% RDF + 15 t/ha SS. The Zn showed highest uptake (356.24 g/ha) at 100% RDF + 15 t/ha SS which was statistically similar with 75% RDF + 15 t/ha SS. The uptake of micronutrients improved as the dose of sewage sludge increased compared to the control. The combined use of chemical fertilizers and sewage sludge significantly enhanced micronutrients uptake. Roy et al (2013) observed that integrating sewage sludge with synthetic fertilizers increased micronutrient uptake in *Spinacia oleracea*.

Concentration and uptake of micronutrients by roots: The significant increase in the concentrations of Fe, Mn, Cu, Zn and Ni in the roots was observed when sewage sludge was applied, either alone or in combination with chemical fertilizer, compared to the control. The concentration of iron in the roots notably increased with higher doses of sewage sludge. The highest levels of iron, copper, zinc and nickel were recorded at 100% RDF +15 t/ha SS (428.3, 13.74, 23.34 and 1.62 mg/kg, respectively), which were still well below toxic levels (Table 2). Manganese concentration peaked at 22.05 mg/kg with 15 t/ha of sewage sludge, which was comparable to the concentration found with 50% RDF + 15 t/ha SS. The uptake of micronutrients (Fe, Mn, Cu, Zn and

Table 2. Concentration range of micronutrients in shoot, root and litterfall under different treatments

Micronutrients (mg/kg)	Shoot	Root	Litterfall
Fe	158.7-197.3	256.3-428.3	814-1461
Mn	21.79-27.16	17.81-22.05	152.1-193
Cu	3.23-12.61	9.17-13.74	12.22-17.49
Zn	8.95-19.34	15.57-23.34	65.45-116
Ni	0.527-0.877	0.74-1.62	3.27-5.04

Ni) by roots significantly increased compared to the control when different doses of sewage sludge were applied (Table 4). The highest micronutrient uptake was recorded with the combination of sewage sludge and chemical fertilizer. The greatest uptake of Fe and Ni (1386.9 and 5.20 g/ha, respectively) occurred with 100% RDF + 10 t/ha SS, which was similar to the uptake observed with 75% RDF + 15 t/ha SS. For Mn and Zn, the highest uptake (74.33 and 75.19 g/ha, respectively) was achieved with 75% RDF + 15 t/ha SS. The uptake of iron by poplar roots increased with the

Table 3. Uptake of micronutrients by shoot after application of different levels of chemical fertilizer and sewage sludge

Treatments	Iron (g/ha)	Manganese (g/ha)	Copper (g/ha)	Zinc (g/ha)	Nickel (g/ha)
T1 (control)	1485	203.2	30.33	84.14	4.95
T2 (50 % RDF)	1541	217.1	27.65	87.79	5.24
T3 (75% RDF)	1618	230.1	42.15	103.27	5.70
T4 (100% RDF)	2267	367.3	54.38	170.55	7.49
T5 (5 t/ha SS)	2407	306.6	73.30	152.78	8.90
T6 (10 t/ha SS)	2567	332.8	71.30	173.21	9.87
T7 (15 t/ha SS)	2847	398.5	90.35	253.32	10.74
T8 (50% RDF + 5 t/ha SS)	2455	320.5	78.95	197.25	10.10
T9 (50% RDF + 10 t/ha SS)	2666	335.2	85.63	219.46	10.25
T10 (50% RDF + 15 t/ha SS)	2954	431.5	109.21	273.07	11.87
T11 (75% RDF + 5 t/ha SS)	2503	303.8	70.09	184.04	10.12
T12 (75% RDF + 10 t/ha SS)	3229	336.6	85.96	289.67	12.91
T13 (75% RDF + 15 t/ha SS)	3538	373.1	97.89	310.14	14.46
T14 (100% RDF + 5 t/ha SS)	2668	290.5	149.95	187.07	11.37
T15 (100% RDF +10 t/ha SS)	3727	460.4	241.68	335.55	16.35
T16 (100% RDF + 15 t/ha SS)	3627	409.5	232.13	356.24	16.16
CD (p=0.05)	583.8	67.34	25.84	56.84	2.30

Table 4. Uptake of micronutrients by roots after application of different levels of chemical fertilizer and sewage sludge

Treatments*	Iron (g/ha)	Manganese (g/ha)	Copper (g/ha)	Zinc (g/ha)	Nickel (g/ha)
T1	665.0	45.92	23.67	40.35	1.92
T2	722.8	53.67	24.55	42.96	2.59
T3	810.8	56.65	26.64	47.45	2.69
T4	759.7	60.63	31.62	52.82	3.14
T5	966.8	56.56	31.24	60.51	3.58
T6	1070.5	63.35	33.72	66.37	3.64
T7	1074.0	67.14	34.92	67.95	3.78
T8	933.8	58.51	33.75	59.81	3.96
T9	1137.9	59.48	39.66	70.13	4.37
T10	1196.8	69.40	41.56	71.09	4.66
T11	1038.5	56.16	35.65	63.04	3.99
T12	1150.2	62.35	38.86	66.05	4.66
T13	1221.6	74.33	41.36	75.19	4.77
T14	1120.9	61.82	35.09	62.24	4.44
T15	1386.9	66.70	41.33	72.46	5.20
T16	1374.5	69.76	44.02	74.89	5.20
CD (p=0.05)	184.9	10.89	4.60	10.66	0.71

*See Table 3 for details

application of chemical fertilizer, sewage sludge, or a combination of both, compared to the control. The boost in iron uptake with sewage sludge application is attributed to the micronutrients provided by the sludge. Additionally, the addition of sewage sludge lowered soil pH, enhancing the availability of micronutrients in the soil, which further increased iron uptake (Sridhar 2002). The combination of sewage sludge and chemical fertilizer also improved iron uptake by poplar roots, likely due to the greater availability of micronutrients in the root zone. These findings are consistent with the study by Sreeramulu (2001).

Concentration and uptake of micronutrients by litterfall: The concentrations of Fe and Mn rose with increasing doses of sewage sludge. The highest levels of Fe, Cu, Zn and Ni (1461, 17.49, 116 and 5.04 mg/kg, respectively) were recorded at 100% RDF + 15 t/ha SS (Table 2). Meanwhile, the peak accumulation of Mn (193 mg/kg) was observed at 15 t/ha of sewage sludge, which was statistically similar to the levels found with 50% RDF + 15 t/ha SS. Applying sewage sludge alone or in combination with chemical fertilizer significantly increased the uptake of micronutrients (Fe, Mn, Cu, Zn and Ni) by litterfall compared to the control. The uptake of micronutrients, except Ni, increased notably with higher doses of sewage sludge (Table 5). The highest Mn uptake by litterfall (227.3 g/ha) occurred with 50% RDF + 15 t/ha SS, while the greatest uptake of Cu and Ni (19.98 and 5.76 g/ha, respectively) was observed with 100% RDF + 15 t/ha SS. This level of Cu and Ni uptake was similar to that achieved with 50 or 75% of the recommended fertilizer dose combined with 15 t/ha of sewage sludge. When litterfall is returned to the soil, the nutrients it contains are released back into the soil as it decomposes. Numerous studies have noted significant enhancements in soil nutrient levels as a result of adding litterfall and the subsequent nutrient release during its decomposition (Sharma et al 2015, Singh et al 2021).

Build-up of micronutrients in soil: Applying sewage sludge at various rates significantly enhanced the accumulation of micronutrients in the soil compared to the control (Table 6). The highest levels of Fe, Mn and Ni were achieved with 100% of the recommended fertilizer dose combined with 15 t/ha of sewage sludge, while the greatest accumulation of Zn was observed with 100% of the recommended fertilizer dose plus 10 t/ha of sewage sludge. The addition of sewage sludge to the soil resulted in an increased accumulation of micronutrients. This is because sewage sludge lowers soil pH, which enhances the availability of micronutrients by dissolving metals associated with organic matter (Singh and Sharma 2007, Delibacak et al 2009). Additionally, sewage sludge provides a substantial amount of micronutrients to the soil. The micronutrient content in the soil also rose with the application of both chemical fertilizer and sewage sludge, likely due to the

Table 5. Uptake of micronutrients by litterfall after application of different levels of chemical fertilizer and sewage sludge

Treatments*	Iron (g/ha)	Manganese (g/ha)	Copper (g/ha)	Zinc (g/ha)	Nickel (g/ha)
T1	754.5	141.1	11.36	60.82	3.03
T2	947.0	154.2	12.95	69.26	3.43
T3	1025.1	172.0	13.24	76.40	3.86
T4	1006.6	180.2	14.06	76.50	3.85
T5	1128.4	177.0	14.94	78.71	4.16
T6	1306.4	201.7	17.17	85.71	4.71
T7	1352.3	213.1	18.52	92.02	4.90
T8	1245.3	189.7	15.78	82.15	4.40
T9	1412.2	217.9	18.96	94.02	5.33
T10	1508.3	227.3	19.58	102.9	5.65
T11	1251.2	183.9	15.56	80.1	4.48
T12	1454.4	212.3	16.29	90.2	4.88
T13	1409.5	214.3	17.39	96.6	5.20
T14	1499.3	198.3	16.37	103.1	5.38
T15	1537.7	204.2	17.63	116.7	5.46
T16	1668.6	213.3	19.98	132.4	5.76
CD (p=0.05)	79.7	13.11	2.85	9.5	0.85

*See Table 3 for details

Table 6. Build-up of micronutrients in soil after application of different levels of chemical fertilizer and sewage sludge

Treatments*	Iron (g/ha)	Manganese (g/ha)	Copper (g/ha)	Zinc (g/ha)	Nickel (g/ha)
T1	4.51	6.63	0.387	1.361	0.154
T2	4.63	6.60	0.388	1.367	0.159
T3	6.01	7.99	0.395	1.413	0.161
T4	5.81	7.92	0.384	1.410	0.164
T5	5.20	7.22	0.559	1.610	0.172
T6	5.30	8.26	0.599	1.670	0.174
T7	5.66	9.42	0.656	1.760	0.176
T8	5.57	7.57	0.609	1.695	0.201
T9	5.89	8.57	0.635	1.774	0.222
T10	6.50	9.99	0.673	1.780	0.223
T11	6.62	7.82	0.587	1.892	0.224
T12	7.08	8.85	0.590	2.018	0.227
T13	7.22	10.02	0.679	2.086	0.233
T14	6.84	8.05	0.612	2.133	0.239
T15	7.17	9.94	0.626	2.263	0.242
T16	7.38	10.10	0.631	2.184	0.303
CD (p=0.05)	1.37	1.13	0.128	0.284	0.032

*See Table 3 for details

increased availability of micronutrients. These findings are consistent with those reported by Sridhar et al (2002).

CONCLUSIONS

Sewage waste, which is rich in organic matter and essential nutrients needed for plant growth, can be utilized as manure. In this study, applying various doses of sewage sludge significantly enhanced growth parameters such as plant height and collar diameter as well as plant biomass. The highest plant height and collar diameter were achieved with 100% RDF + 10 t/ha SS, which was comparable to the results from 50% RDF + 15 t/ha SS and 75% RDF + 10 t/ha SS. The dry biomass of shoots, roots, and litterfall increased notably with sewage sludge treatment compared to no sewage sludge or chemical fertilizer application. Additionally, varying rates of sewage sludge and chemical fertilizers significantly boosted the concentration and uptake of micronutrients (Fe, Mn, Cu, Zn and Ni) in shoots, roots and litterfall compared to the control.

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