Project Report

The impacts of microplastics in biosolids on land and water ecosystems through land applications in British Columbia

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Abbreviations

ALR	Agricultural Land Reserve Use Regulation
BC	British Columbia
CECs	Contaminants of Emerging Concerns
EMA	Environmental Management Act
FW	Fresh Water
LAP	Land Application Plan
MMP	Million Metric Ton
MP	Microplastics
OMRR	Organic Matter Recycling Regulation
PA	Polyamide
PES	Polyester
PET	Polyethylene Terephthalate
POPs	Persistent Organic Pollutants
PP	Polypropylene
RDN	Regional District of Nanaimo
UV	Ultraviolet

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Executive summary

The study provides valuable insights into the sources, distribution, and potential impacts of microplastics when biosolids are applied to agricultural activities. The findings indicate that in British Columbia (BC), about 182 – 293 million particles of microplastic (equivalent to approximately 0.21 – 4.3 tons in weight) could be released into agricultural land each year through the application of 29,000 tons of biosolid annually.

The presence of a large number of microplastics in agricultural ecosystems has negative effects on soil quality, food security and human health. It alters the water retention capacity, soil microbial functions, and immobilization of essential nutrients for plant growth. Moreover, these microplastics can enter the food web, potentially endangering human health. Additionally, microplastics have extensive impacts on both aquatic and terrestrial ecosystems due to their slow degradation, residual effects, and physical-chemical conversion over time.

Given the importance of food safety and health when consuming crops from urban farms and community gardens, it is imperative to urgently address the issue of microplastic contamination in biosolids used for these purposes. Serious action must be taken to mitigate the presence of microplastics and protect our ecosystems while ensuring food safety. The following recommendations are suggested:

(i) Applying high-quality composts or biosolids;
(ii) Reduce plastic waste and consumption;
(iii) Concern about the quality of irrigation water;
(iv) Improve awareness of microplastics in agriculture through urban farming; and
(v) Enhance the legal framework for biosolid output quality.

By implementing these recommendations, urban farming and community gardens can play a crucial role in reducing the presence of microplastics in agricultural systems, ensuring the safety of food production, and protecting the environment

The report also acknowledges certain limitations. The estimation of potential microplastics released into agricultural soils in BC relies on a literature review from previous studies conducted in other regions, which may not accurately reflect the specific biosolids production in BC. As well, due to the scope and timeline of this study, some significant findings from previous publications may have been missed. Therefore, further research focusing on specific biosolids production in BC is necessary, and practical experimental data should be gathered from the local farms to provide more comprehensive insights in the future.

In conclusion, the presence of microplastics in soils and plants resulting from the utilization of biosolids in agriculture poses a significant threat to human health and the environment. Urgent measures are required to mitigate microplastic contamination in biosolids, safeguard our ecosystems, and ensure the safety of our food production systems. The report suggests exploring feasible solutions to minimize microplastics in urban farms and community gardens, thereby addressing this critical issue. Further research and experimental data collection from farms in BC are essential for a deeper understanding of the problem and the development of effective strategies to tackle it.

1. Introduction

Microplastics have been tracked in many environments within the past decade, including surface water, wastewaters, soils, sediments, atmospheres, and even food chains. They are recently considered Contaminants of Emerging Concerns (CECs) that should be monitored in surface water bodies (Jain et al., 2021). Microplastics adversely affect the quality of the soil, including compromising the soil structure, affecting water retention capacity, pore size, hydraulic properties, soil conductivity, and soil microbiome (Arp et al., 2021; Maddela et al., 2023; Yu et al., 2022). Consequently, there may be indirect impacts on food security and safety (Prata & Dias-Pereira, 2023).

Studies have recently discovered that significant amounts of microplastic particles between 100 nm and 5 mm remain in treated sewage and treated sludges produced from wastewater treatment processes (Christian & Köper, 2022; Huang et al., 2023). The residual concentration of microplastics in treated sewage varies depending on the treatment technologies, locality, population size, and waste management practices (Lebreton et al., 2017). According to Golwala et al. (2021), the microplastic removal efficiency varies between 35 and 58% in the preliminary treatment and up to 97.8% after the three stages, which include the primary, secondary, and tertiary treatment. However, the actual removal efficiency may be lower because of the treatment efficiency, technologies, and components of influence wastewater (Gies et al., 2018).

By using various keywords, including “microplastics”, “soil”, “water”, “agriculture”, “weathering”, “biosolids”, and “sewage sludge” to identify relevant publications on ScienceDirect, the results indicate a stepped increase in microplastic research from 2018, while only a few publications existed before 2015. The number of publications related to microplastics increased from 7.6 times to 14.8 times in the last five years (2018 - 2022) (Fig.1). The studies associated with soil ecosystems have the highest increase in publication numbers at 14.8 times, followed by microplastics in agriculture and microplastics in biosolids at 11.6 and 11.2 times, respectively. Undoubtedly, microplastics pose a significant risk to natural ecosystems, as demonstrated by the numerous studies on their impacts. Therefore, it is essential to ensure proper management and disposal of biosolids to reduce the risk of microplastic contamination.

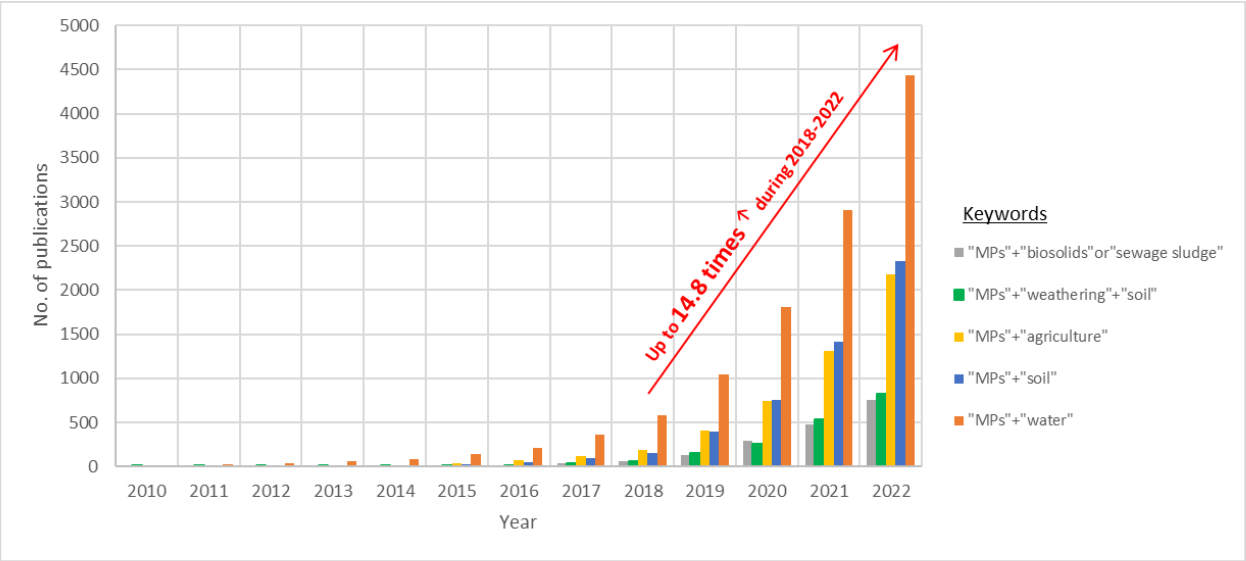


Figure 1. The number of publications related to microplastics during 2010 – 2022.

<u>Note</u>: "MPs" – microplastics; data for graph analysis were derived from www.sciencedirect.com, accessed on May 16, 2023.

About 38,000 dry tons of biosolids are generated in BC each year, of which 50 to 70 percent are used as soil amendments in agriculture and landscaping (Province of British Columbia, 2020). The Metro Vancouver government uses biosolids to produce NutriforTM fertilizer, which can be applied to parks, forests, hayfields, and rangelands to provide nutrients and organic matter as a fertilizer (Metro Vancouver, n.d.). As mentioned above, microplastics might not be removed entirely from biosolids, this application of biosolids could lead to their accumulation in the soil and finally in the marine environment.

The issue of Persistent Organic Pollutants (POPs) and CECs in biosolids has been gaining increased attention from policymakers, regulators, and the public recently (North East Biosolids and Residuals Association, 2011). In 2020, the BC Ministry of Environment and Climate Change Strategy released a report on the management of biosolids, which included a section on the presence of a biosolids sampling project. The report called for further research and monitoring to better understand the risks of microplastics in biosolids and to develop appropriate management strategies. (BC Ministry of Environment and Climate Change Strategy, 2020).

Generally, biosolids have been widely applied to agricultural soil in BC, but there are few studies on the impact of microplastics on agricultural soils. To better understand how microplastics affect the local environment and community, we need to identify and assess the risks associated with microplastics in soil, particularly in areas where biosolids are applied.

2. Objectives and target audience

This project aims to provide critical information on the negative influence of microplastics on nature and encourage changes in daily habits to reduce microplastic release into the environment. The project findings could help biosolids suppliers, farmers, and owners of community gardens and small-scale urban farms and the general public a more and better understanding of the impacts associated with microplastic accumulation in soil by using biosolids in farming activities.

This project introduces and presents the most current published information, and up-to-date knowledge of microplastic accumulation in agricultural soil by utilizing biosolids as fertilizer and hazards to the environment, focusing on soil ecosystem, and human health.

The study aims to achieve these objectives:

- Overview of the potential impacts of microplastics on soil, water, biota and human health from utilizing biosolids in agriculture.
- Quantify the levels of microplastics in biosolids applied to agricultural land in BC.
- Briefly discuss how to reduce and manage microplastics in biosolids and safer alternatives for biosolids in community gardens and small-scale urban farms.

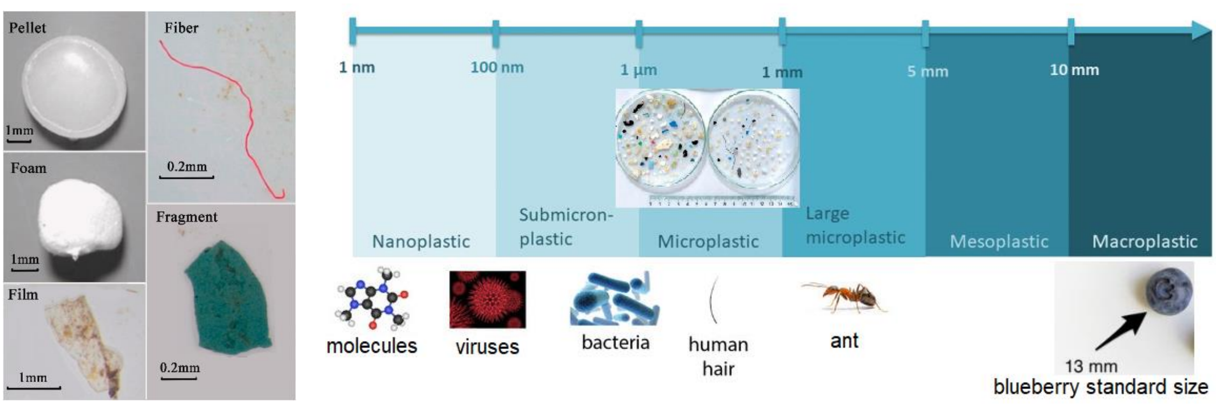
3. Methods

The systematic documentary research approach was applied in this study by analyzing existing documents, including literature reviews, policy documents, and reports. A thorough analysis of the collected data has been conducted to gain insights and identify potential gaps in the existing literature on the microplastics in soil by applying biosolids as fertilizer in agricultural activities.

4. Microplastics in the environment

4.1. Types of microplastics

Microplastics are known as plastic fragments, or very small plastic particles, with a size of less than 5mm. Microplastics are present in the environment in various shapes, polymer components, and colours with different chemical-physical characteristics (Christian & Köper, 2023). See Figure 2 for a variety of microplastics in size and shape.



(A) Common shapes *(B) Classification by size and relevant objects for comparison*

Figure 2. Common shapes and sizes of microplastics

<u>Note</u>*: obtained from Bloemen (2015); Christian and Köper (2022); Yang et al. (2022).*

There are two types of microplastics according to the origin of sources, including primary and secondary microplastics:

Primary microplastics: are manufactured as microsize for a purpose and used in personal care products (known as “scrubbers” or “microbeads”), synthetic textiles, or in many industries applications such as industrial air-blasting media for removing rust and paint or for coatings, and in many medical applications as drug vectors (Rani-Borges et al., 2021).

For instants, approximately 3.2 million tons of primary microplastic are released each year worldwide from households and commercial activities, according to Boucher and Friot (2017). Besides, every person released up to 400 grams of primary microplastics each year from their daily activities and about 50 percent of the microplastics potentially be ended up in the ocean (European Environment Agency, 2022).

Secondary microplastics are products of the breakdown of larger plastic wastes due to the environmental effects of photodegradation, wind erosion, and weathering processes (Cole et al., 2011).

For example, the abrasion of vehicle tires on road surfaces, the wear and tear of synthetic textiles during wearing and washing, and the dust in cities are the dominant primary sources of microplastics in land-based activities (European Environment Agency, 2022). Recently, the disposed biodegradable plastics are considered secondary microplastic sources as they are gradually decomposed into small pieces and left in the environment to form biodegradable microplastics (Wang et al., 2021).

4.2. Sources of microplastics in the environment

Microplastics can be found in most ecosystems, including soils, sediments (Christian & Köper, 2022; Huang et al., 2023), water bodies, oceans and sea beds (Eriksen et al., 2023), in the atmosphere (O'Brien et al., 2023), in animals and humans bodies through the food chain (Siddiqui et al., 2023). Recently, a high amount of microplastics have been even found in the Arctic polar waters raising concern about the extreme spreading of microplastics in most of the natural ecosystems (Grøsvik et al., 2022; Kanhai et al., 2020). Besides the variety of impacts of microplastics in different environments, the dangers of microplastics are strongly dependent on the shape, size, type of polymers, and weathering level of microplastic particles (Prata & Dias-Pereira, 2023; Sajad et al., 2022). Figure 3 demonstrates the common sea-based and land-based sources of microplastics in the environment.

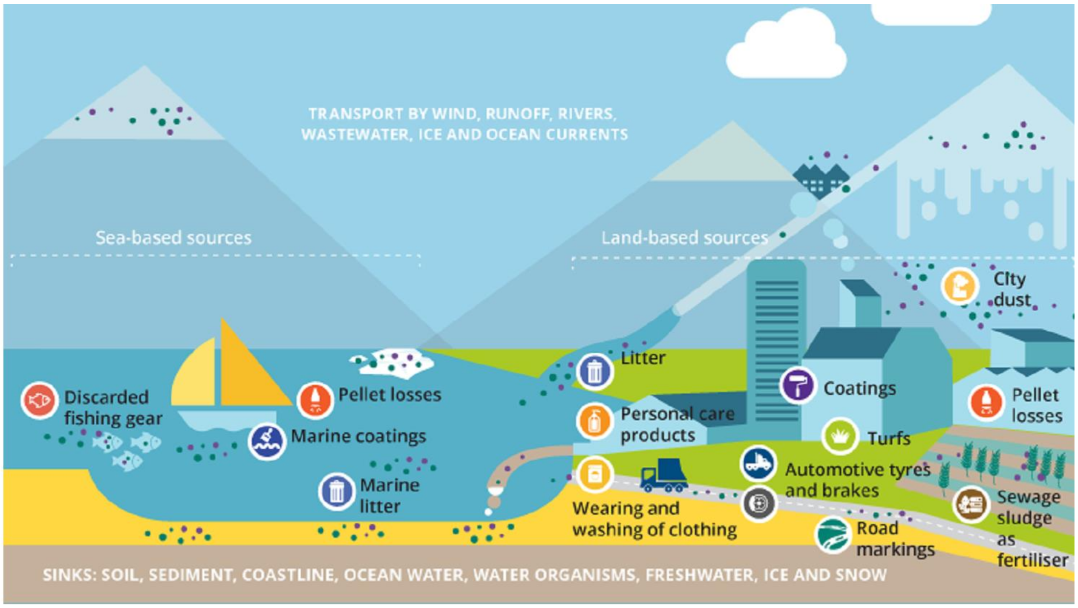


Figure 3. Sources and transportation of microplastics in the environment. *Source: European Environment Agency (2022).*

4.3. Microplastics in Agricultural Soil

Agricultural ecosystems serve an important role as sources of food for humans, therefore the contamination of microplastics in agricultural soils poses a risk to farming ecosystems and food security (Kedzierski et al., 2023; Zilinskaite et al., 2022). Using biosolids on agricultural land has been reported to potentially accumulate microplastics in the soil, leading to contamination of aquatic ecosystems and biota via plant and animal consumption (Khalid et al., 2020).

The major sources that contribute to microplastic accumulation in agricultural soils can be categorized as direct and indirect sources:

Direct sources mainly come from agricultural plastic supplies for use on the farm, such as plastic mulching films, plastics used to protect plants, bale nets, twine, plastic pipes, and other improperly disposed plastic containers. The microplastic particles from those plastic wastes are then released into the environment by photodegradation, mechanical abrasion and bioturbation processes under UV, and sunlight over time (Lwanga et al., 2022).

Indirect sources are the other agricultural supplies that contain microplastics, such as: treated sewage sludge or biosolids, compost, manure, and coated fertilizers (Kedzierski et al., 2023; Radford et al., 2023). In addition, the microplastics deposited in the agricultural soils from airborne and recycled wastewater for irrigation are considered indirect sources (Tian et al., 2022).

The current understanding of the sources, effects, and fate of microplastics on agricultural soil ecosystems is summarized in Figure 4.

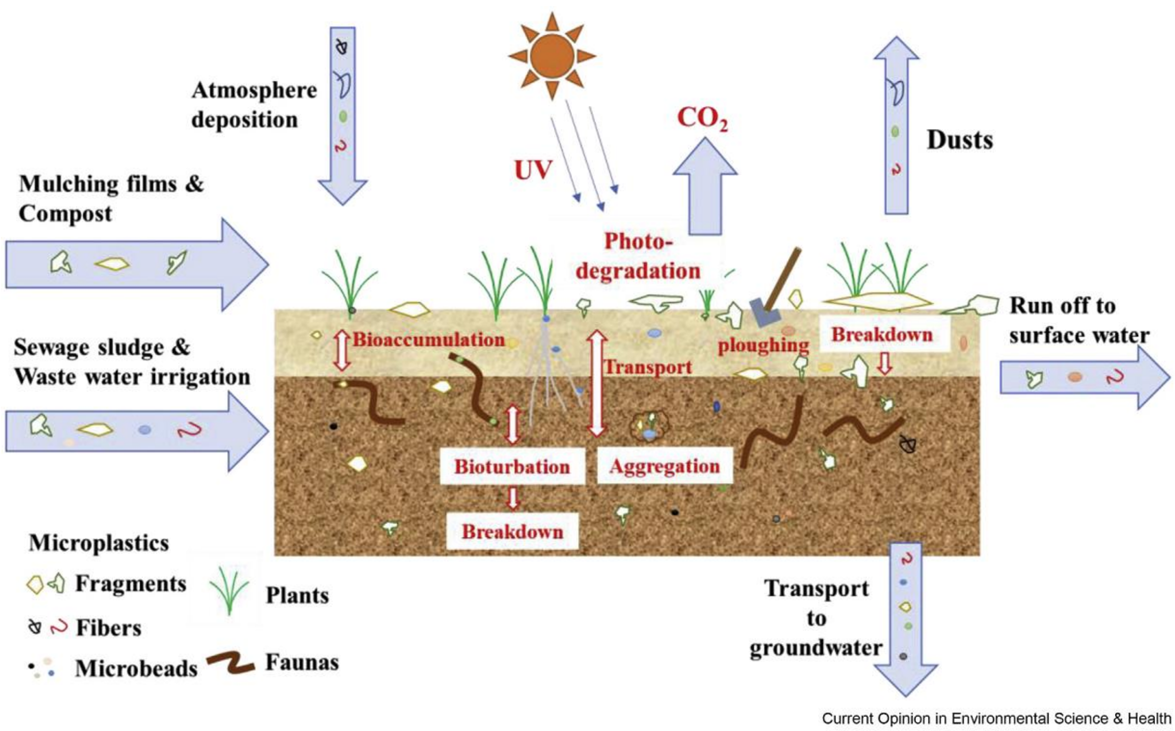


Figure 4. Sources, and transportation of microplastics in agricultural soil. *Source: Tian et al. (2022)*.

5. Biosolids and potential microplastic accumulation

5.1. What is biosolid?

The two primary outputs of the wastewater treatment processes are treated water and the other is sludge, which contains most of the pollutants. To ensure proper disposal, the sludge needs to be appropriately treated to become solid before being disposed into landfills or used in other ways, such as fertilizer for soil and land reclamation. Those residual solids are called biosolids (Mateo-Sagasta et al., 2015).

Figure 5 summarizes the liquid and solids streams in the 3 stages of sewage treatment processes.

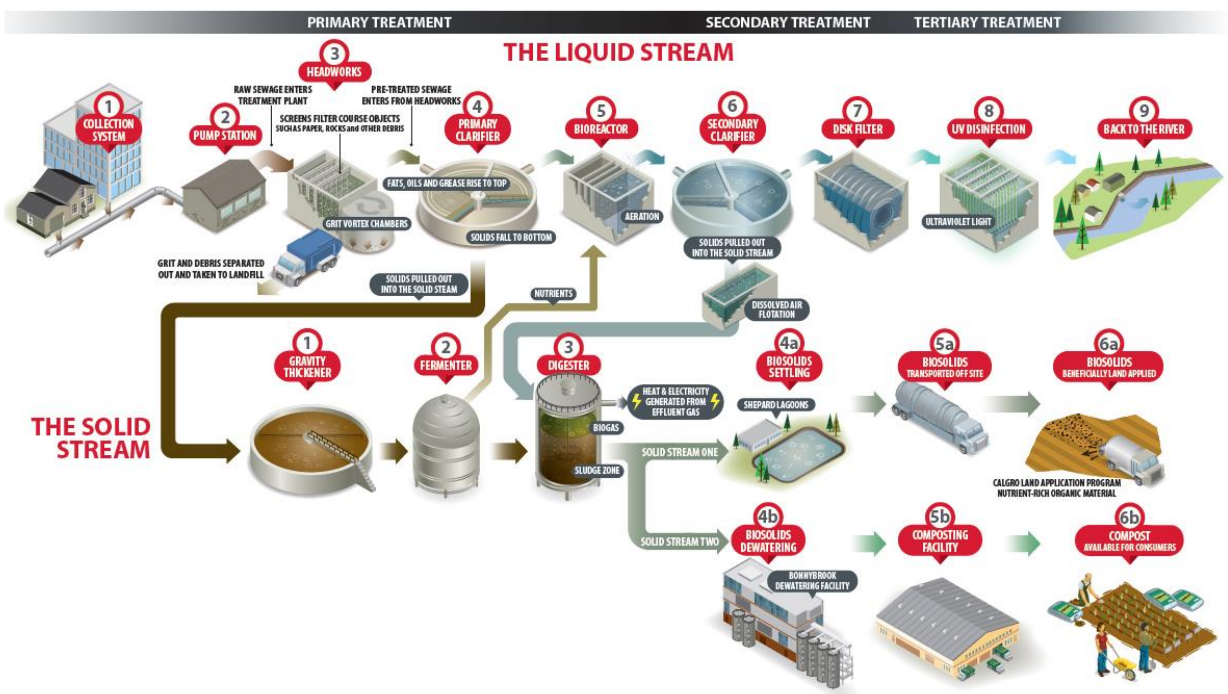


Figure 5. The sewage treatment processes. *Source: The City of Calgary (n.d.)*.

Generally, biosolids contain 50 to 70% organic matter, including humic and fulvic substances (Fischer et al., 2020). Moreover, this product is rich in both macro nutrients (such as Ca, Mg, N, P, K, P, and S) and micro nutrients (such as Fe, Cu, Mn, and Zn), which are essential to the plants (Kanteraki et al., 2022). Due to their high organic carbon content and nutrients, treated biosolids are widely used in agriculture and landscaping (Kanteraki et al., 2022; Metro Vancouver, n.d.; Regional District of Nanaimo, 2023c).

Figure 6 summarizes the management of biosolids in different approaches among the countries where data is available. It is shown that more than 50% of the biosolid production is utilized for land applications in most of the surveyed countries, except Newfoundland Canada and Greece most of the generated biosolids are landfilled. Particularly, up to 94% and 95% of the biosolids in BC and Alberta are utilized for land application purposes, respectively. While incineration is the leading solution for biosolids management in Quebec, Ontario in Canada, Belgium, Germany, Romania, and Japan. (Capital Regional District, 2017).

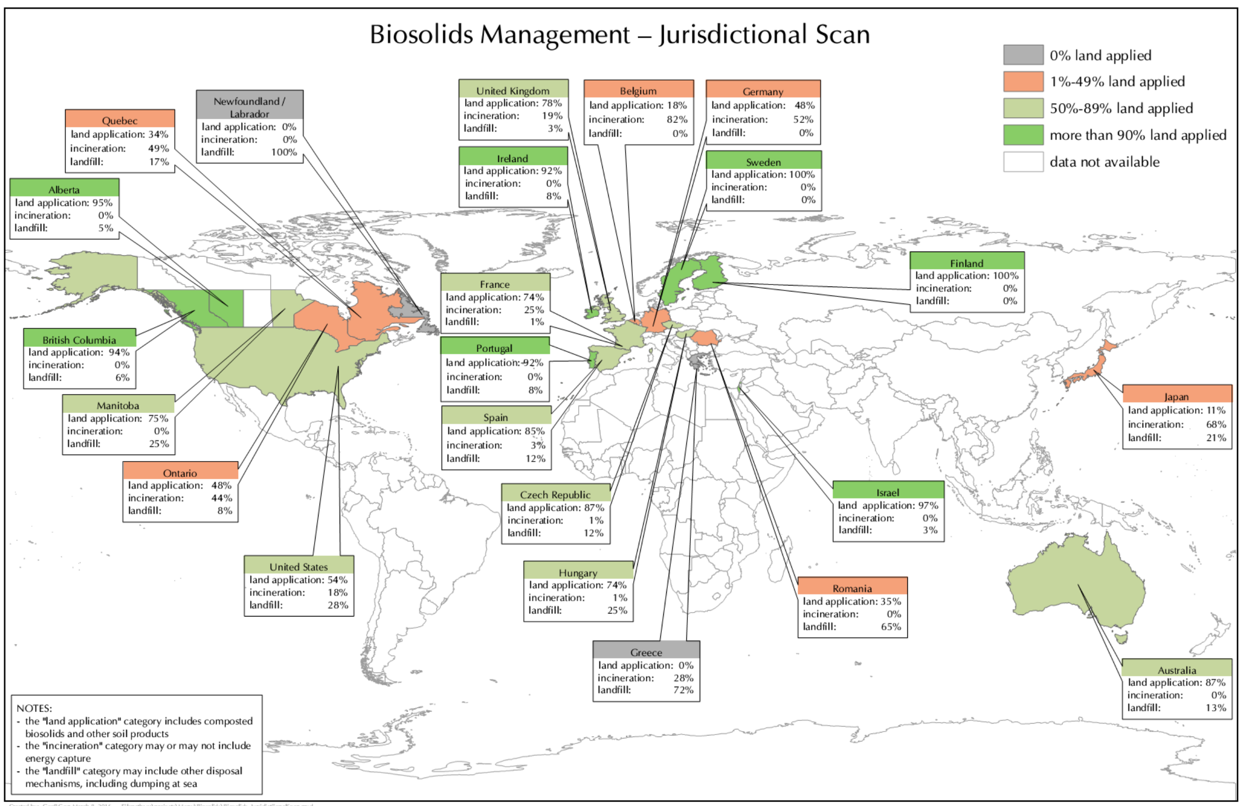


Figure 6. Statistics on biosolids management approaches in different countries. *Source: Capital Regional District (2017)*.

5.2. Microplastic in biosolids

Sewage wastewater is generated from domestic activities, including residential households, commercial buildings, hospitals, etc. This wastewater might contain various pathogens, organic and inorganic pollutants, or other chemical substances (Kanteraki et al., 2022). A study by Jones et al. (2021) estimated that the yearly production of global wastewater is approximately 359.4 billion cubic meters, of which more than 188 billion cubic meters of wastewater is treated before discharge to the environment, accounting for approximately 52% of the total generation and the rest (48%) is freely discharged into nature without treated.

The microplastics are accumulated from surface runoff, sewage, industrial effluents, and landfill leachate before reaching wastewater treatment plants (Huang et al., 2023). During the treatment processes, the microplastics removed from wastewater are retained in the sewage sludge and can be released and accumulated on land through biosolids applications (Government of Canada, 2020).

For example, microplastic pathways have been investigated by monthly samplings at local wastewater treatment plants and other surface water effluent discharges in the Niagara Region, Ontario, Canada. The study found 1.22 ± 1.59 microplastics per litre in treated wastewater with mostly polyester fibres, while they also found 3.17 ± 2.37 polyethylene microplastic particles per cubic meter in surface water downstream of the wastewater treatment effluence receiver, this could be explained by the accumulation of microplastics from the effluence in a long period (Ham, 2019). That is the reason why microplastics present in biosolids received more concern for their negative impacts on human health and ecosystems over the past few years (Radford et al., 2023).

Figure 7 illustrates a comparison of the total biosolid production and the microplastic concentrations in biosolid samples from wastewater treatment plants in different countries. China is the country that generates the largest amount of biosolids among the surveyed countries with approximately 35 million metric tons per year (MMT/year). The concentration of microplastics in the biosolid samples was 8.03 particles/g of dry weight at the average level among the countries. Italy had the highest concentration of microplastics in the biosolid samples at 113 particles/g, while the Netherlands had the least microplastics at 0.45 particles/g. Standing at the 5th highest number of microplastics in biosolids was Canada with an average of 9.65 microplastic particles in each gram of biosolid (Rolsky et al., 2020).

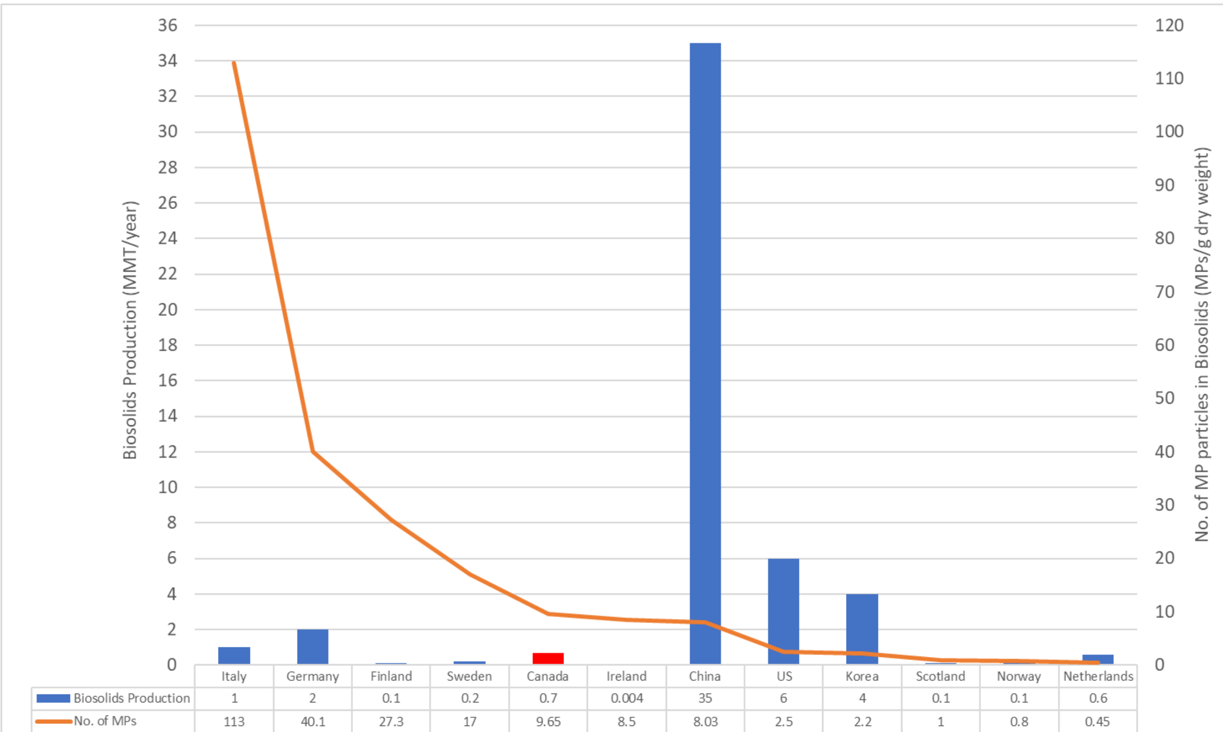


Figure 7. Microplastics in biosolids from wastewater treatment plants *(graph plotted according to the data of Rolsky et al. (2020))*

It should be noted that these biosolid productions were sampled from the output of wastewater treatment plants. The biosolids which can be utilized as fertilizer for agricultural soil must be required further processing to remove metals and other harmful substances, the microplastics should be less in the treated biosolid for fertilizing as a consequence.

6. Impacts of microplastics

6.1. Impacts on soil quality and plant development

Microplastics potentially remain in soils for long periods due to vertical transportation and contribute to the moving downward deeper in the soil profile (Government of Canada, 2020). When discharged into the soil, microplastics disrupt soil water retention causing a decrease in soil bulk density, increasing water-holding capacity with polyester fibres, and reducing the soil microbial activity (de Souza Machado et al., 2018). On the other hand, microplastics are found to reduce soil density, which improves soil aeration and results in increased root growth (Rillig et al., 2019). This might create channels for water movement, causing more water evaporation (Wan et al., 2019). Consequently, the soil dries out quickly, potentially affecting the performance and growth of plants (Rillig et al., 2019).

The microplastics are proven to alternate the plant root trails, including increasing the biomass of the root system, the root and leaf dry biomass ratio could be changed by alteration of microplastic exposure *(e.g. PA causes a decrease while PES, PET and PP cause a significant increasing this ratio)*. Besides, the presence of microplastics in soils causes more length of root and decreases the root average diameter (de Souza Machado et al., 2018). In addition, microplastics are photochemically weathered over time when exposed to sunlight, due to ultraviolet rays. As a result, they become less hydrophobic, stiffer, and fragmentable and have surface charges, altering soil properties and changing heavy metal and antibiotic absorption capacities. (Büks & Kaupenjohann, 2022; Zhao et al., 2021).

Besides, it has been demonstrated that microplastics in the soil can alter the microbial community by ingesting, digesting, and excreting microplastic particles at the micro-scale (Büks & Kaupenjohann, 2020). The charge of the microplastics' surface causes microbial colonization and the formation of biofilms on their surfaces, which mask the plastic surface characteristics. Therefore, the altered soil microbial community is characterized not only by the surrounding soil's physiochemical properties but also by the type of microplastics and their additives (Büks & Kaupenjohann, 2022; Wang et al., 2020).

A study by Crossman et al. (2020) found that the concentration of microplastics increased by depth showing the downward movement of microplastics in the soil profile at the three agricultural fields which applied biosolids for up to 4 years in Ontario, Canada. Interestingly, the study has found that the soil hydraulic properties and rainfall amount affected soil saturated conductivity and strongly influenced the accumulation of microplastics. This directly led to the loss of microplastics in the soil, and the potential transfer of microplastics from the soil to the surrounding groundwater. The authors concluded that soil macropores, soil matrix, potential, accumulation of organic matter, and soil biota might affect the number of microplastics in the soil profile.

Microplastics could affect the growth of plantations. A study by Boots et al. (2019) has documented that microplastics cause a decrease in the number of germinated grass seeds and lower the height of *Lolium perenne* grass. Microplastics are also reported to cause a significant change in the biomass of plants, the elemental composition of plant tissue, and the root traits of spring onion *(Alliumfistulosum)* (de Souza Machado et al., 2019). In addition, the microplastics released from degraded plastics mulch could cause a negative influence on the reproductive growth of wheat *(Triticum aestivum)* (Qi et al., 2018).

It has also been hypothesized that microplastics in soil induce nutrient immobilization (Rillig et al., 2019). This can be explained by the high concentration of C in the microplastic particle. The degradation and weathering of microplastic in soil over time may alter the soil's C:N ratio, leading to microbial nutrient immobilization (Rillig, 2018). This hypothesis was supported by the study by Qi et al. (2018), which found that plant performance, such as the leaf area parameter, decreased in soils containing biodegradable plastics.

Figure 8 is an illustration of the influence of microplastics on soil characteristics and the growth capacity of plants.

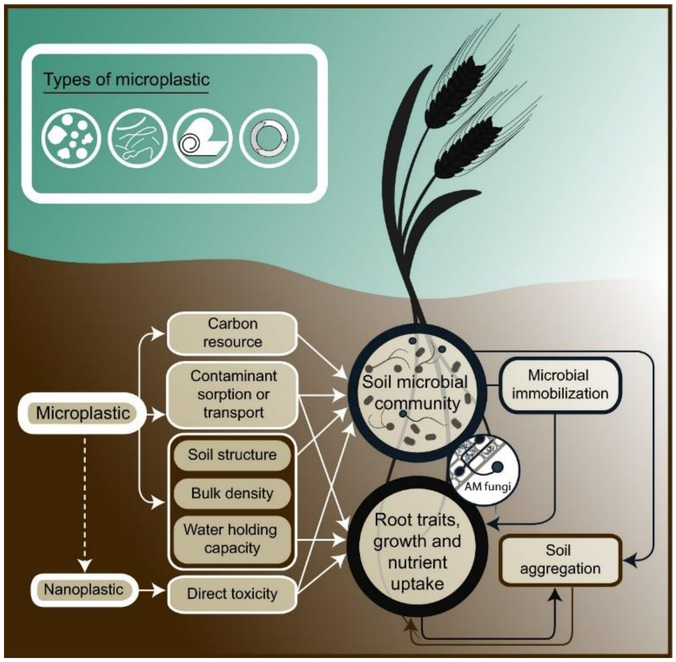


Figure 8. The influence of microplastics on plant growth. *Source: Rillig et al. (2019)*.

6.2. Impacts on aquatic ecosystems

Microplastics can be exchanged between the two environments as there is always a linkage between terrestrial and aquatic ecosystems (Horton et al., 2017). The microplastics from terrestrial systems can be transferred to aquatic systems through erosion, runoff, or drainage water. Especially, drainage water from agriculture is commonly released into the aquatic ecosystems without any treatment leading to the addition of microplastics in agricultural soils that could potentially be transported to the aquatic environment from drained soils (Bigalke et al., 2022).

The particle size strongly affects the number of microplastics that can be transferred from soil to surface water through drainage water (Triebskorn et al., 2019). A study by Bigalke et al. (2022) found 10.5 ± 9.5 microplastic particles/litre in drainage water sampled from a high-density agricultural area which uses considerable amounts of mulch foil, tunnels, and plastic items in Swiss Seeland, Switzerland. The amount of microplastics was higher than the amount in the local surface water which was about 7 ± 5 particles/litre.

Microplastics are also considered vectors that cause transporting of harmful chemicals into aquatic organisms' cells (Weis, 2020). Upon ingestion by aquatic life, these microplastics bioaccumulate and pose a serious threat to the food chain, as well as to human health (Bajt, 2021). There is evidence that microplastics are small enough to be easily ingested by the aquatic habitat and may affect the tissues of invertebrates, causing pathological and oxidative stress, reproductive issues, interference with enzyme activity, or stunted growth. As a result, microplastics can accumulate in the food web and finally be consumed by people (Chaukura et al., 2021; Triebskorn et al., 2019).

6.3. Impacts on air quality

Microplastics have been detected indoors and outdoors, indicating that the air is also a significant pathway for their transport. The very lightweight microplastic particles are readily transported in the air by wind erosion across soil surfaces and toward surface water bodies. It is also possible for microplastic particles to be picked up by the wind and transported into the atmosphere in wind erosion-prone areas, which in turn can negatively affect the quality of the air in those more remote areas (Lwanga et al., 2022).

Statistics from previous studies suggest that the concentration of microplastics in indoor air could be higher than in outdoor atmospheres (Government of Canada, 2020). In addition to microplastics found outdoors, settled house dust can also contain microplastics. Most of the recent studies on airborne microplastics indicated that indoor and urban activities are the main sources of microplastic emission into the air rather than agricultural activities (Government of Canada, 2020).

These findings suggest strongly the need to fill the knowledge gaps in the understanding of the amount and transportation process of microplastics from the outdoors, especially from agricultural activities where microplastics could be adsorbing other pollutants, such as chemicals and pesticides from agricultural soils (Lwanga et al., 2022). By adsorption of other pollutants, airborne microplastics become more of a potential threat for being inhaled by humans or animals (Kik et al., 2020).

6.4. Impacts on human health

Microplastics can enter the human body through three different pathways, including ingestion of food, inhalation of microplastics in polluted air and epidermal contact with microplastics (Anand et al., 2023; Liu et al., 2022). Cox et al. (2019) reviewed and analyzed 402 data sets from 26 previous studies on the concentration of microplastics in different foods and beverages consumed by Americans such as seafood, salt, honey, sugar, alcohol, water and air. The study estimated that 39,000 - 52,000 microplastics could be ingested by each person annually depending on sex and age with the assumption that approximately 15% of Americans' caloric intake. The organic and inorganic pollutants and even harmful viruses and bacteria that are associated with microplastics can be transferred into the human body where they can accumulate in the tissues of our body when ingested (Atugoda et al., 2021).

Researchers have reported associations between exposure to high levels of microplastics and adverse health effects in both laboratory animals and humans, however, these health effects cannot be attributed solely to exposure to the general population. Despite this, there is limited information regarding microplastics' effects on human health. Further research is necessary to provide a more complete understanding of the target tissues, threshold doses, and mode of action of these substances (Government of Canada, 2020).

7. Biosolids application for agriculture

7.1. Microplastics from biosolids in Canada

Recently, many studies have proved the accumulation of microplastics in agricultural soils through biosolids utilized for agriculture in Canada. About 1.5 million cubic meters of biosolids have been applied to agricultural land every year, resulting in an annual addition of 410 to 1,300 billion microplastic particles to agricultural soil due to biosolid applications (Crossman et al., 2020). A study by Ham (2019) has found 4.4 ± 4.8 microplastics per gram in soil samples taken from the two farms that applied biosolid as supplementary fertilizer in Niagara, Ontario and approximately 4.3 ± 2.4 particles of microplastic found in the biosolid samples that have been utilized at those to farms.

In addition, another study by Crossman et al. (2020), published one year later, analyzed the presence of microplastics in biosolid samples from the two suppliers and the soil samples from three agricultural fields where those biosolids were applied in Ontario, Canada. The study found up to 14 x 10^3 microplastic particles in every kilogram of dry biosolid samples from one supplier, while there were only 8.7 x 10^3 particles in the samples from another supplier, believed to be because of the difference in storage and pre-treatment processing between the two suppliers. While the results from the soil samples from the three fields where biosolids were applied showed the highest amount of up to 541 microplastics per kilogram at the location where biosolids have been applied twice 2 and 4 years before. This amount is more than double the other fields with recently applied biosolids. In addition, polyethylene, polypropylene and polyester were the three most dominant microplastic types in all the samples.

Consequently, these investigations revealed that microplastics will accumulate in agricultural soils in Canada as a result of biosolids application and that these microplastics may make their way into the food chain, causing potential risks to the health of humans and ecosystems.

7.2. Biosolid products for agriculture in BC

In the Greater Vancouver Regional District (GVRD), five wastewater treatment plants are the main sources of producing biosolids, including Annacis Island, Lulu Island, Lions Gate, Iona Island and Northwest Langley. The number of biosolids produced in GVRD accounts for the major portion of the annual mass of biosolids in BC approximately 17,500 dry tonnes of the total 38,000 dry tonnes produced in the province (Bright & Healey, 2003; Province of British Columbia, 2020). A summary of biosolids products from some regional cities in BC is provided in *Appendix 2*.

Nutrifor is Metro Vancouver's biosolids brand and is well known for its use in land restoration, where it provides soil nutrients without using chemical fertilizers. It has been used in Metro Vancouver's landscape facilities and parks for over 30 years. In particular, Nutrifor is widely used for restoring disturbed soils at mining sites and gravel pits for re-introducing vegetation. Aside from creating high-quality topsoil for landscaping and fertilizing hayfields, Nutrifor also enhances topsoil quality. The product can be used to enhance the top layer of landfills to absorb methane gas and reduce greenhouse gas emissions (Metro Metro Vancouver, n.d.).

In addition, the Regional District of Nanaimo (RDN) produces 7,500 tonnes of biosolids every year which has won the “Excellence in Biosolids” award twice for its advanced cost-effective and environmentally beneficial practices (Regional District of Nanaimo, 2023c). Two current biosolids application programs are taking place in RDN including the “Forest Fertilization Program” and “Soil Fabrication Program”. The forest fertilization program helps to enhance the soil’s water-holding capacity, supply nutrients and organic matter for the stronger growth of trees and help to increase soil carbon sequestration in the Blackjack Ridge Forest. This program utilizes up to 85 percent of RDN’s annual biosolids product (Regional District of Nanaimo, 2023a). While the remaining 15 percent of annual products from RDN are utilized for the soil fabrication program. In this application, the RDN’s biosolids are mixed with wood waste and sand to create a fabricated material for soil and applied at the Harmac Pacific Pulp mill in Duke Point (Regional District of Nanaimo, 2023b).

In BC, certain requirements are set for the production of high-quality biosolids and their subsequent use for land application and composting under the Organic Matter Recycling Regulation (OMRR). Besides, the classification of biosolids can be split into two categories: Class A and Class B. For Class B applications involving more than 5 cubic meters of biosolids per parcel of land, a "Land Application Plan" is required, whereas the plan is not required for Class A applications. (BC Ministry of Environment and Climate Change Strategy, 2020). Figure 9 overviews the legal framework required for utilizing biosolids in agriculture.

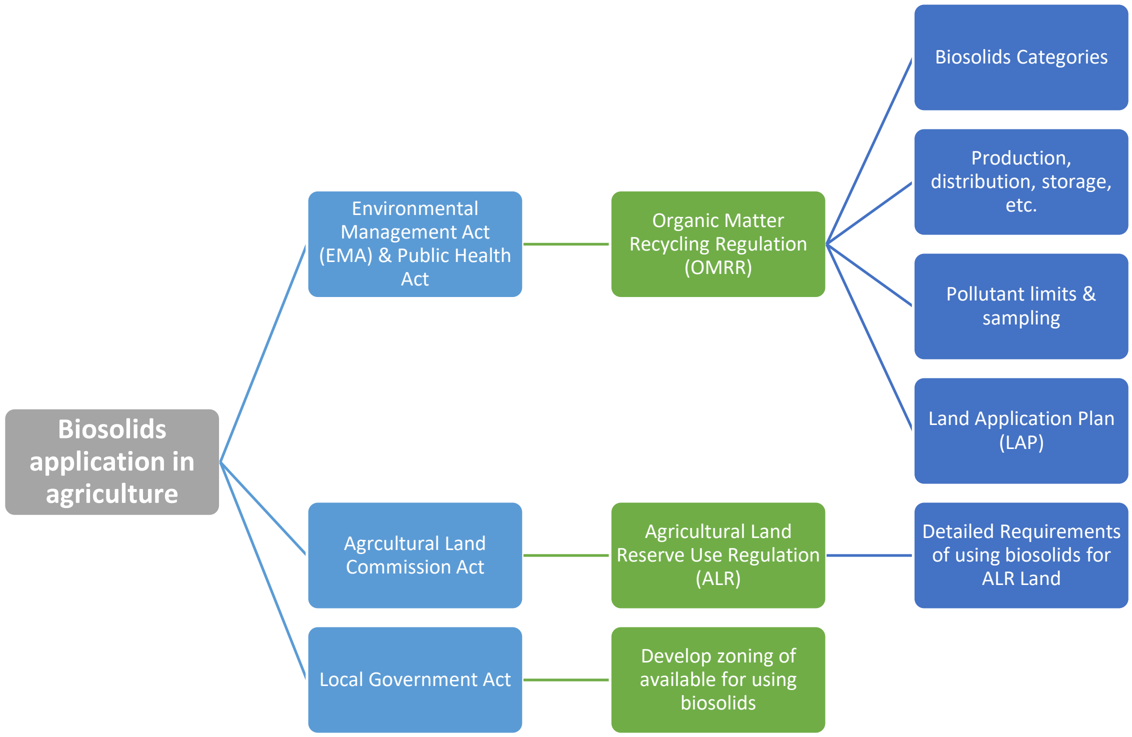


Figure 9. BC's Regulatory Framework for biosolids application in agriculture

7.3. Amount of microplastics in agriculture from biosolids application in BC

In BC, most of the biosolids production is used in many beneficial ways, including land application to support agriculture, forestry, land reclamation and landfill closure, while about one-third of the total amount is lagooned, landfilled or utilized for other purposes. Among the beneficial applications, the three applications including composting (24%), growing medium (22%), and agriculture (9%) are the potential sources of microplastics from biosolids to the agricultural soils in BC, which is approximately 20,900 dry tonnes (see Figure 10).

According to the available resources and documents that have been reviewed in this study, there is currently not any specified study on the number of microplastics in BC's biosolid products which are ready for use as fertilizers in agriculture, except the study by Crossman et al. (2020) mentioned in Section 7.1 which estimated the average amount of microplastics in biosolids samples from the two biosolids suppliers and in the agricultural soils where applied those biosolids as fertilizers in Ontario, Canada.

The findings of Crossman et al. (2020)'s publication (i.e. 8.7 – 14 thousand microplastics per kilogram of biosolids in dry weight) was applied to estimate the potential amount of microplastics in agriculture from biosolids application in BC in this study,

As a result, it could come up 182 – 293 million microplastic particles released every year from biosolids into agricultural soils in BC. Assumed that the average weight of microplastics is in the range of 130 – 2670 grams per 113,000 particles (Isobe et al., 2021), at least 0.21 – 4.30 tons of microplastics could be released to agricultural soils from biosolids application in BC every year.

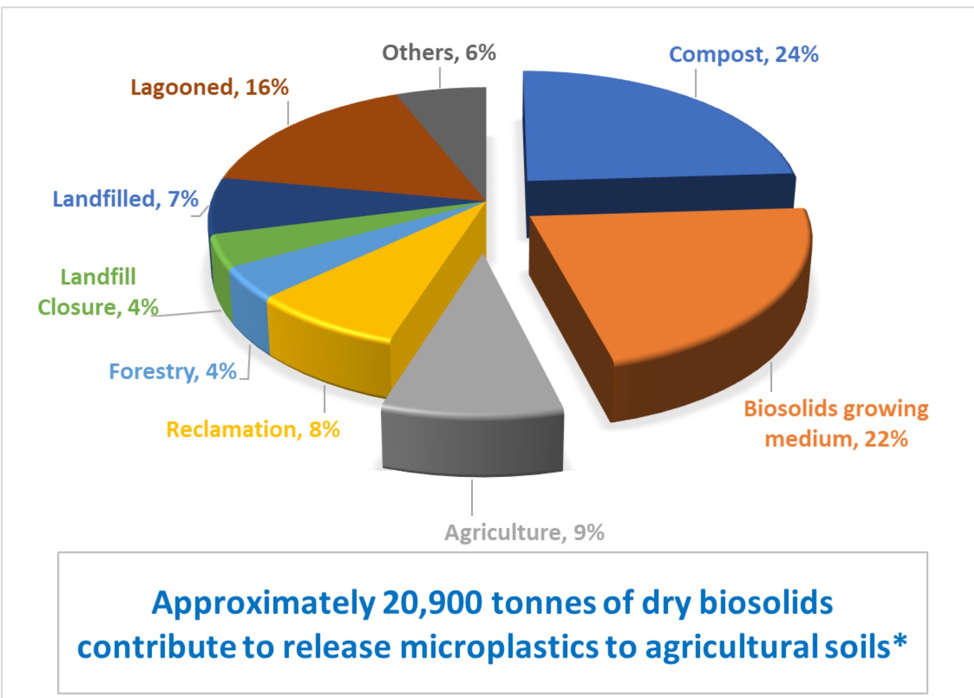


Figure 10. Industry users of Biosolids in BC.

*Note: * Annual biosolids production of BC is 38,000 dry tonnes. Assume that 55% of total production was used as composting (24%), biosolids growing medium (22%) and agriculture (9%) that can be applied to agricultural soils when sold to the market. Source: Province of British Columbia (2020).*

8. Recommendations for urban farming and community gardens

According to the Vancouver Urban Farming Society (2020), there are 4,960 food assets in Vancouver, including community gardens, community orchards, community kitchens, community composting facilities, farmer markets, and urban farms. Up to 17,000 people are engaged with urban farms in Vancouver in 2019, through events, volunteering, and farming education programs. In addition, urban farms help to create jobs, grow food with organic practices for the citizens to learn farming skills, and enhance the connection between urban dwellers and the food system. For instance, among the community gardens and orchards in Vancouver, there are more than 110 located in parks, school yards, and on private properties (City of Vancouver, n.d.). Therefore, urban farming and community gardens could be effective places to create awareness for the public on the impacts of microplastics on food security and the best management practices to reduce microplastics in agriculture.

Reducing microplastics in biosolids by controlling sources is considered one of the best solutions generally. To reduce the microplastics from sources, a multiple-strategy approach must be considered. This should include reducing the usage of plastics, public awareness to eliminate plastic waste littering, improving stormwater runoff harvesting and management practices, improving the wastewater and sludge treatment technologies, revolution and improving the biosolids disposal and utilizing methods, enhancing the regulations on microplastics (Meegoda & Hettiarachchi, 2023).

The following section presents some initial approaches that can help to reduce the impacts of microplastics in urban farming and the potential application of community gardens as a localized solution to minimize the release of microplastics into the water ecosystems.

8.1. Applying high-quality composts or biosolids

It is important to use high-quality organic fertilizers, which are strictly concerned with the microplastic residues in production for urban farms to minimize the potential of microplastic accumulation in the food products. A recent study by Steiner et al. (2023) has found that the microplastic fragments in the fertilizers from the biowaste treatment plants have considerable quantities, as compared to the fertilizers from the agricultural biogas plants and greenery composts. Also, the study suggests that residual contamination is affected by both the quality of the incoming biowaste and also dependent on operating conditions of the biosolids treatment processes.

Despite this growing awareness, it is remarkable that the province of British Columbia currently lacks regulatory measures specifically targeting microplastics within the OMRR. The existing regulatory framework, which includes Class A and B classification for biosolids, primarily focuses on controlling the levels of metals, pathogens, and other contaminants. However, the absence of regulations on microplastics raises a significant concern. Although there are not any requirements on the limitation of residual microplastics in both Class A and B biosolids, however, with more strict requirements for meeting the criteria outlined under the provincial OMRR. As required by OMRR, Class A biosolids must meet higher standards on limits of metals, and pathogens and also a higher requirement on sampling and analysis protocols and frequency (City of Abbotsford, 2023).

In general, the Class A biosolids treatment could help to remove more microplastics than Class B products and could be safer for the urban farms' application. Therefore, the application of biosolids to urban farms or community gardens must strictly apply the Class A biosolids production (BC Ministry of Environment and Climate Change Strategy, 2020; Province of British Columbia, 2020) for both input materials and treatment processes ensuring to minimize the residual microplastics in the products in the short-term. While, implementing comprehensive microplastic monitoring and regulatory measures as improving the BC’s legislation framework must be helpful for the long-term management of microplastics in biosolids, which will be mentioned in Section 8.5 below.

Furthermore, in the long-term biosolids’ quality management, there is an emerging need for further research and studies related to sampling and analysis of the number of microplastics in biosolid samples with standardized testing methods for consistent and reliable measurements across the province or Canada. In addition, microplastic source tracking to identify the sources of microplastics in biosolids to target mitigation efforts effectively is important. Sources can include personal care products, synthetic clothing, and industrial runoff. Besides, the investment in wastewater treatment technologies that can effectively remove microplastics from sewage before they enter the biosolids treatment process is very important for the sustainable management of biosolids quality.

8.2. Reduce plastic waste and plastic consumption

Minimize plastics production during the crops by utilizing non-plastic products for daily use on farm activities, such as plastic mulches. Local urban farms or community gardens could apply the Cleanfarms programs, which are available across Canada and can help to reduce, recover, and recycle agricultural plastics from packaging and products to target the goal of zero agricultural plastic waste going to landfills in Canada (Cleanfarms, 2023). For example, Cleanfarms conducted a clean-up program at Vancouver Island and in the Fraser Valley of BC in the fall of 2020 to help farms safely dispose of unwanted plastic wastes, including pesticides and old, obsolete livestock and equine medications without costs (Waste & Recycling, 2020).

According to the guideline from FAO (2021), many plastic products that are commonly used in agricultural activities can be substituted with alternative materials that are less harmful to the environment, such as:

- *Tree guards and shelters*: substituted by cardboard or bamboo which can be left in situ and do not require collecting for recycling after use.
- *Plant and seeding pots*: can be alternated by coconut shells, paper or soil blocks which all can be composted at the end of the life circle or left in situ.
- *Mulch films*: substituted by cover crops or biomass which can help to reduce the cost of purchasing and removing the film after use. Besides, those materials are easily available at the sites and help improves the soil.

- *Plastics plant support twines and nets*: can be replaced by plan-based twines. This help the farmer save labour to separate the plastic wastes from plant residues or all those wastes can be composted together without classifying.
- *Plastic boxes plant*: can be replaced by wooden boxes which help to enhance the site landscaping.

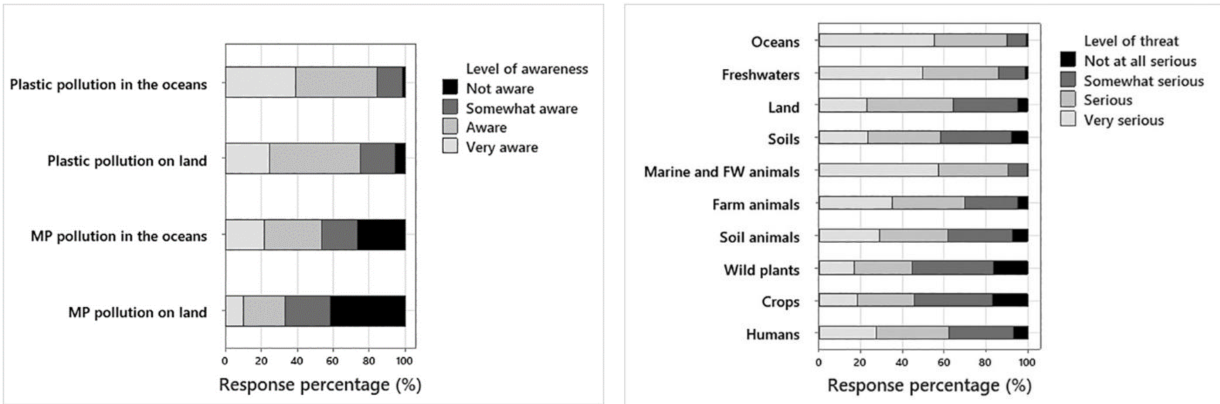
8.3. Concern about the quality of irrigation water

Agricultural soils that are irrigated with contaminated water can introduce microplastics to the urban farms' soils, especially, since there is a high potential for microplastic pollution in roof-harvested rainwater (Zhou et al., 2020). In case the irrigation water of the farms comes from rainwater, the microplastics, and also other pollutants can be present in this water source via several routes, such as microplastic erosion from roof material or rain-harvest piping system, rainwater storage containers, and wet deposition (i.e. rainfall scavenging pollutants from the air) (Deng, 2021). These might lead to excessive pollutants and microplastics in soils and crop health. Therefore, there is a requirement for a tailored rainwater treatment facility for urban agricultural irrigation, and also the requirement for a microplastics removal facility tailored for urban agricultural irrigation, monitoring microplastics and other pollutants to ensure harvested rainwater quality for irrigation.

8.4. Improve awareness of microplastics in agriculture through urban farming

A study by King et al. (2023) evaluated awareness of microplastics and perceptions of the impacts of microplastics on farming activities on the environment of 430 farmers in Ireland. The finding showed that more than 88% of farmers in Ireland, surveyed were concerned about the risks of the amount of plastics waste generated from agricultural activities, however, only 57.5% of the farmers are aware of microplastics, and most of the farmers answered that they know more about plastics pollution than microplastics pollution and those issues have mostly occurred in the aquatic systems (Figure 11).

This lead to the common perception of believing that risks from plastic wastes cause greater risks in the aquatic environment than in terrestrial environments.



(A) Level of awareness (B) Level of threat

Figure 11. Awareness of farmers on microplastics in agricultural activities.

Level of awareness of plastic and microplastic pollution (A), and perception of how serious plastic pollution in different components (B) of farmers in Ireland. Source: King et al. (2023).

Although most of the farmers have good awareness and concern about the negative impacts of microplastics on the environment, some farmers have admitted to burning or burying plastic wastes on-site illegally and harmful to the environment, and even risky to release microplastics into the crops in the long-term (King et al., 2023). Therefore, further research and awareness education programs on the potential effects of microplastics on soils and plantations, and guidelines on how to properly recycle and manage plastic wastes for farmers and the general public to minimize the accumulation of microplastics in soils are needed.

According to the statistics from the Vancouver Urban Farming Society (2020), many skills have been developed through urban farms during the last years, including growing food skills, working with food skills, and many others (Table 1). Therefore, urban farms and community gardens could be the best places for combing education on the awareness of microplastics on soils and the food web, then the practical research or study on best management practices on plastics waste management to minimize microplastic accumulation in agricultural activities could be conducted with cooperation with research institutes or universities. Table 1 summarizes the skills that have been developed for urban farmers during urban farms operation in Vancouver and recommendations for integrating microplastic awareness into the activities.

Table 1. Recommendation for microplastic awareness improvement

Skill types	Skills(*)	Recommendation for microplastic knowledge integration
Growing food	Organic/ecological/sustainable food production methods Other environmental practices	- Awareness of microplastic sources in each production method - Impacts of microplastics on the growing environment and surrounding ecosystems - How to prevent, reduce, reuse, and recycle plastic wastes to minimize the microplastics leasing into the environment
Working with food	Food literacy and nutrition Food preparation and cooking Food processing Food safety	- Awareness of microplastics and their fate in the food web - Microplastics and their impact on human health and food safety - Choosing recipes and cooking equipment to minimize microplastics in food
Other	Social skills (e.g. communication, working with people from diverse backgrounds) Marketing and distribution Business planning	- Life cycle of microplastics in the food distribution network and its impacts on the agricultural business - How to minimize the impacts of microplastics in the food distribution systems

(*) retrieved from the report of the Vancouver Urban Farming Census 2017 to 2019.
Source: Vancouver Urban Farming Society (2020).

8.5. Enhance the legal framework for the output quality of biosolids

Currently, there is a lack of requirements for monitoring the residual amount of microplastics in biosolid productions mentioned in the OMRR. The difference in the monitored parameter in Class A and Class B biosolids, however, pathogens (such as Fecal Coliform, Salmonella Sp., heavy metals, and volatile solids are monitored), but not microplastics. Fortunately, Class B is not applied in the lawns and home gardens sites. However, the estimated counts of microplastic particles in the biosolids vary widely among the different laboratory methods. That is why there is an emerging need for more regulatory guidelines on the standardized methods for consideration of microplastics in biosolids, the standard on limits of the residual amount and types of microplastics in biosolids productions which can be utilized for agricultural activities.

Although this is a challenging situation, it also presents an opportunity for proactive action. There is a need for regulations or guidelines for acceptable levels of microplastics in biosolids for both Class A and Class B biosolids. These regulations can be based on scientific research and risk assessments to determine safe exposure thresholds. Incorporating specific guidelines and limits for microplastics into biosolids would ensure that these essential resources do not unintentionally contribute to microplastic pollution.

Through the implementation of this improvement, it is possible to address microplastic contamination in agriculture and emphasize the importance of harmonizing local regulations with international regulations. This effort should prioritize the protection of human health, biodiversity, and water resources from microplastic accumulation in the environment. Additionally, it should promote public-private partnerships to ensure the effective implementation of policies and regulations in microplastic management.

9. Conclusions

Up to
20,900 tons
of dry biosolids could be applied to agriculture in BC every year.

Resulting in
182 - 293 million
particles of microplastic released into soils.

In summary, the microplastics accumulating in soils and plants from utilizing biosolids for agricultural purposes are a serious concern for the health of humans and the sustainability of the environment. The findings of this study have provided insights and an overview into the sources, distribution, and potential impacts of microplastics through the application of biosolids to agricultural activities. As a result, there is a potential of 182 – 293 million particles of microplastic (approximately 0.21 – 4.3 tons in weight) that could be released into the agricultural soils every year in BC by applying biosolids to agricultural activities. A large number of microplastics in agricultural ecosystems has potentially harmful impacts on the soil's quality by alternating its water retention capacity, soil microbial functions, immobilization of nutrients required for plant growth, and finally potentially available to humans through the food web. In addition, microplastics cause strong impacts on both aquatic and terrestrial ecosystems through their residual, slow degradation, and physical-chemical conversion over time.

Raise awareness among the public, wastewater treatment operators, biosolids producers, farmers and policymakers about the issue of microplastics in biosolids. Encouraging a reduction in the use of plastics and promoting responsible waste disposal practices is very important for sustainable microplastic management in agriculture. Besides, the issue of microplastic contamination in biosolids used for urban farms and community gardens requires urgent attention to ensure the safety of food production and protect the health of individuals consuming harvested crops.

In summary, the removal of microplastics from biosolids will require a combination of regulatory measures, technological advancements, public awareness, and collaborative efforts across various industries. Taking these steps can mitigate the adverse effects of microplastics on the environment and human health.

10. Limitations

The potential microplastics that could be released into agricultural soils in BC in this study are estimated according to the literature review from the previous studies in another region rather than BC. This is a source of error as the quality of biosolids production is different among the producers. As a result of the project's scope and timeframe, all published studies on the topic may not be included, which could result in the omission of important findings.

Therefore, there is an emerging need for further study on specified biosolids productions and practical experimental data should be conducted from the farms in BC in future.

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Appendices

Appendix 1. Biosolids production and counts of microplastics in biosolids

Country	Population (million)	Biosolids production (million metric tonnes /year)	The average number of microplastic particles in sludge (particles/g biosolids dry weight)
Italy	60	1	113
Germany	80	2	40.1 ± 24
Finland	5	0.1	27.3
Sweden	10	0.2	17
Canada	37	0.7	9.65 ± 5.2
Ireland	4	0.004	8.5 ± 1.6
China	1400	35	8.03 ± 8
US	332	6	2.5 ± 1.5
Korea	77	4	2.2 ± 0.3
Scotland	5	0.1	1
Norway	5	0.1	0.8 ± 0.4
Netherlands	17	0.6	0.45 ± 0.2

(Source of data: Rolsky et al. (2020))

Appendix 2. Summary of biosolids products of some regional cities in BC

City	Quantity of biosolids	Product name	Biosolids Treatment processes	Percentage of Class A biosolids in production	Beneficial applications
Greater Vancouver Regional District	17,500 dry tonnes/year (Bright & Healey, 2003)	Nutrifor	Thermophilic anaerobic digestion	80%	Mine reclamation, landfill closure, regional landscaping, forest fertilization, ranch land fertilization.
City of Kamloops, Silver Star, Lake Country, Vernon, and Kelowna	6855 dry tonnes/year* (City of Kamloops, n.d.; City of Kelowna, 2021)	Ogogrow, Ingerbelle	Aerated static pile composting	100%	Commercial landscaping, residential gardening, nurseries & orchards, landfill closure
Capital Regional District, Victoria Island	3173 dry tonnes/year (Capital Regional District, 2023)	PenGrow	RDF Lime-pasteurization	5%	Alternative fuel at Lafarge in Richmond, land applied at Hartland Landfill Residential gardening and landscaping
Regional District of Nanaimo	7,500 dry tonnes/year (Regional District of Nanaimo, 2023c)	-	Mesophilic and Thermophilic anaerobic digestion	30%	Class A & B for Forest Fertilization Program & Soil Fabrication Program
Comox/Strathcona Regional District	-	SkyRocket	Aerated static pile composting	100%	Commercial landscaping, residential gardening, nurseries and orchards, slope stabilization project, and local reclamation projects.

(*) Estimated from 12,500 from Kamloops and 33,205 of wet tonnes from other cities with ~ 15% of solid in centrifuged & dewatered wet biosolids)

Source: Capital Regional District (2017)

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