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Direct and residual effect of sewage sludge on yield, heavy metals content and soil fertility under rice–wheat system

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ABSTRACT

Soil application of sewage sludge in crop production offers an alternative technique for its disposal and management. The present study was taken up to evaluate the effect of sewage sludge on yield of rice, soil fertility and heavy metals accumulation in grain and straw in a glass house. The residual effect of sludge application was evaluated in subsequent wheat crop in the sequence. Five doses of sludge i.e., 0, 10, 20, 30 and 40 t ha^{-1} were applied to rice and their effects were compared with the recommended dose of fertilizers i.e., 120, 60 and 60 kg N, P_2O_5 and K_2O ha^{-1}, respectively. There was significant increase in straw and grain yields of both the crops with application of sludge. The grain yield of rice increased 45% at 40 t ha^{-1} sludge application over no sludge. The residual effect on wheat yield was more pronounced. Soil pH in post harvest rice soil increased with the application of sludge, however, it decreased in post harvest wheat soil at higher levels of sludge application. Increase in available nutrients content of soil was also recorded with increasing levels of sludge application after harvest of rice and wheat crops. Application of sludge also increased the heavy metals contents in soil and plant. The Cd content in rice grain was above the Indian safe limit at 20 t ha^{-1} or higher levels of sludge application. There was a significant build up of P, S, Zn, Fe, and Mn in post harvest wheat soil at 40 t ha^{-1} sludge application.

1. Introduction

Large scale urbanization is leading to increased production of sewage sludge in India. Its management and disposal in a cost effective and environment friendly manner is one of the most pressing problems of the country. Soil application offers a good promise for using this waste material in agriculture. Sewage sludge is a good source of plant nutrients such as N, P, K, S, Ca, Mg, Fe, Cu, Mn and Zn (Martinez et al., 2003; Singh and Agrawal, 2010a,b). It is also a rich source of organic matter (Jamil et al., 2004). The nutrients content of sewage sludge sustains soil fertility and the organic constituents improve soil properties (Singh and Agrawal, 2008, 2010a,b). However, sewage sludge may contain high amount of toxic heavy metals such as Pb, Cd, Ni, Cr and Hg due to the mixing of industrial wastewater with sewage (Bright and Healey, 2003; Przewrocki et al., 2004; Dai et al., 2006; Singh and Agrawal, 2007). Application of metal contaminated sewage sludge may cause soil and water pollution, crop damage and accumulation of heavy metals in the food chain. The magnitude of the problem depends on the composition of the sludge, rate of its application, soil properties, crop species and management practices.

Rice–wheat cropping system (RWCS) is a major cropping system contributing one third of cereal production in the country. However, the system is not sustainable due to the decline in soil fertility, especially in organic matter. The factor productivity of fertilizers also decreased, asking for a higher amount of plant nutrients to obtain the same yield. There is little information that confirms the agronomic and environmental sustainability of the sewage sludge application under rice–wheat system in India. Results of several studies in the laboratory, greenhouse, and field indicate that repeated application of sewage sludge has several beneficial effects on soil properties and crop yields (Hernandez et al., 1991; Sort and Alcaniz, 1999; Monera et al., 2002). However, the residual effects of sewage sludge application under rice–wheat cropping system have not properly studied. The present study aimed at identifying the effect of sewage sludge on soil fertility, yield and heavy metal uptake in rice and its residual effect on wheat.

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2. Methodology

2.1. Study area

An experiment was carried out in the glass house of the Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, India, during July 2009 to April 2010. Varanasi is located between 25.14° and 25.23° N latitude and 82.56° and 83.03° E longitude and falls in a semi-arid to sub humid climate. The mean ambient temperature varied from 14.6 to 36 °C during rice (July to October) and 7.0 to 35.5 °C during wheat (November to March) cultivation. The maximum and minimum relative humidity varied from 70% to 87% and 30% to 81% during rice and 60% to 92% and 27% to 70% during wheat cultivation, respectively.

2.2. Collection of soil and sewage sludge

For the pot experiment, the bulk of soil was collected from the Agricultural Research Farm, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi. The soil was an alluvial representing an Inceptisol (Typic Ustochrept). Ten kg of soil was filled in each pot after grinding to pass through 2 mm sieve. Sewage sludge was collected from Sewage Treatment Plant (STP), Bhagwanpur, Varanasi in the month of May 2009. The dry sludge was ground to get a homogenous mass.

2.3. Experimental design and raising of plants

The experimental soil (0–15 cm) had pH 7.95 (1:2.5), EC 0.2 dS m^{-1}, organic carbon 0.24% and available N, P and K of 62.7, 16.1 and 139.3 kg ha^{-1}, respectively. The DTPA extractable Fe, Mn, Cu and Zn contents of soil were 32.5, 9.6, 6.1 and 1.6 mg kg^{-1}, respectively. There were six treatments including five levels of sludge i.e., 0 (S_0), 10 (S_{10}), 20 (S_{20}), 30 (S_{30}) and 40 (S_{40}) t ha^{-1} applied to rice crop and wheat was grown as residual crop and one level of recommended dose of fertilizer (RDF) with 120, 60 and 60 kg ha^{-1} of N, P_2O_5 and K_2O, respectively was kept each in rice and wheat crop. The sludge contained 1.6% N, therefore, N supplied through these 5 doses of sludge were 0, 71.3, 142.7, 221.8 and 285.4 mg kg^{-1} soil. The experiment was conducted in completely randomized design (CRD). Ten kg soil was filled in each pot and required quantities of sewage sludge were mixed with the soil. Fertilizer N, P and K were applied in liquid forms in the RDF treatment. Half of N and full dose of P and K were applied at the time of transplanting of rice and remaining N fertilizer was applied in two equal splits at tillering and flower initiation stages. Rice (*Oryza sativa* L.) variety PRH 10, developed at Indian Agricultural Research Institute, New Delhi was used in the study. This variety suits well in irrigated condition, fits in the rice–wheat cropping system of Northern India with average yield of 6.5 t ha^{-1}. It is world's first superfine grain aromatic rice hybrid possessing typical aromatic qualities and tolerant to major insect and diseases.

After harvesting of rice crop, wheat (*Triticum aestivum* L. cv. Malviya 234) was grown in the same pot without fresh application of sewage sludge. The chemical fertilizers were applied only in RDF treatment in wheat. Half of N and full dose of P and K was applied at the time of sowing of wheat and remaining N fertilizer was applied in two equal splits at tillering and flower initiation stages. Pots were irrigated as per requirement of the wheat crop and for rice, continuous submerged condition was maintained up to the physiological maturity.

2.4. Plant, soil and sewage sludge analyses

Harvested plant samples were washed in detergent solution (0.2% liquid), 0.1 N HCl solution and deionised water in sequence and dried at 70 °C till the constant weight. Straw, grain and sludge samples were digested in a di-acid mixture (HNO_3:$HClO_4$::3:1 v/v), and analyzed for P and K, however, N was determined in samples digested in H_2SO_4. The content of Fe, Cu, Mn, Zn, Cd, Cr, Ni and Pb in the diacid digest was determined using atomic absorption spectrophotometer (UNICAM – 969) as per procedure outlined by Tandon (2001). The soil samples were collected after the harvest of rice and wheat crop. The soil samples were analyzed for pH in 1:2.5 soil: water suspension; organic carbon by methods of Walkley and Black (1934); available N by alkaline potassium permanganate (Subbiah and Asija, 1956); $NaHCO_3$ extractable-P (Olsen et al., 1954) by spectrophotometer, ammonium acetate extractable K (Hanway and Heidel, 1952) by flame photometer and 0.15% $CaCl_2$ extractable S by developing turbidity using $BaSO_4$ (Chesnin and Yien, 1950) and DTPA extractable Fe, Cu, Mn, Zn, Cd, Cr, Ni and Pb (Lindsay and Norwell, 1978) by atomic absorption spectrophotometer following the procedure outlined in Sparks (1996).

2.5. Statistical analysis

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

3. Results and discussion

3.1. Sewage sludge characteristics

The sewage sludge had pH (6.16), EC (2.7 dS m^{-1}), organic C (12.6%), total N, P, K and S content as 1.6%, 1.3%, 0.8% and 2.1%, respectively. The contents of DTPA extractable Fe, Cu, Mn and Zn of sludge were 52.3, 28.7, 38.2 and 32.8 mg kg^{-1} and the total were 232, 186, 260 and 161 mg kg^{-1}, respectively. As regards to Cd, Cr, Ni and Pb, the DTPA extractable amounts were 1.49, 1.28, 17.3 and 6.43 mg kg^{-1} and the total were 32.3, 44.3, 54.7 and 28.5 mg kg^{-1}, respectively. According to Council of the European Communities (1986), the permissible levels for potential toxic elements such as Zn, Cu, Cd, Pb, Ni and Cr in sludge to be used in agricultural soils are 2500, 1000, 20, 750, 300 and 750 mg kg^{-1}, respectively. The sludge used for study contains 161, 186, 28.5, 54.7, 32.3 and 44.3 mg kg^{-1} of Zn, Cu, Pb, Ni, Cd and Cr, respectively. Thus only Cd was above the permissible limit.

3.2. Growth and yield

Application of 40 t ha^{-1} sludge in rice increased plants height over no sludge application (S_0) both in rice and wheat (Table 1). Maximum plant height was observed with RDF. Significant effect of sludge on plant height in rice was at 30 days after transplanting (DAT) when 40 t ha^{-1} sludge was applied, however, at 60 DAT its effect was significant even at lower rates of application. This might be as the decomposition and release of nutrients from sludge takes time thus its effect was more visible at 60 DAT. In wheat, residual effect of sludge on plant height was significant at 30 t ha^{-1} and higher application rates at 30 days after sowing (DAS). Significant increase in plant height of dry bean grown at 2, 4, 6 kg m^{-2} SS was reported for 2 years of study, the increase being maximum at 6 kg m^{-2} (Togay et al., 2008). Similar effects on plants height were also reported by Jamil et al. (2004) and Yamur et al. (2005).