Chapter

Influence of Sewage Sludge and Heavy Fertilization on Nitrate Leaching in Soils: An Overview

Sidra Sohail, Muhammad Fraz Ali, Usman Zulfiqar, Saddam Hussain and Shaharyar Khosa

Abstract

Sewage sludge is now widely used for production of crops throughout the world. Utilizing the sewage sludge for crop production has various advantages such as nutrient recycling, reducing the need for mineral fertilizer, increasing organic matter amount in soils, and improving physical properties of soil. A large amount of sludge is generated during the sewage treatment process, and it is disposed off on land in the form of fertilizer or soil conditioner. In this, heavy metals are usually in greater concentration than in soil, which is one of the main problems which restricts its utilization as a fertilizer. Nitrate leaching and heavy fertilization cause serious problems for the groundwater and this issue of nitrate leaching is usually neglected. Continuous used of swage sludge cause contamination of soil and water and affects plant growth and soil microorganisms. In this chapter, we have focused on i) various factors which affects nitrate leaching in soil, it includes soil texture, rate of fertilization, season and climate, ii) strategies to reduce nitrate leaching and iii) nitrogen conversion mechanism in sewage sludge.

Keywords: sewage sludge, nutrient source, nitrogen conversion, nitrate leaching

1. Introduction

Nitrogen (N) is essential nutrient in agricultural system that influences various aspects of agroecosystems and other ecosystem services that are mainly depended on nitrogen availability in soil system [1, 2]. Nitrogen plays a cardinal role in the agroecosystem and energy balance of the Earth so any kind of change in nitrogen cycle will bring negative impacts on agroecosystem and health of other living beings [3]. Agroecosystems are extremely complex and have entangled webs of interactions between different plants, microorganisms, and soils, identifying critical components in crop production remain indescribable [4]. Consequently, understanding nitrogen fate in agroecosystems is really challenging.

Nitrogen plays a crucial role in life cycle of plants [5]. It is also involved in several critical processes, like growth, expansion of leaf area, production of biomass and increase in yield [6–8]. Agricultural crop production and yield mainly depends on N availability for protein synthesis [9], chlorophyll, photosynthesis and many other essential processes in plants [10]. Insufficient availability of N to the plants can hinder their growth and development. Nitrogen improves plant root growth, increase root volume, area of root, root diameter, total root length, root dry mass and subsequently enhance uptake of nutrients and dry mass production [11–13]. Nitrogen is lost from the agroecosystems in different forms like nitrate and nitrous oxide that contaminate aquatic ecosystems and also contribute to the climate change [14].

About 80% of the atmosphere is composed of N_2, that is relatively inert gas, it is further converted into other reactive forms of nitrogen like nitrate (NO_3^-) and ammonium (NH_4^+) through biological and industrial processes, to satisfy nitrogen requirement of crops [15, 16]. Nitrogen more important in the agricultural systems [17], nitrogen is added to sustain crop growth and improve yields that is a fundamental feature of modern crop management [18]. On the other side, there are some significant costs that are associated with the agricultural nitrogen additions. Nitrogen is mobile in nature [19], it is hard to sustain, even nitrogen that is conserved by the plants and taken away in harvesting eventually makes the way to return back to environment [20, 21]. Most of the nitrogen that is mobilized from the agricultural systems is highly reactive in nature; it is available in biologically active forms in soils and surface waters and chemically reactive forms in the atmosphere [22].

The main problem is excess of N that lead to N losses. This is difficult to supply precisely enough N to full fill plant physiological requirements while controlling reactive N fate to avoid losses into the environment [23, 24]. As agricultural system is responsible for food supply, and it leaks too much nitrate, causing degradation of aquatic ecosystems [25]. Nitrogen also loss in the form of gas from agroecosystem as ammonia, nitrogen oxides, and nitrous oxide that reduce quality of air and account for much contribution to the climate change [26, 27]. Therefore, there is an urgent need to make an agroecosystem that efficiently retain more nitrogen and that must remain productive as well as resilient to face changes of climatic conditions.

Nitrogen that is present in mineral forms are more prone to losses i.e. ammonia volatilization (loss of NH_3 from soil surface), denitrification and/or losses of nitrogen gasses (dinitrogen gas and nitrous oxide) and leaching (nitrate) [28]. Loss of nitrogen via leaching mainly occur in the nitrate form but sometimes NH_4^+ leaching may occur in light texture soils [29]. There are some other factors which are also involved in nitrate leaching. Irrigation amount and its distribution is responsible for nitrate leaching below plant root zone in the soil profile [30]. Soil structure may also affect movement of nitrate within the soil profile [31]. Sandy soil has poor soil structure so chances of leaching are more in sandy soils as competed to clayey soils having a good soil structure [32]. Additionally, macrofauna in the soil is also responsible for this phenomena, movement of macrofauna and growth of root allow speedy movement of nitrate in the soil profile [33].

There are many strategies to overcome nitrogen losses from various sources. Nitrate leaching risk is primarily reduced by decreasing inorganic fertilizers application and changing irrigation methods [34]. There are some other approaches that proved to be helpful in reducing nitrate leaching i.e. growing grass cover, application if controlled-release nitrogen fertilizer, nitrification inhibitors, organic amendments, etc. In recent years, organic amendments are being used by the farmers as soil improver. A well-known organic amendment sewage sludge (SS) contain nitrogen in higher amounts hence SS can be applied instead of inorganic fertilizer to provide sufficient nitrogen that is required to plants for growth and development. Sewage sludge contains 60% of total nitrogen in organic form and rest of 40% in present in mineral form [35]. Mineral N is released during decomposition of organic matter that is further immobilized in organic forms [36]. Organic form of nitrogen is slowly released into the soil, hence it reduces risks of groundwater contamination with nitrates [37]. Applying of sewage sludge into the soil improves texture of soil and slow down nutrients release from the soil. Sewage sludge is very useful in reducing nitrate losses from soils as it improves soil NUE for a sustainable production of crops. Sewage sludge plays a vital role in building up soil OM, increase fertility of soils and improve soil retention of inorganic N-forms e.g. nitrate. Heavy fertilization is a common practice used by farmers to obtain higher yield. Indiscriminate application of inorganic fertilizers are polluting our natural resources. This chapter reviewed the measures and methods to reduce leaching of nitrate from the agricultural soils. This review brings further insight to the role of sewage sludge to reduce leaching of nitrate from the soil by improving soil attributes.

1.1 Excessive use of nitrogen fertilizers

Nitrogen is a deficit nutrient in most of the agricultural soils [38, 39] and it is recommended to use nitrogen mineral fertilizer as external inputs for improving crop growth and yield [40, 41]. Many leguminous crops and soil microorganisms took part to fix nitrogen available for plant uptake [42]. However, to meet the target yields this is inadequate, so farmers are dependent on synthetic nitrogen fertilizers. Fertilization with these chemical fertilizers in excessive amounts is harmful to the environment [43], it causes an imbalance of several ecosystems' functions and services [44]. For sustainable agriculture and the ecosystem, judicious application of fertilizers plays major role.

Nitrogen fertilizer management has a vital role in sustainability, by reducing its various losses and enhancing nutrient uptake [45]. juidicious application of nitrogenous fertilizers and management of irrigation water are important practices that are helpful in reduction of nitrate leaching into the groundwater and they also improve NUE. Under current circumstances, integrated nitrogen management and balanced fertilizers use is needed. Gu et al. [46] conducted lysimetric research to monitor the role of irrigation and fertilization in nitrate leaching, results concluded that heavy fertilization of N fertilizer (urea) with high levels of irrigation led the nitrate leaching. It was also reported that manure applications have less N leaching than the urea application. The higher the N fertilizer rate, there will be more chances for leaching out with drainage, especially if the crop does not respond. Delin and Stenberg, [47] checked the role of heavy N fertilization on nitrate leaching and reported that if the N fertilizers were applied at higher rates when crop response was minimal then nitrate was leached down with drainage and nitrate leaching increased exponentially with heavy fertilization. Jia et al. [48] observed that application of higher N fertilizer rates at maize crop showed higher nitrate concentration in leaching water, which makes it dangerous pollution for underground water. Higher nitrogen fertilizer rates, irrigation water, and their interaction affected both leaching and volatilization losses of nitrogen.

Raveendrakumaran et al. [49] evaluated the leaching behavior of various fertilizers on spinach crop and reported that nitrate leaching were inclined type of fertilizers and their application frequency. Frequent split uses of urea are beneficial in reducing nitrate leaching. Klaus et al. [50] observed a negative relation between nitrate leaching risk and legume cover; according to them, the reason was that legume cover has higher land use intensity and decreased plant density by high rates of nitrogen fertilization. Nitrates are most commonly found in agricultural land as a result of inorganic fertilizers i.e. urea.

Nano fertilizers are best options to control nitrate leaching in the agriculture field. Nano fertilizers increase fertilizer use efficiency as it facilitates nutrients availability to the plant leaves. A study by Alimohammadi et al. [51] evaluated effect of urea fertilizer with nano-nitrogen chelate (NNC) on nitrate leaching in soil and it was reported that use of nano nitrogen fertilizer decresed leaching of nitrate to minimize special effects of nitrate leaching in crops, environment and human health as compared with urea. Loss of ammonia gas from urea fertilizer significantly decrease efficiency of urea-nitrogen fertilizer [52]. Latifah et al. [53] reported that when urea is mixed with zeolite and sago wastewater, it is even more beneficial than mixing urea alone because it encourages ammonium and nitrate ions formation over ammonia gas. They confirmed that use of this mixture makes nitrate available within soil and it also improved exchangeable ammonium retention.

2. Nitrogen conversion mechanism

The process of conversion of ammonium (NH_4^+) via nitrite (NO_2^-) into nitrate (NO_3^-) is called nitrification [54]. During nitrification, ammonia is converted into nitrate through oxidation and microorganisms from two different genera are involved in this process. For example, ammonia-oxidizing bacteria (AOB) nitrosomonas,

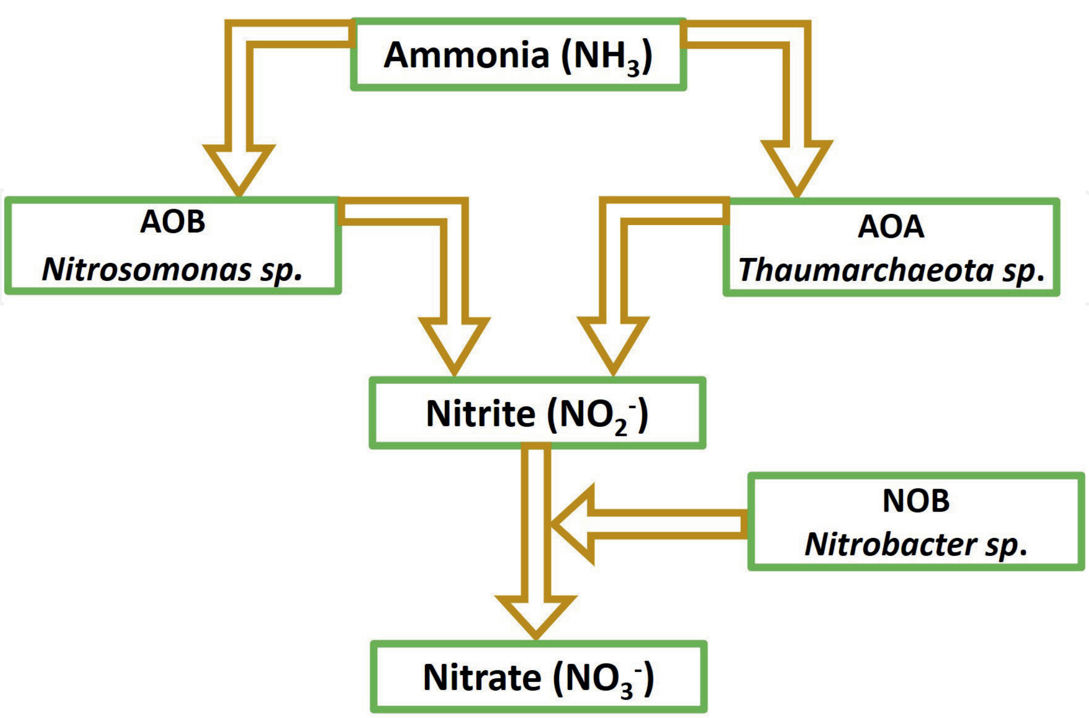

Figure 1.
Nitrogen conversion mechanism.

ammonia-oxidizing archaea (AOA), and nitrite-oxidizing bacteria (NOB) nitrobacter [55]. These bacteria are autotrophic having mutual symbiosis. [56].

In the first step ammonium oxidation into nitrite is done by AOB and AOA [57]. The reaction of ammonium oxidation takes place by ammonia monooxygenase (AMO) enzyme [57, 58]. Ammonia-oxidizing archaea (AOA) are usually present in larger numbers in soil but are less important than AOB. In nitrogen-rich agricultural soil systems, AOB are found in abundance, on the other hand, AOA are mostly found in low fertile environments [59, 60] (**Figure 1**).

The second step is the oxidation of nitrite into nitrate (final product). This is done by nitrite-oxidizing bacteria (NOB) (**Figure 1**) i.e., Nitrosomonas. This conversion process of NO_2^- to NO_3^- occurs very speedily hence accumulation of nitrite in soil takes place rarely. Or this whole process of nitrification is done by recently discovered commamox bacteria (complete ammonia-oxidizing bacteria) involves in direct oxidation of ammonia into nitrate [61].

3. Factors affecting nitrate leaching

3.1 Soil texture

Nitrate leaching is strongly inveigled by the texture of soil [62], different soils have different flow rates of nitrate leaching [63]. It is crucial to have knowledge about soil texture while studying nitrate leaching mechanisms. The permeability of water depends upon soil structure and texture [64, 65]. Macro pores within the soil interconnect and make channels for nitrate leaching. Therefore, leaching losses are more in coarse texture or sandy soils just because of their macropores [66]. Clayey and silty textured soils have slow nitrate leaching rates these are favorable for denitrifications. Kasper et al. [67] observed effects of different soil textures on nitrate leaching and reported that rate of nitrate loss was low in silty loam as compared to silty clay loam and sandy loam soil texture. Rainfall is a considerable factor in this leaching while keeping in mind that well-drained soils are prone to high nitrate leaching [68]. Because sandy soils have large pores and high infiltration rate when fertilizers are applied in larger amount, these macropores made the leaching of nitrate easy [69]. So, the texture of soil should be improved for retention of fertilizer and water. This will ultimately reduce nitrate losses, cost of fertilizers, yield loss and protect the environment from pollution.

3.1.1 Season and climate

Season and climate are important factors for nitrate leaching [68]. Nitrate leaching is usually more during time period of late autumn, early spring and winter [70] because in these seasons temperature is low and uptake of nitrate by plant is slow [71]. Due to high precipitations drainage is more in soils. Rainfall during autumn results in the leaching of residuals of fertilizers [72]. During dry summers, nitrate accumulated in surface soil reason is lower uptake of nitrogen and plant growth, this nitrate leached over the upcoming winter. After dry summers, rewetting of dry soils can boost up the rate of mineralization hence more nitrates are leached [32]. Heavy rainfall after fertilizer application can cause leaching in the root zone. On the other hand in tropical areas, summer monsoon rains cause a greater loss of nitrate as compared to winter rains [73].

3.1.2 Agricultural drainage systems

The agricultural drainage systems also conribute in nitrate leaching [74]. Leaching losses are more under efficient drainage systems because of high N mineralization. They also help to shorten the distance traveled by nitrate into rivers and lakes through the soil [75].

3.1.3 Soil organic matter

Soil organic matter and its mineralization have a great role in nitrate leaching [76]. Unfertilized lands or fallow soils have high rate of nitrate leaching as compared to fertilize lands [77].

3.1.4 Earth worms

Earth worms create macrospores when they move along the soil. Those pores help in plant root penetration as well as nitrate is leached quickly through these pores. So nitrate losses are more [78, 79].

4. Strategies to reduce N losses

By adoption of local and scientific means, recovery of nitrogen can be improved that ensure efficient use of fertilizers, irrigation, crop as well as land. It helps to improve beneficial uses of N fertilizer for crops and also reduces losses through leaching [13, 80]. For management of nitrogen following strategies can be used (a)Beneficial use of native soil nitrogen, as well as externally applied N fertilizers [81, 82] (b), conserve nitrogen present in soil by reducing its losses via different mechanisms and to enhance the utilization of nitrogen that is conserved in soils for grown crops [83] (**Table 1**).

4.1 Integrated nitrogen management

Integrated Nitrogen Management (INM) means optimal application of nitrogen inputs i.e. biological nitrogen fixation (BNF), chemical fertilizers, resides of crops, organic fertilizers [84]. Better root growth, higher supply of secondary and micronutrients, and optimum soil environment can be achieved by integrated use of N either Organic or inorganic. Interaction of N with micronutrients and secondary nutrients increases NUE and improves crop yields [85].

4.2 Enhance fertilizer use efficiency

Increasing fertilizer use efficiency (FUE) can be achieved by minimizing nutrient losses. Some fertilizers are based on two important ideas either (a) slow nutrient release or (b) nutrient transformation and reduction in their losses [85, 86].

4.3 Slow-release fertilizer

Slow-release fertilizers have the potential to reduce losses of nitrogen by delaying patterns of N release [87]. They increase NUE and management between

Crop	Sewage Sludge Rate	Effect on Soil Properties	Effect on Crop	Reference
Mung bean	6; 9 and 12 kg m^{-2} (SSA)	decrease pH; increase organic carbon; increase total iron and heavy metals	Increase Contents of Pb, Cd and Ni in grains; increase in plant shoot length, leaf area and plant total biomass	[102]
Cucumber	25; 50; 75; 100 and 124 t ha^{-1}	Increase Soil EC; Increased soluble cations and anions; Increased available phosphorous, micronutrients and heavy metals; decreased soil pH and HCO3-; improved soil physical properties (sandy and calcareous soils)	Increased macro- and microelements in cucumber leaves and fruit; Improved number of cucumber fruits	[103]
Sunflower	9; 18; and 36 Mg dry weight ha^{-1} $yr.^{-1}$		improved vegetative growth of sunflower; enhanced achene yield; decreased achene oil concentration; increased achene N concentration	[104]
Durum Wheat	20; 30; and 40 tons ha^{-1} (dry sludge)		improved grain yield and other components of yields; upsurge in fertility of spike and yield of straw;	[105]
Sunflower	15; 30; 60 and 120 t ha^{-1} (dehydrated SS)	soil pH decreases; soi EC increased; increase mineral N and available phosphorus;	Vegetative growth increased; Increased in dry biomass accumulation; increasedCO_2 Net assimilation; stomatal conductance and decresed transpiration rates;	[106]
Wheat	0;10; 20; 30; 40 and 50 g kg^{-1} (dry sludge)	Increased the soil OM content; decreased pH of soil; increased physicochemical properties of soil	Increased soil fertility and improved crop production; Increased heavy metal accumulation in wheat (except grains Cr and spikes Pb)	[107]
White Radish and Green Beans	22 kg Kala compost with treated waste water	Increased EC and decreased pH; Increased total organic carbon; Increased heavy metal contents except Fe	Increased growth and productivity of vegetables No metal toxicity detected in both crops;	[108]

Crop	Sewage Sludge Rate	Effect on Soil Properties	Effect on Crop	Reference
Wheat	10; 20; 40; 60; 80 and 100 t ha^{-1}	decreased pH; increased soil OM, EC, NPK, Ca, Mg and some other trace metals like Fe, Cu, Mn and Zn	Increased crop yield and yield components as compared to control treatments	[109]
Wheat	control (As 50 mg kg-1); SS (30 g kg^{-1}) + TU (6.5 mM) + As; TU + As; SS + As		SS + TU improve carotenoids, P and K uptake in wheat; SS + TU decreased POD, SOD and APX in wheat under As stress	[110]
wheat-white head cabbage-tomato	10; 20; 30; 40 and 50 tons sludge ha^{-1}		crop yield and yield components were increased (wheat, white head cabbage and tomato) with increasing SS application rates as compared to untreated control	[111]
Wheat	10 ton per hectare		Increase spikelets/spike and number of grains/spike	[112]
Palak (*Beta vulgaris*)	22.4 g kg^{-1} soil of sewage sludge from 3 locations	significant build-up in DTPA-extractable micronutrient and heavy metal over control; increase of N, P and SOM for production of crop	Increase in micronutrients and heavy metal accumulation; biomass yield of Palak was significantly increased	[113]
Ridge Gourd (*Luffa acutangula* (L.) Roxb.)	Sewage Sludge and Plant Growth-Promoting Rhizobia		improve seedling, plant biochemical response, ridge gourd yield; improved production of crop and recycling of nutrients;	[114]
Barley	0, 4, 8 and 12 t da^{-1} of Sewage Sludge		sewage sludge is effeicinet way to increase yield and metal content (Na, K, and Ca) of grain of barley	[115]

Table 1.
Effect of sewage sludge on soil characteristics, growth and yield of crop.

nitrogen demand of crops and nitrogen supply capacity of soils. Nitrogen losses depend on the form of applied N fertilizers which affects nitrogen available with its recovery [32]. Now a days, neem coated urea fertilizer is used as slow-release N fertilizer [88, 89].

4.3.1 Nitrification inhibitors

Conversion of NH4+ into Nitrate can be inhibited by these inhibitors. With the help of soil MOs, reduce the accumulation of NO3- in soils. Dicyandiamide (DCD) is used as inhibitor (useful in nitrification inhibition) [90]. Neem cake is used as efficient nitrification inhibitor [91]. By using such fertilizers, nitrate leaching can be reduced.

4.3.2 Urease inhibitors

Delay hydrolysis of urease is important because higher amount of nitrogen residual in the soil system can cause problems for environment. UIs help to inhibit urea hydrolysis and reduce nitrate losses [92].

4.3.3 Improved methods of N application

Well-known/common practice broadcasting is the reason for large amount of Nitrogen losses. In rice field where puddling conditions are created, mud balls techniques are used to place urea inside, this enhances recovery of N and crop yield [93]. Deep placement is also a well-known method to avoid N losses [94]. Foliar spray of fertilizers is absorbed by plant surface i.e., urea spray not only improves NUE but also reduced chances of N losses through runoff, denitrifications, and volatilization [81, 95].

4.3.4 Crop rotation and catch crops

Losses of nitrogen in the form of leaching can be reduced by growing cover crops [96–98] or catch crops for example cereal rye, ryegrass, oats, clover, oil-seed radishes etc. Leguminous crops with lower N demand and those having low water requirements like tees are the best options to grow for reducing N-use and nitrate leaching [70, 99].

4.3.5 Treatment of well waters

Wells water should be properly checked either having high nitrate contents or not. If yes then treatments should be done to remove leached nitrate or water should not be used for drinking purposes. It can be used as irrigation water for crops but use of N-fertilizer should be restricted while using well water with higher nitrate contents [100, 101].

5. Sewage sludge: a source of nutrient

Sewage sludge is a residual and semi-solid substance in nature [116], which is a by-product of different treatment stages of municipal (domestic, household) and industrial wastewater effluents, it is also known as bio-solids [116–118]. Untreated domestic wastewater is considered as pollution, and its production is increasing rapidly by urban industrial units which is increasing day by day [119]. The most common way to clean out this waste is its disposal in landfills which is harmful to both environment and public health [120]. Dealing it wisely as a valuable resource can reduce its harmful impacts on the environment. Only 1% of wastewater is found in sewage sludge when it is entered into the sewage treatment plant, digested anaerobically, and wastewater is removed from sludge [121] and if it is treated properly, it becomes bio-solid, organic material that is rich with nutrients [117, 122]. Treatment of sewage sludge is done to make sure that the residual is not the source of pathogens, then recycled sewage sludge is utilized as fertilizer for agricultural crops instead of disposing them off into landfills or water bodies. Sewage sludge has different organic and inorganic elements but a small number of heavy metals are also present in it [123, 124]. Through indiscriminate use, it continues to pollute land and groundwater and enters the food chain via crops and vegetables, damaging the environment.

When sewage sludge is added to the soil, it show beneficial impacts on fertility of soil [125]; it enriches the soil with nitrogen (N), phosphorus (P) and other vital micronutrients [126], improves soil physical, microbial, chemical, and enzymatic properties [127] that ultimately increase crop yield [128]. In different parts of the world, management strategies for sewage sludge are not implemented. Mohamed et al. [106] used dehydrated activated sewage sludge application on sunflower crop. It affected soil properties to increase mineral nitrogen, available phosphorus and soluble potssium. High levels of N and P in sewage sludge explain the beneficial effects on growth of sunflower crop. When Sunflower crop was treated with sludge it showed the highest yield of sunflower seeds. The higher yield was associated with increase in number as well as weight of sunflower seeds.

Throughout the past few years, the use of sewage sludge in agricultural and cropping activities has become broadly accepted as an efficient way to improve crop growth. Khaliq et al., [108] conducted an experiment and it said that 'Kala compost' is a good soil media for production of higher yield in contrast to synthetic fertilizer i.e. NPK. They used "green beans and white radish" as a test crop and the result said that crop yield, total organic carbon, and chlorophyll contents in plants of green beans and white radish were increased when experimental soil recieved "Kala compost" as compared to fertilizer NPK. Soil and crops chemical analysis did not show accumulation of of heavy metals. Baawain et al. [129] and Onwudiwe et al. [130] conducted similar experiments in which their results showed that sewage sludge can improve soil physicochemical properties and it affect crop growth and yields. There are many micro and macronutrients in these fertilizers, which plants uptake to improve their physical and physiological performance and increase soil fertility [131].

The sewage sludge from wastewater treatment systems has become a crucial source of nutrients for urban and peri-urban farmers, predominantly because it is more readily available and cheaper than inorganic fertilizers. Gwenzi et al. [132] experimented to compare the three organic amendments; sewage sludge (SS), sludge biochar (SB), and their combination (SS + SB) to untreatmed control and synthetic fertilizers on maize crop. The results revealed when sewage sludge and sewage sludge biochar is applied to the soil, it significantly improved soil properties, maize growth, plant biomass productivity, and essential nutrients uptake, and reduced uptake of heavy metal. Biochar alone has low nitrogen because nitrogen is volatilized during its production process, so the application of biochar with sludge improves its nutrient content which after application improves soil properties and provides essential nutrients to plants [133].

Compost made from organic municipal solid waste (OMSW) or sewage sludge (SS) provides an opportunity to recycle plant essential nutrients, thus reducing requirement of inorganic/synthetic fertilizers in agriculture. Jamil et al. [109] said that organic fertilizer application (OMSW and SS) is useful in agricultural sustainability. They reported that OMSW and SS consists of several essential nutrients for plants like N, P, K, Zn, Cu, Fe, Mn, and some other trace elements. Debiase et al. [134] confirmed that SS application gives rise to yield of wheat crop 12% more than municipal solid waste. According to him, sewage sludge minimizes nitrogen leaching risk from the soil. Tyagi and Lo, [135] studied that water-activated sludge (WAS) is source of nutrients like nitrogen and phosphorus, when WAS is further solubilized and disintegrated it is converted into ammonia and phosphate possibly resulted in the formation of magnesium ammonium phosphate or struvite; a cost-effective fertilizer.

Sewage sludge amendment (SSA) improved different properties of soil and provide nutrients to crop. Zuo et al. [136] conducted an experiment to effect effects of SSA on soil physical properties, soil chemical properties, sweet sorghum crop yield, and quality in mudflat saline-alkaline soil that was newly reclaimed. Results said that SSA significantly improved plant biomass and crop gross energy content. SSA also elevated soil physical and chemical properties as it decreased soil bulk density, EC, pH, and increased organic carbon contents, water-stable aggregate fraction, CEC, N, and P contents in mudflat soil. Soua and Figueiredo [137] conducted a greenhouse experiment to observe possible effects of different SS biochar doses on soil fertility components and radish crop agronomic development, results said that N concentration in plant leaves was significantly increased that was improved because of higher nitrogen levels in biochar SS. This ultimately increased soil nitrogen in following forms i.e. NO_3^- and NH_4^+. The growth of radish was increased because of nutrients enrichment in the soil amended with biochar, foremost available-P, total-N, and exchangeable cations. According to Chu et al. [138] absorption of nitrogen is more in ammonium form than nitrate as the pH of the soil was almost neutral, neutral pH favors ammonium absorption.

Sewage sludge is used as an organic fertilizer for crop production. A better way to utilize waste is to use it as a resource. Addition of treated sewage sludge into agricultural soils increase fertility; it is a source of nitrogen in soil. Its utilization as an alternative to expensive inorganic fertilizer. But the condition is that SS should be used after its proper treatments, indiscriminate use can cause detrimental effects on soil, groundwater, and food chain.

6. Conclusions

Nitrate leaching is a major problem in certain soils owing to inequitable use of synthetic ferilizers. Moderate application of different organic amendments for example sewage sludge can supply available nitrogen and reduce the use of conventional synthetic fertilizers that may lead to reduced nitrate leaching. Sewage sludge is an organic source of nutrients, that not only provide nutrition to crops but also improve physico-chemical properties of soils and agro-morphological attributes and yields of different crops. It can replace mineral fertilizer in modern cropping systems. Prior application, there should be proper screening of sewage sludge for heavy metals or other toxic elements. Moreover, attention should be paid on nutrients amount as well as their ratio present in the sewage sludge that it can fulfill plant needs for growth and development. In addition, it is recommended for prolonged vegetation period because of slow release of esseantial nutrients. There is also a need for further studies on phytotoxic effects of sewage sludge.

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