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Impact of sewage sludge on crop growth, soil quality and nutrient dynamics in system-based approach

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Abstract
Organic manures have been used as a nutrient source since the dawn of agriculture, but after the widespread usage of inorganic fertilizers, bulky organic manures became the second best option for nutrients. In this regard, the use of treated sewage sludge as an organic source is a critical tool that is gaining attraction among farmers and government agencies due to its high nutrient content and abundance. The addition of sewage sludge to the soil system enhances soil chemical, biological, and physical features, as well as soil structure, porosity, compaction, and crusting, as well as the total water holding capacity of the soil. It can be used alone but its application with inorganic fertilizers was found to be a better combination for soil health. Sewage sludge also increase the biological activity of the soil. However, because heavy metals like nickel (Ni), cadmium (Cd), and lead (Pb) are typically detected in sewage sludge, its long-term usage in agriculture requires extra caution due to the danger of phytotoxicity.

Keywords: Sewage sludge, inorganic fertilizers, soil properties, heavy metals, phytotoxicity

1. Introduction

The stagnant yield arisen due to intensive use of lands without proper replenishment of plant nutrients especially where high yielding cultivars or cropping system are being practiced using unbalanced doses of mineral fertilizers with little or no organic recycling. The main reasons for declined soil fertility under these intensive systems are the exhaustion of soil organic matter and degradation of soil physicochemical properties due to an inadequate and imbalanced nutrient application without the application of organic manures. Because the nutrients in the soil are in insufficient quantities and proportions for plants to produce maximum yields on a long-term basis, plant nutrients must be added to the soil through mineral fertilizers, organic manure, and other means (Singh *et al.*, 2012) [50]. There would be an increase in plant nutrient loss as crop productivity increased. To keep crop productivity up, ongoing mining must be refilled. This is a major soil health issue that must be addressed by using all sources of plant nutrients in a balanced and integrated manner. Therefore, it is important to look for the issue immediately as the cotton-wheat system is the deciding factor of livelihood of farmers in this region and its successful cultivation is feasible only with the espousal of appropriate nutrient management approaches to alleviate the grueling conditions of farmers. Despite significant advancements in fertilizer manufacturing and application in agriculture, their appropriate management in cotton-wheat based system is ignored. Therefore, apposite nutrient management is of utmost importance for achieving high yields in this system. Despite an increase in the usage of nitrogen (N) and phosphorus (P) fertilizers in recent decades, it failed to provide the break-through in the stagnant crop. In this system, farmers mainly use N & P-fertilizers for wheat and N-fertilizer only for cotton; the use of fertilizer P and potassium (K) are ignored continuously in cotton. Furthermore, N and P usage rates are low, and the fertilizer N: P_2O_5 use ratio is excessively high (3.4:1) to meet crop nutrient requirements (GOP, 2008). The soil production may be harmed by such unbalanced nutrient management. As a result, the formation of numerous nutrient shortages, low SOM content, and low fertilizer usage efficiency are the most significant restrictions to long-term crop yield. The utilization of organic fertilizers as a nutrient source has been in use since the beginning of established agriculture, but after the induction of prevalent utilization of inorganic fertilizers, the bulky organic manures were deemed as the second alternative of nutrients. To protect the environment and the health of soil, plant, and human beings from further degradation, we should reduce our usage of chemical fertilizers and switch to biological agriculture for crop nutrition (Deshmukh *et al.*, 2004) [15].

Subsequently, to sustain the agriculture and soil fruitfulness, organic fertilizers and various other organic materials got importance as constituents of plant nutrient management. Bulky organic manures provide most of the essential plant nutrients (instead of one or two nutrients by chemical fertilizers) besides enhancing the soil carbon stock and improving soil physical and biological conditions. In this respect, the usage of treated sewage sludge as an organic source is an imperative tool that is of increasing interest of farmers and governmental bodies due to its over production and higher nutrient content. Sewage sludge technology promoted by an excess generation of solid waste is the strong growth promoter which helps to fulfill our basic object of reducing the usage of inorganic fertilizers, restoring soil organic matter, enhancing nutrient use efficiency and maintaining soil quality while improving the crop yield and production economics. The addition of sewage sludge to the soil system improves soil chemical, biological, and physical characteristics, as well as soil structure, porosity, compaction, and crusting, and increases the soil's overall water holding capacity. As we know, sewage sludge alone cannot supply sufficient nutrients for optimum crop growth because of their slow and limited availability. Hence, an ample supply of inorganic P is crucial at the initial stage of crop growth for better root establishment and their growth. Besides, proper supply of nitrogenous fertilizers is also needed as it affects the crop growth resultant in improved crop yield and nutrient use pattern in the cotton-wheat cropping system (Islam and Borthakur, 2016) [24]. Sewage sludge refers to the solid waste left over after sewage treatment. Because of the rising pressure on existing resources, sewage sludge generation in India is expanding at a faster rate as a result of rapid population increase, urbanization, and industrialization. Presently, in India, the total annual solid waste generation is around 42 million tonnes which varies from 200-600 kg/capita/day (Meena *et al.*, 2018) [37]. In a global context of rising concern over waste generation exclusively because of untreated wastewater, which pollutes the environment and puts people's health at danger, now there is a compelling need to look treated waste as a valuable resource rather than a waste. Therefore, it is crystal clear that water, wastewater, and the associated biosolids (sludge) must also be managed more seriously, and in a focused, coordinated, and cooperative manner, for the sake of our planet's well-being. Notably, agricultural application cum environmental usage of sewage sludge is the most cost-effective, ecologically friendly, and recommended approach. Sewage sludge is a good source of plant nutrients, including macro and micronutrients, as well as other organic elements, because it is an organic waste. As a result, it is a nutrient-rich fertilizer. The major nutrients are found in extremely high amounts, such as total nitrogen 1.54-1.92 percent, phosphorus 0.61-0.92 percent, and potassium 0.35-0.43 percent (Outhman and Firdous, 2016) [41]. As a result, sewage sludge could be regarded a valuable biological resource for long-term agriculture. When employed as an organic fertilizer, it provides beneficial plant yield responses. The majority of micronutrients are provided in an acceptable amount and at the right time in sewage sludge. The addition of organic materials to the soil, such as sewage sludge, boosts its biological activity. However, the heavy metals such as nickel (Ni), cadmium (Cd), and lead (Pb) are commonly found in sewage sludge, its use in agriculture for the long term requires special attention due to the risk of its phytotoxicity. There is a possibility of heavy metals to transfer to the food chain posing threat to human and animal life. Heavy metals have a negative impact on biological functions in soil, such as the size, activity, and diversity of the soil microbial population, as well as the activity of enzymes in biotransformation. For this reason, regulations in form of legal compliances have been enacted for the use of sewage sludge application in agriculture. Farmers are using sewage sludge to the fields without knowing its ill effects, rate and time of application. Since, sewage sludge is derived from municipal wastes so it may contain varying amounts of heavy metals depending upon the kind of a waste. The field where farmers are applying sewage sludge, soil testing should be done on regularity basis to reveal soil health whether it is beneficial or not or how can we improve its efficacy to get more crop production without deteriorating soil health. Therefore, by applying sufficiently clean and properly treated sewage sludge on arable land, the nutrients can be recovered, which reduces the requirement of mineral fertilizers. No single source of plant nutrients, as in modern agriculture, can meet a crop's entire nutritional requirement; instead, they must be maintained in conjunction with an economically and environmentally appropriate management system. Because of positive effects of sewage sludge and the perpetually increase in cost of chemical fertilizers and their limited availability, the combined use of sewage sludge and chemical fertilizers is gaining importance in crop production as well as for maintenance of soil productivity. In this respect, the method of integrating plant nutrient sources has a lot of potential for fulfilling nutrient demands under intensive cultivation and maintaining higher crop output while improving the quality of the resource base and farmer's economics. Therefore, the potential solution to combat these challenges is the combined usage of sewage sludge with chemical fertilizers which play a vibrant role towards refining various soil physical conditions, make available essential plant nutrients and ensures soil productivity and sustainability over a considerable period of time (Shaabazi *et al.*, 2017). This helps to correct the imbalances in nutrient supply to prevent further deterioration of soil quality, to break the yield barriers and sustaining livelihood security. The fertilizer requirements of both the crops on an individual basis have already been worked out and well documented. There is a general tendency that both the crops in sequence receive their recommended fertilizer doses regardless of the fact that whether the previous crop has received the fertilizer or not. Nitrogen and phosphorus are the most limiting nutrients because of low organic carbon and high phosphorus fixation. This cropping sequence has high nutrient requirements, which may have a detrimental effect on crop productivity in the long run; thus, effective nutrient management is required for long-term output. Nutrient management is the most essential component in determining crop production and preserving soil fertility among the agronomic packages of actions. Out of the primary macronutrients, nitrogen is applied in the highest amount to both cotton and wheat cultivated in the rotation (Latare *et al.*, 2014) [31]. Cotton has a more complicated nitrogen requirement and usage than other major field crops due to its determinate growth habit. Chemical fertilizers are still the fastest approach to slow down the rate of nutrient depletion. However, there are technological, economic, logistical, and environmental reasons to practice integrated nitrogen management. In northern India, combining mineral fertilizer with organic amendments like sewage sludge proven to be a viable alternative for the cotton-wheat combination. Notwithstanding the numerous benefits of sewage sludge, its application is ignored by the farmers. Recognizing its potential, we need to give attention on the need for promoting the use of sewage sludge along with synthetic fertilizers in crops to derive maximum benefits and investment on research for initiating its use in crop production technologies.

2. Characterization of sewage sludge

Agricultural use of sewage sludge is gaining popularity due to the possibility of recycling valuable components such as organic matter, nitrogen, and phosphorus, as well as other plant nutrients. However, because there is a possibility of harmful substances accumulating in soil, sewage sludge must be characterized before being applied to farmland. The original pollutant load of the treated water, as well as the waste water and sludge treatment processes, will determine the content of the sewage sludge. As a result, sludge treatment has an impact on its composition. A report of Global atlas of excreta, wastewater sludge and bio-solids management highlighted that sewage is an extreme source of plant nutrients and showed that general content of N, P_2O_5, and K_2O in raw sewage sludge is shown to be 3.51%, 3.53% and 0.21%, respectively. Similarly, the average range of toxic metals in raw benchmark sewage sludge (ppm) is 0.10, 40, 10, 15, 20 and 0.05 for Cd, Zn, Cu, Ni, Pb, and Hg, respectively. The amount of metal in sludge varies depending on the type of sewage generating factories. (Rajurkar and Kulkarni, 1997) [44]. Chitdeshwari *et al.* (2002) [12] analyzed the sewage and sludge for different properties and results obtained that available N, P_2O_5, and K_2O (1230, 633 and 380 mg kg^{-1}) and available Zn, Fe, Mn, Cu, Pb, Cd, Cr and Ni; 55.2, 27.9, 35.4, 23.0, 35.6, 2.92, 8.96 and 26.40 ppm, respectively. Sridhar *et al.* (2006) [51] reported that the sewage and sludge collected from different municipal sewage treatment plant located at Hyderabad (India) and obtained that sewage sludge is a good source of plant nutrients such as macro and micronutrients. The sewage and sludge analyzed and reported that the available micronutrients (Fe, Mn, Zn, and Cu) in the sewage and sludge were 130.98. 24.32 33.88 and 29.74 mg kg^{-1}, respectively. Jamali *et al.* (2009) [25] reported that the without water collected sludge from Hyderabad city and observed organic carbon (35.6%), total N (9508 mg kg^{-1}) and S (825 mg kg^{-1}), respectively. The available Cd, Cr, Cu, Ni, Pb and Zn were observed 0.391, 0.098, 0.767, 2.93, 2.34 and 4.97 mg kg^{-1}, respectively. Similarly, Singh *et al.* (2012) [50] reported that the sewage and sludge from treatment plant Varanasi had 12.65% OC, while the available N, P_2O_5, and K_2O was about 73.78, 78.37 and 191.85 ppm, respectively. Similarly, the concentration of available Zn, Cd, Cr, Pb, and Ni was 38.3, 1.26, 0.56, 9.44 and 0.422 ppm, respectively, however, the total content of these available micronutrients were161, 1.77, 44.34, 83.47 and 18.63 ppm, respectively. Latare *et al.* (2014) [31] studied that the sewage sludge for EC (2.7 dS m^{-1}), pH (6.16), OC (12.6%), total content of N (1.6%), P_2O_5 (1.3%), K_2O (0.8%) and S (2.1%) nutrient. Similarly, the concentration of available Fe, Cu, Mn and Zn of without water sludge was found to be 52.3, 28.7, 38.2 and 32.8 ppm and their total content was 232, 186, 260 and 161 ppm, respectively. In terms of available Cd, Cr, Ni and Pb, these values were 1.49, 1.28, 17.3 and 6.43 ppm, respectively, while their total concentration were 32.3, 44.3, 54.7 and 28.5 ppm, respectively.

3. Effect of sewage sludge on crop production

Being an important organic fertilizer, sewage sludge is used in all developed and developing countries of the world. Crop responses to sludge application have been mixed. Grain yield increase with higher SS rates up to 40 t ha^{-1} in a pot trial on wheat. (Jamil *et al.*, 2004) [26]. Above this level there were declining trends in grain yield. However, straw yield (15.04 $plant^{-1}$) was significantly higher with the application of sewage sludge @ 80 t ha^{-1}. Sewage sludge had the high content of OM, macronutrients and micronutrients, they also reported that sewage and sludge application had a cumulative effect on wheat crop. Similarly, Mathakiya and Meisheri (2007) [35] investigated the possibility of saving N, P_2O_5 and K_2O fertilizers in cabbage and found significant increase in head and stump yield with application of biological sludge @ 5 t ha^{-1} along with RDF as compared to control. Samaras and Kallianou (2000) [47] in their experiment recorded significantly higher cotton yield in treatments receiving sewage sludge @ 42, 58 and 77 tons ha^{-1} $year^{-1}$. This increment in yield might be due to the increased amounts of P and N applied in the soil of experimental plots after sewage sludge addition. Likewise, Samaras *et al.* (2008) [48] revealed that the sludge application of 10 Mg ha^{-1} was adequate to increase nutrient uptake and cotton yield along with improvement in soil chemical properties. Even at a reduced application rate, sludge was shown to be able to replace inorganic fertilizer requirements. Tamrabet *et al.* (2009) [52] conducted an experiment to evaluate the effect of sewage sludge application on the growth parameters and yield performance of wheat (*Triticum durum*). Fertilization with 33 kg ha^{-1} N as urea and 20, 30, and 40 tonnes dry sludge ha^{-1}, applied at the tillering stage, and an unamended control were the treatments. The results examined that a significantly higher grain yield and yield parameters, mainly has compounded effect on fertility and straw yield. 30 tons ha^{-1} of sewage and sludge dry matter was as best as 66 kg ha^{-1} of mineral nitrogen. According to the findings, sewage and sludge application could be used to boost and stabilise wheat output in arid environments, as well as a safe disposal method for these wastes. Cerny *et al.* (2012) [11] conducted a field experiment on a black soil to report fertilizer N efficiency of maize. Nitrogen treatments were examined 0, 60, 120, 180, and 240 kg N ha^{-1} prior to maize sowing, 60 kg N ha^{-1} at planting in fertilizer application; 120 and 240 kg N ha^{-1} in sewage sludge were applied. When sewage and sludge were applied, maize yields increased by 19.02–25.04 percent over control, especially in the first and second years following application. These findings were consistent with those of earlier sewage sludge tests (Nedved *et al.*, 2008 and Cerny *et al.*, 2010) [40, 10]. Likewise, Hernandez *et al.* (1991) [22] reported the significant variations in the yield of maize and barley crop. The sludge application enhanced their yields by providing a sufficient amount of available N to the plants. Ozyazici (2013) [42] studied that significant rise in grain and straw yield of wheat under various rate of sewage and sludge application. The treatments modified with sewage and sludge @ 20 t ha^{-1} produced the highest grain production, with a 70.01 percent increase over control. During the first period, the treatment 40 t ha-1 of sewage sludge (SS) produced the highest straw yield, followed by 30 t ha^{-1} SS, which were statistically similar to the treatments 20 and 50 t ha^{-1} of SS. Latare and Singh (2013) [32] used a greenhouse experiment to investigate the impact of cumulative sewage sludge and mineral fertilizer applications on rice yield parameters and hazardous metal accumulation. Various doses of sewage sludge, ranging from 0 to 10, 20, 30, and 40 t ha^{-1}, were combined with various quantities of RDF, ranging from 0 to 25, 50, 75, and 100%. The treatments that used 100% RDF without sludge and 40 t ha^{-1} sewage sludge without RDF, respectively, demonstrated a 33 and 46 percent improvement in grain production over control. The impact of sewage sludge on Palak production was found by Roy *et al.* (2013) [46]. (Beta vulgaris). They discovered that the treatments that combined sewage sludge and 50 percent NPK produced much larger Palak yields than the prescribed amount of NPK fertilizer or sewage sludge alone. The results demonstrated that sewage sludge and inorganic fertilizer had a cumulative impact in enhancing crop productivity. Because sewage sludge works as an effective source of organic matter, nitrogen, phosphorous, and various micronutrients, the cumulative application of sewage sludge and fertilizer results in a higher dry matter yield. Kamal *et al.* (2013) [28] in their experiment revealed that contents of N,P, K, Ca, Mg and heavy metals (Fe, Cu, Zn, Mn, and Pb) in rice grain increased gradually with increasing sewage sludge application and were significantly highest in SS240 treatment (240 t ha^{-1}). In a sequence cropping system, Latare *et al.* (2014) [31] investigated the impact of sewage and sludge on rice production performance and the residual effect on future wheat crops. They discovered that applying sewage sludge to both crops resulted in a considerable increase in straw and grain yields. Rice grain production improved by 45 percent when sewage sludge 40 t ha^{-1} was applied instead of no sewage sludge. The application of sewage sludge over the control resulted in a considerable increase in plant height and number of tillers pot^{-1}. A beneficial effect of sewage sludge application on winter wheat has also been noted by Koutroubas *et al.* (2014) [30]. They registered higher grain yield, grain weight, N concentration and trace element concentrations with SS-3 treatment (60 Mg dry weight sewage sludge per ha per year). Outhman and Firdous (2016) [41] investigated the effect of sewage sludge on cereal crop vegetative growth. With the application of sewage sludge @ 12 t ha^{-1}, they were able to get significantly increased plant metrics such as test weight, plant height, number of tillers, and grain yield of wheat and barley. Pasqualone *et al.* (2017) [43] in an experiment on barley concluded that 12 mg ha^{-1} composted sewage sludge, or the combined application of 6 mg ha^{-1} sewage sludge and mineral fertilization, led to yield parameters (seed yield, 1000-seed weight, and test weight) not significantly different from mineral fertilization. Thus, indicating the potential effectiveness of sewage sludge in reducing the use of fertilizers. Arpali *et al.* (2016) [4] evaluated the impact of sewage sludge application on yield and nutrient status of wheat. They recorded an increment of 99% higher yield as compared to control and with the increasing rate of sewage sludge other yield attributes were also increased and were highest with the application sewage sludge @ 30 t ha^{-1} of. Grain mineral concentration was significantly enhanced with sewage sludge application and grain Al, Cd, Cr, Ni, Pb, and Cu contents were unaffected by the use of sewage sludge. Evangelou *et al.* (2017) [19] conducted a field experiment for two consecutive years and quantified that sewage sludge application at 6000 kg ha^{-1} affects cotton yield positively. Cocarta *et al.* (2017) [14] also studied the effect of sewage sludge application on wheat crop and found that the highest production was registered with the sewage sludge application @ 25 t ha^{-1}. Also in grain, Pb level was below the allowed value but cadmium level was so close to the maximum allowed value. Similarly, In Iran, Shaabazi *et al.* (2017) conducted an experiment to analyse sewage sludge affected heavy metal concentrations in wheat crops (var. Shivand and Roshan). They recorded that concentrations of Zn, Cd, Fe, and Mn were found to be below the standard toxicity level in the treated seed and stem of the Sivand variety, but concentrations of Cu and Pb were found to be above the standard limit. The concentrations of Zn, Cd, Pb, Fe, and Mn in the Roshan variety were below the standard limit, whereas the concentration of Cu was above it.

3.1 Concentration and uptake of nutrients and heavy metals

The enhanced uptake of Cd, Ni, and Zn in wheat, carrot, and spinach grown in soils treated with sewage and sludge was due to bioaccumulation of Cd, Ni, and Zn. Only a slight increase in Cu and Pb bio-accumulation was detected. Over to an acid response and coarse texture soils, a non-acidic pH of soils and clay texture tended to obtain proper control of metal accumulation in edible plants (Hooda *et al.*, 1997) [23]. Silva *et al.* (2006) [46] found out that proper applications of sewage sludge resulted increases level of Mn and Zn contents in maize leaves and grains in relation to the control conditions. The use of the highest dose promoted an increase of up to 270 and 625% of Mn, and 35 and 115% of Zn concentration, respectively. Maize leaves found higher toxic metals contents than the grains. Bose and Bhattacharya (2008) [8] investigated Wazirpur industrial area; northeast part of Delhi. They conducted a glass house experiment for heavy metal and found that harmful metal buildup was lower in grain than in wheat shoots. Each of these heavy metals were found to be within the acceptable limit. Heavy metals in 10% sewage sludge with 0.5 percent lime improved soils (USEPA). The metal content of plant matter increased as a result of sewage and sludge amendment. Five of the eight elements identified in 30 percent sewage sludge amendment above the phytotoxicity limit, namely Zn, Cr, Ni, Cd, and Pb. Alcantara *et al.* (2009) [1] reported chemical changes and toxic metal partitioning in a highly weathered cultivated soil with maize crop with application of domestic and factories sewage sludge. They find out that the levels of Fe, Mn, Zn, and Cu in maize grains and leaves increased with the various type and rate of sewage sludge application. Similarly, compared to both control and DAP fertilizer treatments, Rusan and Athamneh (2009) find out that adding original and Cd enriched sewage sludge to radish boosted shoot N, P, and K content. All rates of original and Cd enhanced SS, ranging from 40 to 160 tonnes sewage and sludge ha^{-1}, resulted in greater N, P, and K concentrations in the shoots and tubers. The increased amounts of accessible nutrients in the soil following sewage sludge application is primarily responsible for the increased plant concentrations of N, P, and K. Similarly, the concentrations of Fe, Cu, Mn, and Zn in the plant changed according to sewage and sludge application. In the mustard-wheat cropping system, Balan *et al.* (2010) [7] recorded hazardous metal bioaccumulation and transfer with soil-plant interactions. The results showed that Cd concentration increased with the enhancing fertility level. The second year of cultivation had a higher Cadmium level in wheat grain than the first. Singh *et al.* (2012) [50] reported the influence of sewage and sludge application on toxic metal accumulation in the marigold plant. Sewage and sludge was application @ 0, 5, 10, 15, 20 and 30 t ha^{-1} to the soil under the greenhouse experiment. The Cd content gradually increased with the addition of 20 t ha^{-1} and higher doses of sewage sludge. The highest content of Cd, Cr, Pb, and Ni was found with the application of sludge 30 t ha^{-1}, which showed an increase of 35, 10, 98, and 87% respectively, over their respective controls. Hamidpour *et al.* (2012) [20] studied that the levels of Zn and Cu in wheat grain produced in sewage sludge plots were higher than in wheat grain cultivated in control plots. Wheat planted in sewage sludge plots had lower Cu concentrations in the stalk than wheat cultivated in control plots. Plants grown on control soil had zinc and copper concentrations of 25.6 and 4.3 mg kg^{-1}, respectively. While grain concentrations of this heavy metal were in the range of sufficiency in soils treated with sewage sludge (27-150 and 5-30 ppm for Zn and Cu, respectively). The significance of applying low quantities of compost to improve grain Zn and Cu contents was demonstrated by these findings. Wolejko *et al.* (2013) [14] investigated the hazardous metal buildup in lawn grass using two different concentrations of sewage and sludge control, 7.5 kg m^{-2} and 15.0 kg m^{-2}. Cd (80.0 percent) had the greatest variance in heavy metal level in plants, with contents ranging from 0.2 to 0.6 ppm dry matter (DM). The highest levels of cadmium were found in samples of sewage sludge with the concentration, whereas the lowest levels were found in treatment without the use of sewage sludge. Zinc, on the other hand, had the lowest factor of variation (13.5%) in plants, with concentrations ranging from 46.6 to 55.9 ppm DM. When increasing concentrations of sewage sludge were applied to plants, the lead concentration in the above-ground sections of the plants dropped. When increasing doses of sewage sludge were applied to plants, the lead concentration in the above-ground sections of the plants dropped. Meena *et al.* (2013) [36], studied the combination application of FYM and sewage sludge increased crop nutrient uptake. In comparison to control by bajra (49.2, 53.2, and 60.3 kg ha^{-1}, respectively) and rape, total uptake of N, P, and K was greatest under FYM10 t ha^{-1} + sewage sludge 10 t ha^{-1} (113.6, 41.0 and 90.6 kg ha^{-1}, respectively). The combined application of FYM and sewage sludge at a lower rate may have had a positive impact on soil biological and chemical characteristics, increasing root demand for nutrient absorption. Roy *et al.* (2013) [46] investigated the impact of sewage sludge on the content and uptake of nutrients and harmful metals in spinach. The combined use of sewage sludge @ 11.2 g kg^{-1} and 50% RDF considerably boosted Fe, Cu, Mn, and Zn content and absorption in spinach. Pb was the only detectable heavy metal found in spinach among hazardous metals (Pb, Ni, Cr, and Cd). Using sewage sludge, Manas and Heras (2018) [34] investigated the uptake of nutrients in wheat crops. When sewage sludge was used instead of commercial fertilizers and compost, wheat grain uptake of P, K, Mg, Fe, Cu, and Zn was shown to be higher.

3.2 Effect of sewage sludge on heavy metals concentrations in plant

Kabata-Pendias and Pendias (1984) [27] reported harmful, key content levels of heavy metals in plant parts Mn 300 to 500, Cu 20 to 100, Zn 100 to 400, Pb 30 to 300, Ni 10 to 100, and Cr 5 to 30 ppm. Magnicol and Beckett (1985) demonstrated in a composite study that the critical level of heavy element toxicity in plant parts causes a 10% reduction in plant dry matter output. The following levels (ppm) were found in plants: Cd 8-25, Cr 28, Co 10-20, Cu 10-20, Mn 100-400, Ni 10-20, Zn 150-300. For Zn, Cu, Cd, Pb, Ni, and Cr, the critical concentrations (mg kg^{-1}) for growing crop are 2500, 1000, 20, 750, 300,750, and the necessary values are 3000, 1500, 40, 1000, and 400 ppm, respectively, according to CEC (1986). The European Union has set a cadmium concentration limit of 0.2 ppm fresh weight of plant in grains, and 3 ppm in soil (European Commission, 2001) [18]. The EU standard for cadmium in maize forage fodder is 1.14 parts per million of dry matter of the plant (European Commission, 2002) [17].

4. Effect of sewage sludge on soil properties

Deshmukh *et al.* (2004) [15] used an onion as a test crop to investigate the effects of various sludge components on the physic-chemical properties of black soil in a pot experiment. According to the findings, sewage sludge increased the pH and electrical conductivity of post-harvest soil samples. There was also an increase in available key nutrients (N, P, and K), micronutrients (Fe, Mn, Zn, and Cu), organic carbon content, and heavy metals (Pb, Cd, and Ni). Hamuda and Ligetvari (2011) [21] studied the effects of sewage sludge on organic matter and soil biological activity in clay loam brown forest soil were studied by. With the sewage sludge application, they saw an increase in organic carbon content and microbial population. Rakshit *et al.* (2015) [45] looked at the impact of super-optimal fertilization on soil microbial abundance and biomass during different phases of wheat crop development. The microbial population and biomass in the soil were found to be considerably altered by crop growth stages. At 75 days after sowing in pearl millet, Dotaniya *et al.* (2014) [16] measured maximal dehydrogenase activity (37.48 g TPFg-124 h^{-1}) and alkaline phosphatase activity (0.546 mg PNP g^{-1} h^{-1}). Dotaniya *et al.* (2014) [16] recorded higher EC, organic carbon (0.44%), available nitrogen (50.17 kg ha^{-1}), potassium (268 kg ha^{-1}), dehydrogenase, urease and alkaline phosphatase activities with the application of sewage sludge @ 1.5% (w/w) as compared to control treatment. They noticed decreased pH in sewage treated plots as compared to control. Likewise, Mondal *et al.* (2015) [39] studied the short-term effects of sewage sludge application under cowpea-wheat cropping system. They recorded the highest mineralizable N, available K, organic carbon, microbial biomass carbon, and dehydrogenase activity at each depth in sewage sludge-treated plots (sewage sludge @15 t ha^{-1}). Antoniadis *et al.* (2015) studied N, P & K availability in manure and sewage sludge applied to soil for two years and observed higher soil organic matter, Olsen P, exchangeable K, ammonium N, yield and N, P & K uptake with treatment SS-3 (60 Mg dry weight sewage sludge per ha) and M-2 (32 Mg dry weight FYM ha^{-1}). Later these findings were confirmed by Kepka *et al.* (2016) [29] and recorded an increase in the content of organic carbon, total nitrogen, and available phosphorus, potassium, and magnesium with the application of municipal sewage sludge under spring barley at a dose of 5.34 Mg ha^{-1} DM. Meena *et al.* (2016) [38] determined the impact of municipal solid waste compost and chemical fertilizers on soil characteristics in a mustard-pearl millet cropping system at CSSRI, Karnal. They discovered that the T9 treatment [25 percent RDF + RSC (rice straw compost) @ 3.5 t/ha + GEC (gypsum enriched compost) @ 3.5 t/ha + MSWC (municipal solid waste compost) @ 4 t/ha] significantly increased organic carbon, NPK, microbial carbon biomass, dehydrogenase activity, alkaline phosphatase activity, and urease activity. Islam and Borthakur (2016) [24] recorded at flowering stages, higher soil microbial biomass carbon and enzymatic activities in rice crop. Angina *et al.* (2016) revealed that the application of sewage sludge induced significant changes in soil chemical properties. Sewage sludge significantly decreased soil pH. Soil organic matter and other macro plus micronutrients and heavy metal concentration (within permissible range) were obtained with the dose of sewage sludge @ 10 kg of dry matter per plant as compared to control. Samra *et al.* (2017) found that applying sewage sludge to soils at 30 g kg^{-1} and 10 g kg^{-1} significantly increased EC, soil accessible NO_3-N and P, biomass yield, and total plant uptake of practically all nutrients. Meena *et al.* (2018) [37] proposed combining municipal solid waste compost and mineral fertilizer to improve soil fertility. Over three years, they observed improved yields, Olsen-P content, soil organic carbon, and biological activity using MSWC @ 8 Mg ha^{-1} + RDF-50 percent as compared to control for both crops (mustard-pearl millet) (Usman *et al.* 2012) [53]. Baccar *et al.* (2018) [6] found that sewage sludge application resulted in significant changes in soil characteristics. With increasing doses of sewage sludge, he observed lower pH and increased EC. In comparison to control, sewage sludge application @ 18 t ha^{-1} resulted in higher NPK content of 0.42 percent, 77.21 ppm, and 1066.2 ppm. The amount of nitrogen and phosphorus in wheat shoots and grains increased as sewage sludge rates increased. The sewage sludge application @ 18 t ha^{-1}, on the other hand, resulted in greater N content in the shoot (4.16 percent) and grain (14.03 percent), as well as P content in straw (0.07 percent) and grin (0.10 percent).

4.1 Effect of sewage sludge and inorganic fertilizers on soil nutrients build up in soil

Azam *et al.* (2003) [5] studied and concluded that sewage sludge considerably boosted the mobility of nitrogen to plants. The increased availability of soil N and free-living microorganisms due to N_2 fixation contributed to the other plant component N in sludge-treated soil. The use of inorganic nitrogen boosted the accessible form of nitrogen to plants derived from soil organic carbon and sewage sludge. The results showed that utilising sewage sludge on rice fields can save a lot of nitrogen fertilizer. Ananda *et al.* (2006) [2] investigated the impact of sewage sludge on nitrogen input output balance and micronutrient status in paddy-groundnut cropping system soils after crop harvest. The findings revealed that organic nutrient sources significantly enhanced the status of micronutrients in the soil as compared to the control. Fe, Cu, Zn, and Mn were all increased to a range of 20.6 to 32.1, 1.21 to 1.41, 1.72 to 2.45, and 29.4 to 37.8 parts per million, respectively. Sridhar *et al.* (2006) [51] used a greenhouse experiment to see how the combined use of sewage sludge and mineral fertilizers affected the release behaviour of major nutrients over time. They used four different levels of sewage sludge (0, 10, 20, and 30 t ha^{-1}); and four different levels of N, P & K fertilizer (0, 50, 75 and 100 percent of the recommended rate). The release behaviour of main nutrients (N, P, and K) increased dramatically with increasing quantities of sewage sludge and fertilizer over various times of incubation. The highest concentration was found in 30 t sewage sludge ha-1 with 100% of the prescribed N, P & K fertilizer rate, whereas the lowest amount was found in the control treatment with no sewage, sludge and fertilizer applications.

4.2 Effect of sewage sludge on heavy metal accumulation in soil

Silva *et al.* (2006) [49] measured overall hazardous metal levels in soil, leaves, and grains, as well as accessible Cu, Mn, Ni, Pb, and Zn levels in maize. They found that sewage sludge application increased the DTPA extractable Cu, Mn, Ni, Pb, and Zn contents in soil and plants, and that the toxic metal content in sludge and sewage sludge application increased the toxic metal content in sludge and sewage sludge application increased the DTPA extractable Cu, Mn, Ni, Pb, and Zn contents in soil and plant. They also discovered that plots treated with sewage sludge had greater levels of total heavy metals in the soil. Singh *et al.* (2012) [50] investigated the effects of sewage and sludge application at 0, 5, 10, 15, 20, and 30 t ha^{-1} on hazardous metal bio-accumulation in marigold after-crop soil. The findings revealed that without water sludge application in soil, the content of accessible Pb, Zn, and Cr in after crop harvest soil increased significantly; however, cadmium was not identified. The concentrations of available Pb, Zn, and Cr ranged from 1.55 to 3.23, 0.90 to 4.48, and 0.17 to 0.29 ppm, respectively. In the treatment with 30 t ha^{-1} sewage sludge, the maximum accessible Pb, Zn, and Cr were reported. When compared to their respective controls, it was 52, 80, and 41% greater. Nickel and lead concentrations in rice after-crop harvest soils with varying degrees of sludge ranged from 0.84 to 3.57, 0.11 to 0.58, 5.78 to 9.20, and 0.28 to 3.25 ppm, respectively. As sludge was added to rice at a rate of 40 t ha^{-1}, the levels of Cd, Cr, Ni, and Pb increased by 4, 5, 2, and 11 times, respectively, when compared to control. However, compared to control, only a two-fold rise in Cd and Ni was reported in wheat soils following crop harvest. The available Cr and Pb concentrations were below the AAS detection limit. Sludge application had a considerable residual influence on accessible Cd content in soil, which increased from 0.28 ppm in control to 0.62 ppm in S40 (40 t ha^{-1} SS). With the exception of S40, Ni content varied from 1.69 to 3.60 ppm, with no notable fluctuation. The study looked at how sludge application increased the quantities of accessible heavy metals in soils. Because of the addition of sludge and the growing of rice in puddled circumstances, the accessible heavy metals in soil were increased.

5. Future perspectives

Finally, it is critical to continue and improve local implementation of SS and biosolids, whether to amend and recover degraded soils or to support the phytoremediation process of metal-contaminated soils, combining the ease of availability of these discarded bioresources with an assessment of their potential to promote agrosystem sustainability as a future goal. It's crucial to weigh the advantages and disadvantages of utilising these bioresources, and more research is needed into the involvement of indigenous food crops, bioenergy potential, and alteration requirements. Until now, a critical worry that has received little attention in this subject has to be considered: the likelihood of metal leaching from long-term SS and biosolids applications. Although if it is used in strict compliance with the law and under strict supervision, more research is required.

6. Conclusions

Despite the numerous advantages of sewage sludge in terms of increasing soil chemical characteristics, agro-morphological features, and yields in diverse crop species, appropriate heavy metal screening is necessary in all forms (SS, soil, and food items). Agricultural products exhibited alarming values for human food consumption in underdeveloped countries, which could have substantial health ramifications, despite the fact that the bulk of the data presented in this study were within legal limits (in the case of soil and SS). To avoid pollution of agricultural soils, the use of SS and biosolids in these circumstances demands tight rules and regulatory oversight. Furthermore, the use of this bio-resource in food production and as a soil amendment must be strictly controlled. It is critical to add value to waste products, with biosolids being one of the most crucial due to the vast amounts of this residue produced around the world.

7. References

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