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## **One Health benefits greatly from sustainable farming methods.**

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### **Research Article**

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### **Abstract**

According to the One Health philosophy, human, animal, and environmental health are all related. Since food connects human health and the environment, agricultural production is essential to One Health. In addition to giving people nutrition, food is a major source of exposure to potentially dangerous agrochemicals and environmental microorganisms. Furthermore, improper agronomic techniques might harm the ecosystem, which may have unforeseen negative effects on human health. Therefore, as they are closely related, enhancing agricultural production systems and safeguarding environmental health shouldn't be seen as separate objectives. Here, we addressed sustainable agricultural production from the standpoint of One Health using the intersection of soil, plant, and human microbiomes. We outlined three interrelated issues that contemporary agronomic methods must deal with: the spread of antibiotic resistance genes in agroecosystems, the transmission of infections in soil-human microbial loops, and the effects of chemical pesticides on human and environmental health. Lastly, we suggest that using microbiomes to improve sustainable agronomic practices might help achieve some of the main objectives of the One Health concept.

### **KEYWORDS**

Soil microbiome, One Health, antibiotic resistance, agrochemicals, and sustainable agriculture

### **INTRODUCTION**

According to van Bruggen et al. (2019), the One Health concept underlines the relationships between people, animals, and the environment and offers a worldwide strategy that stresses the need of holistic and transdisciplinary methods to enhancing the health and well-being of all components of an ecosystem. Since food is the connection between soil, plants, and animals and human health, agricultural production methods and practices are essential to the One Health concept. In addition to giving people nourishment, food serves as a primary conduit for exposure to both biotic (like diseases) and abiotic (like pesticides or other chemical pollutants) environmental dangers. For instance, eating fruits and vegetables—which are often consumed raw—is known to be a significant way for pathogens and antibiotic resistance genes (ARGs) to enter the human gut microbiota. According to Nicolopoulou-Stamati et al. (2016), food production and consumption are significant sources of human exposure to chemical pesticides, which have been shown to result in several hundred thousand fatalities per year. Furthermore, chronic toxicity linked to long-term chemical pesticide exposure may result in birth abnormalities and cancer (Nicolopoulou-Stamati et al., 2016). Furthermore, it has been shown that the improper and excessive use of agrochemicals harms the ecosystem and causes issues including pollution, resource depletion, soil erosion, and biodiversity loss (Garcia et al., 2020). According to Destoumieux-Garzón et al. (2018), the fundamental tenet of One Health is that human welfare would

be seriously jeopardised in an environment that is harmed by pollution and constantly depleting resources. In order to guarantee food and nutrition security and protect Earth's limited resources, numerous governmental organisations and academic societies have continuously advocated for the creation of novel sustainable agricultural production strategies from the One Health perspective (Food and Agricultural Organization of the United Nations, 2020; National Academies of Sciences, Engineering, and Medicine, 2019). Soil health was not explicitly included in One Health principles, which historically concentrated on the relationship between human and animal health (Zinsstag et al., 2011). However, soil is crucial in influencing human and environmental health (Zhu et al., 2019). A robust microbial loop that transfers chemicals, bacteria, and nutrients between soil and people via plants and animals connects the health of the environment and humans in an ecosystem (Figure 1). Thus, it is essential to design sustainable agronomic techniques that are successful while taking into account the connection between human health and soil health (van Bruggen et al., 2019). In order to illustrate the complex and dynamic connections between human health and sustainable agricultural production from the One Health viewpoint, we chose microbes and chemicals as the link in this essay. We specifically focused on three main

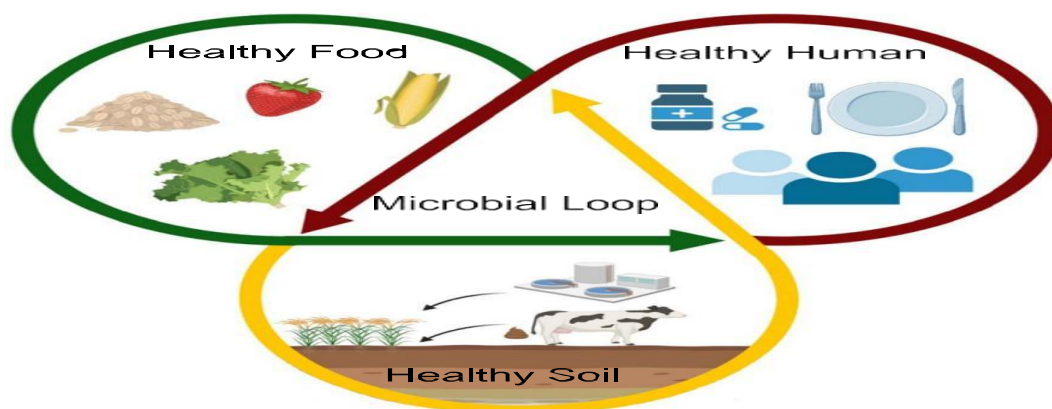


**FIGURE 1** A paradigm that shows how soil, food, and human health are interrelated. A microbial loop connects soil microbiomes, human health, and food safety and security in the terrestrial environment. In addition to being the primary source of food and energy for people, plants also fix atmospheric carbon, which directly affects the security of human food and nutrition. Soil microbiomes control plant nutrient uptake and disease resistance. Additionally, agronomic methods like applying manure to reclaimed wastewater irrigation might affect the soil microbiome by introducing human diseases and antibiotic resistance genes, which will eventually affect human health via plant-based diets. issues related to agronomic practices under the One Health concept, including the possibility for human infections to spread via soil microbial loops, the spread of ARGs in agroecosystems, and the effects of chemical pesticides on human and environmental health. Finally, we suggested how managing the soil and plant microbiomes may help achieve the One Health concept's objectives.

### **1 | SOIL MICROBIAL LOOP– A MICROBIAL LOOP BETWEEN THE BELOW AND ABOVE GROUND**

It is essential to comprehend the connections between the aboveground and belowground that are mediated by microbes (Figure 1). Plants fix atmospheric carbon and provide energy and carbon to heterotrophic ecosystem components, such as animals and microorganisms, in the interconnected ecological processes of terrestrial ecosystems (Walker et al., 2003). In addition to the deposition of litter, terrestrial plants release a significant amount of organic carbon into the rhizosphere via volatiles, soluble root exudates, mucilage, and sloughed-off root cells and tissues (Kuzakov & Razavi, 2019; Walker et al., 2003). The soil life, including bacteria, fungus,

and soil animals, is supported by this carbon produced from plants. In exchange, plant nutrient uptake, disease resistance, and primary production are all regulated by soil microbes and fauna (Huhta, 2007). Through the xylem and phloem system or soil/air dissemination, a considerable proportion of microbial species found in the rhizosphere and bulk soil may colonise the phyllosphere (Liu et al., 2017). Plant health and ecosystem functioning are known to be impacted by the phyllosphere microbiome (Laforest-Lapointe et al., 2016; Liu et al., 2017; Vorholt, 2012). More significantly, the nectar and pollen of flowers, which are components of the phyllosphere, have distinct microbiomes (Morris et al., 2020). These microbiomes include microbial taxa including *Stenotrophomonas*, *Sphingomonas*, and *Microbacterium* that are also shared by several insect pollinator species, mostly in the gut systems (Anderson et al., 2013; McFrederick et al., 2012). Pollinator visiting preferences and nectar odour are influenced by floral microbiomes (Schaeffer et al., 2017). It's interesting to note that beneficial microorganisms may spread to seeds and add to their microbiomes (Mitter et al., 2017). Furthermore, pollinators have the ability to spread plant diseases and helpful microorganisms within plant communities (Mitter et al., 2017). In addition to the microorganisms found in plants and bulk soil, the soil microbial loop also includes bacteria that live on the surface and in the digestive tracts of soil fauna. More than 20% of all known animals on Earth are soil fauna, and their microbiomes control their health and activity, which in turn affect important ecosystem processes ranging from primary production to the breakdown of soil organic matter (Bardgett & van der Putten, 2014). Soil bacteria and fungus may be directly consumed by some soil creatures, including protists, nematodes, and micro-arthropods. Nonetheless, these organisms often have dietary preferences. For instance, protists like Gram-negative bacteria due to their ease of digestion (Chahartaghi et al., 2005; Ruess et al., 2000). As a result, these microbe-consumers have the ability to alter the variety and composition of soil microbiomes while also decreasing their abundance. Additionally, the soil microbiome and plant-microbiome selection are subject to trophic cascade effects. Predatory mites, beetles, and spiders are examples of top predators of the soil that primarily consume the microbial consumers (protists, nematodes, and microarthropods) mentioned above. These predators can have a variety of cascading effects on the soil microbiome and affect the competitive outcomes between soil bacteria and fungi (Ripple et al., 2016). The richness and composition of the soil microbiome are ultimately influenced by intricate biotic interactions, which are predicted to have a domino effect on the health of humans, animals, and plants. The precise processes and extent of the soil food web on plant and animal microbiomes and their health, however, are still poorly known and need systematic research to further our understanding.

## **2 | THE TRANSMISSION OF BENEFICIAL MICROBES AND HUMAN PATHOGENS IN AGRICULTURAL SYSTEM**

It is well recognised that soil is home to a wide variety of microorganisms and serves as a rich microbial seed bank for the microbiome of plants. Crop development and agricultural production depend on interactions between plant and soil microbiomes (Hassani et al., 2018; Müller et al., 2016; Singh et al., 2020). According to Baumgardner (2012) and Steffan et al. (2020), soil microbiomes provide several advantages to the crop host; yet, some potential pathogens that reside in soils may spread to the human system via the soil-plant-food continuum. Finding helpful microorganisms for crops and shielding them from harmful bacteria is one of the biggest difficulties in sustainable agricultural production from a One Health viewpoint. In order to enhance plant development and health, several recent studies have concentrated on identifying keystone species of the plant microbiome and using synthetic microbial consortia (such as *Variovorax*, *Sphingomonas*, *Chitinophaga*, and *Flavobacterium*) (Carrión et al., 2019; Finkel et al., 2020; Matsumoto et al., 2021). It is crucial to assess how these technologies may affect soil-borne human pathogen survival, abundance, dispersion, and transmission as they are being developed. It is significant because soil is a reservoir for many human pathogens, which are among the main causes of infectious illnesses linked to human misery and death (Gerba & Smith, 2005). Numerous microorganisms, such as bacteria, fungi, viruses, protozoa, and helminths (nematodes), may be soil-borne human pathogens (Gerba & Smith, 2005). These pathogens often cause

respiratory tract, gastrointestinal, wound, and skin infections in people. They may also cause catastrophic illnesses including botulism, anthrax, and tetanus (Baumgardner, 2012). Soil-borne human pathogens are often classified as permanent, periodic, temporary, and incidental based on the duration of their presence (Table 1) (Brevik et al., 2020). Permanent pathogens like *Listeria monocytogenes*, *Clostridium tetani*, and *Clostridium botulinum* are soil residents that may complete their life cycle in soils and sometimes become infectious to people (Nieder et al., 2018; Samaddar et al., 2021). *L. monocytogenes* causes gastrointestinal disorders and more severe meningitis via food and drink, whereas *C. botulinum* and *C. tetani* may create neurotoxins that paralyse muscles and can cause death (Steffan et al., 2020). Microorganisms that spend a portion of their life cycle in soil environments are known as periodic pathogens. *Bacillus anthracis*, for instance, is present in soils all over the globe and

**TABLE 1** Soil-borne human pathogens and their potential transmission routes

| Causative agent                  | Disease                                 | Transmission route               | References                     |
|----------------------------------|-----------------------------------------|----------------------------------|--------------------------------|
| <i>Clostridium botulinum</i>     | Produce toxins paralyzing muscles       | Vegetables, fruits, meats, water | Smith (1978)                   |
| <i>Clostridium tetani</i>        | Tetanus                                 | Vegetables, fruits, meat         | Smith (1978)                   |
| <i>Listeria monocytogenes</i>    | Gastrointestinal illness and meningitis | Vegetables, fruits, water        | Vivant et al. (2013)           |
| <i>Bacillus anthracis</i>        | Zoonotic disease anthrax                | Meats                            | Helgason et al. (2000)         |
| <i>Salmonella enterica</i>       | Gastrointestinal illness                | Vegetables, fruits               | Schierstaedt et al. (2020)     |
| <i>Escherichia coli</i> O157:H7  | Gastrointestinal illness                | Vegetables, fruits, water        | Mootian et al. (2009)          |
| <i>Burkholderia pseudomallei</i> | Pneumonia and melioidosis               | Vegetables, fruits               | Limmathurotsakul et al. (2016) |
| <i>Legionella longbeachae</i>    | Legionnaires' Disease                   | Water                            | Steffan et al. (2020)          |
| <i>Campylobacter spp</i>         | Gastrointestinal illness                | Vegetables, fruits, meats, water | Silva et al. (2011)            |
| <i>Clostridium perfringens</i>   | Gastrointestinal illness                | Vegetables, fruits, meat         | García and Heredia (2011)      |
| <i>Francisella tularensis</i>    | Tularaemia                              | Meats                            | Baumgardner (2012)             |
| <i>Yersinia pestis</i>           | Pneumonic and bubonic plague            | Meats                            | Steffan et al. (2020)          |
| <i>Histoplasma capsulatum</i>    | Histoplasmosis                          | Vegetables, fruits               | Steffan et al. (2020)          |
| <i>Coccidioides immitis</i>      | Valley fever                            | Vegetables, fruits               | Steffan et al. (2020)          |
| <i>Blastomyces dermatitidis</i>  | Blastomycosis                           | Vegetables, fruits               | Klein et al. (1986)            |

cause animals, wildlife, and people to get the zoonotic illness anthrax (Steffan et al., 2020). According to Nieder et al. (2018) and Samaddar et al. (2021), transient and accidental pathogens are organisms that either naturally reside in soils (for example, via animal contact) or are introduced into the soils from anthropogenic causes. For instance, agronomic methods may introduce the infamous food pathogen *Salmonella enterica* and the Shiga toxin-producing *Escherichia coli* into agricultural soil, posing serious risks to public health (Samaddar et al., 2021). For example, 93.8 million foodborne illnesses are estimated to be caused by *Salmonella enterica* infections annually (Eng et al., 2015). Effective control of the existence and pathogenicity of human diseases requires an understanding of their mode of transmission (Figure 2). Pathogens may often infect humans by directly entering their systems via contaminated food, such as fruits and vegetables (Beuchat, 2002). The use of animal dung as fertiliser and irrigation with polluted wastewater offer significant avenues for viruses to enter the human food chain, even though the transmission of these diseases in agricultural systems is still mostly unknown (Barak & Schroeder, 2012; Chen & Jiang, 2014). Therefore, the first step in accomplishing

One Health objectives should be to effectively manage the pathogens in animal waste and irrigation water to lower the virulence and transmission of human infections in agricultural systems. Furthermore, physical touch and inhalation of contaminated soil may be a major mechanism for soil-borne viruses to infect humans, thus this should be avoided. Furthermore, soil-borne diseases are also spread by insects and other animals (Sela et al., 2005). Human sickness may be reduced by maintaining good cleanliness and preventing infections from animal vectors in the first place. Furthermore, it has been acknowledged that soil-borne human diseases' survival and success are significantly influenced by biotic and abiotic soil variables, such as microbial diversity and nutrient availability (Bultman et al., 2013; Schierstaedt et al., 2020; Semenov et al., 2009). *Salmonella enterica* and *Escherichia coli* O157:H7, for example, are human diseases that prefer to dwell in nutrient-rich soil (Semenov et al., 2009), but *L. monocytogenes* relies on soil acidity and microbial communities to survive (Schierstaedt et al., 2020). One Health method,

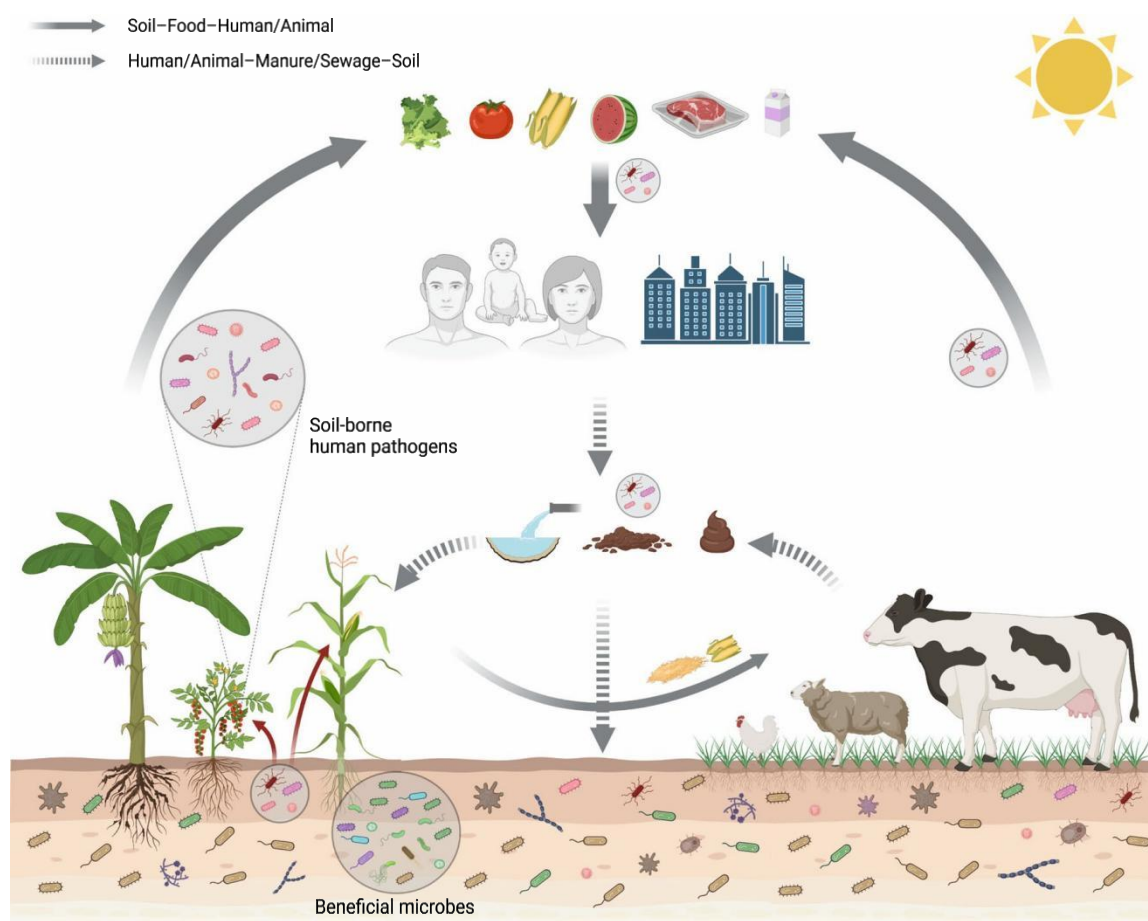


**FIGURE 2;** human pathogen transmission loop including human systems, plants, animals, and agronomic production. Microbiomes in plants, animals, and surroundings are one aspect of health. Plant health and production, as well as soil functions, are substantially determined by soil microbiomes and their interactions. The rhizosphere's soil microbiomes are directly drawn from the bulk soil and are essential to the biology and plant activities of the rhizosphere. These microorganisms may infect people via raw foods and contribute to the phyllosphere microbiomes of fruits, seeds, flowers (including nectar and pollens), and leaves. via soil application, soil-borne pathogens enhanced in crops (such as via wastewater and raw manure polluted water) may enter the food chain and directly affect human health. Food safety and human health so depend on

healthy soil with much lower human pathogen loads. hence necessitates careful observation of possible soil-borne human diseases in various ecosystem components. We know very little about how agronomic practices affect the distribution and spread of soil-borne human diseases. Although soil populations and functions are known to be impacted by global changes (such as land use and climate change), little is known about how these changes will affect soil-borne human diseases and their virulence and transmission.

### 3 | ANTIMICROBIAL RESISTANCE IN AGRICULTURAL SYSTEMS

The development and transmission risk of antimicrobial-resistant organisms have drawn considerable attention from health professionals, politicians, and the general public, despite the fact that antibiotics are essential for preserving human and animal health (Hofer, 2019; Kümmerer, 2003; Sugden et al., 2016). One of the main challenges to global public health and food security, which is a key component of the One Health concept, is antimicrobial resistance (Hernando-Amado et al., 2019). In particular, environmental ARGs that are very likely to be acquired and confer resistance by human infections are seen as a major public health problem (Martinez et al., 2015). Numerous earlier research have examined and described the clinical significance of ARGs in soil settings as well as the shared antibiotic resistomes between human pathogens and the soil microbiome (Esiobu et al., 2018; Forsberg et al., 2012). The most significant cause contributing to the rise of AMR is thought to be the frequent use of antimicrobial medications, which are extensively used in aquaculture, animal farming, and human medicine (Figure 3 and Table 2) (Hernando-Amado et al., 2019; Holmes et al., 2016). Industrial livestock production is thought to account for two-thirds of the world's antibiotic consumption. According to a Chinese study, for instance, veterinary antibiotics accounted for 84.3% of all antibiotic consumption (pig: 52.2%, chicken: 19.6%, and other animals: 12.5%), whereas human medications only accounted for

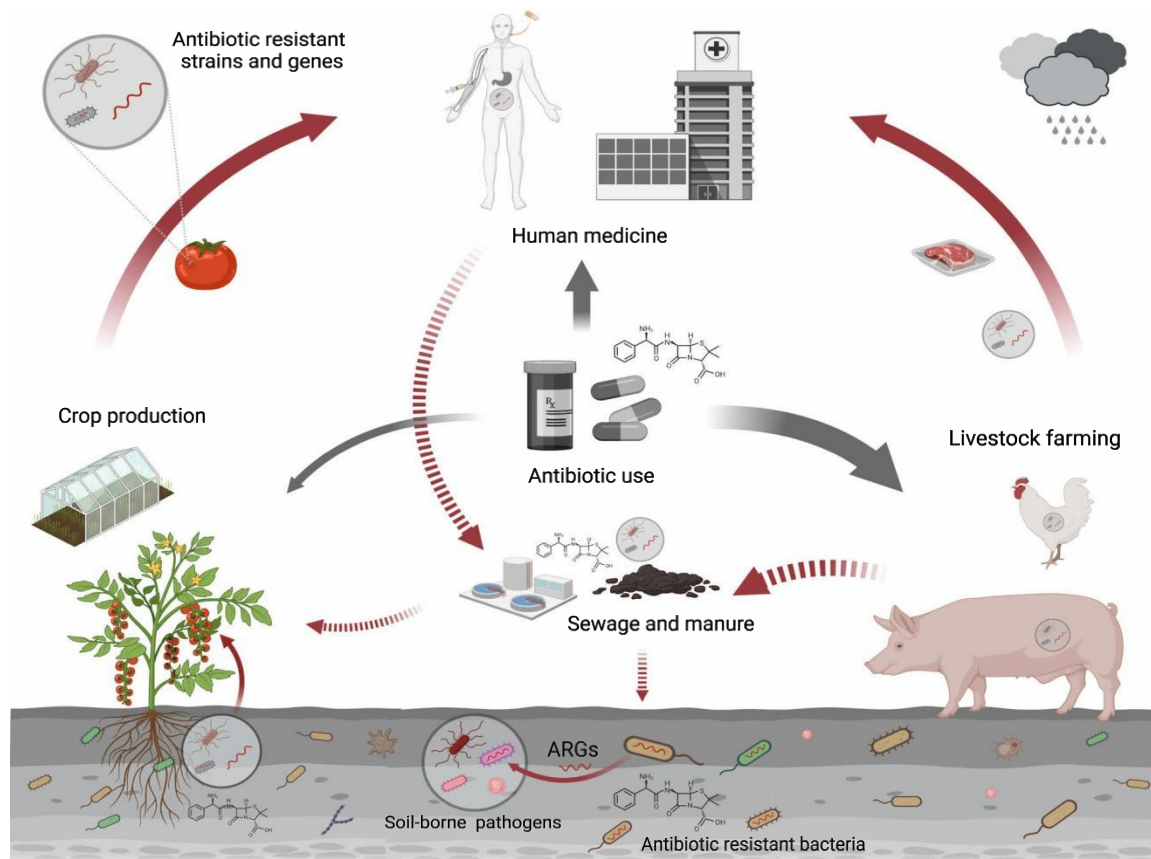


**FIGURE 3;** The use of antibiotics and the spread of antibiotic resistance genes across agricultural and human systems. One of the main sources of selection pressure for antibiotic

resistance genes is the use of antibiotics in agricultural production, animal husbandry, and human medicine. In particular, overuse of antibiotics as growth promoters in animal husbandry contributes significantly to the emergence and spread of antibiotic resistance. Sewage sludges and animal dung may carry antibiotic residues, antibiotic-resistant bacteria, and genes to agricultural soils, where they can then spread to the crop microbiome and the human food chain. Food intake may introduce antibiotic resistance genes into the human microbiome, posing a threat to public health.

**TABLE 2** Use of antibiotics in the human medicine and farming industries

| System            | Name                                                                          | Category                          | References                                                    |
|-------------------|-------------------------------------------------------------------------------|-----------------------------------|---------------------------------------------------------------|
| Human medicine    | Cephalexin, Amoxicillin, Penicillin                                           | $\beta$ -lactams                  | Kümmerer (2003);<br>Zhang et al. (2015)                       |
|                   | Erythromycin-H <sub>2</sub> O                                                 | Macrolides                        |                                                               |
|                   | Ofloxacin, Norfloxacin,                                                       | Ciprofloxacin<br>Fluoroquinolones |                                                               |
|                   | Tetracycline                                                                  | Tetracyclines                     |                                                               |
|                   | Trimethoprim                                                                  | Sulfonamides                      |                                                               |
|                   | Lincomycin                                                                    | Others                            |                                                               |
| Livestock farming | Amoxicillin, Penicillin                                                       | $\beta$ -lactams                  | Zhang et al. (2015);<br>Shao et al. (2021); Zhu et al. (2013) |
|                   | Florfenicol, Lincomycin, Chloramphenicol                                      | Others                            |                                                               |
|                   | Tylosin, Erythromycin-H <sub>2</sub> O,                                       | Leucomycin, Macrolides            |                                                               |
|                   | Ciprofloxacin, Enrofloxacin, Norfloxacin, Ofloxacin, Pefloxacin, Lomefloxacin | Fluoroquinolones                  |                                                               |
|                   | Doxycycline, Oxytetracycline                                                  | Tetracyclines                     |                                                               |
|                   | Sulfamonomethoxine, Sulfadiazine, Sulfaquinoxaline,                           | Sulfonamides                      |                                                               |
| Crop production   | Streptomycin                                                                  | Aminoglycoside                    | Sundin and Wang (2018);<br>Stockwell and Duffy (2012)         |
|                   | Oxytetracycline                                                               | Tetracycline                      |                                                               |
|                   | Gentamicin                                                                    | Aminoglycoside                    |                                                               |
|                   | Oxolinic acid                                                                 | Others                            |                                                               |
|                   | Carbenicillin, Cefotaxime, Timentin                                           | $\beta$ -lactams                  |                                                               |
|                   |                                                                               |                                   | Grzebelus and Skop (2014)                                     |

15.6% (Zhang et al., 2015). Veterinary antibiotics such as  $\beta$ -lactams (e.g., amoxicillin and penicillin), tetracyclines (e.g., doxycycline and oxytetracycline), sulphonamides (e.g., sulfamonomethoxine and sulfa-quinoxaline), and fluoroquinolones (ciprofloxacin and enrofloxacin) are often used as veterinary drugs and growth promoters in the livestock industry (Table 2) (Sha et al., 2021; Zhang et al., 2015). The residues

Sewage sludge and manure may carry these drugs, together with the antimicrobial-resistant strains and genes they enrich, to agricultural soils (Zhu et al., 2013). From there, they can spread to human microbiomes via crop microbiomes. Furthermore, certain antibiotics, such as oxytetracycline and streptomycin, may penetrate soil systems directly when used in plant production to suppress plant-pathogenic bacteria such *Pseudomonas syringae* and *Erwinia amylovora* (Table 2) (Sundin & Wang, 2018). Livestock farms have developed into a significant source of antimicrobial-resistant bacterial strains and genes as a result of the overuse of antibiotics for treatment and growth promotion in animal husbandry (Zhu et al., 2013). Therefore, cutting down on needless antibiotic use in intensive livestock husbandry is a major component of the current One Health strategies to prevent AMR (Hoelzer et al., 2017). Numerous research have shown correlations between decreased antibiotic usage in animal husbandry and decreased ARG abundance in animal-based food items (Hoelzer et al., 2017; Scott et al., 2018). Prior research evaluated the variety and abundance of ARGs in three large-scale swine farms and discovered a clear correlation between ARG abundance and metal and antibiotic concentrations (Zhu et al., 2013). The intricacy of AMR transmission in the agricultural microbial loop is suggested by the little evidence of comparable alterations of ARGs in human microbiota, which also calls into question the role of plant microbiomes in controlling the transfer of ARGs from soil to humans. AMR may arise and spread in agricultural environments due to factors other than the selection pressure imposed by antibiotics. Heavy metals like copper, zinc, mercury, and arsenic, for instance, may serve as co-selection factors for ARGs and aid in the spread of AMR in agricultural environments. This is due to the high degree of similarity between the antibiotic resistance system and the prokaryotic metal-resistance system (Hu et al., 2016; Ji et al., 2012). Furthermore, a rise in the incidence of ARGs in agricultural soils was linked to agronomic practices, such as the use of chemical herbicides (Liao et al., 2021). Through the food chain, sewage sludge, and manure, antimicrobial-resistant strains and genes may transfer between human systems and agroecosystems. Animal manures have a dual effect on agricultural productivity and the spread of ARGs (Figure 3) (McEwen & Collignon, 2018). Organic farming often uses animal dung and sewage sludge as organic fertilisers to recycle nutrients. But these actions may also greatly accelerate the spread of ARGs in agroecosystems. The bulk of ARGs in municipal wastewater, a rich reservoir of ARGs, are released in sewage sludge since existing wastewater treatment methods are ineffective in eliminating ARGs (Munir et al., 2011). Animal manures, in contrast to sewage sludge, may include large concentrations of undigested antibiotics in addition to being a rich source of ARGs (Kumar et al., 2005). Plants may absorb these undigested antibiotics from the soil, which might put ARGs in the plant microbiome under selection pressure (Kumar et al., 2005). More significantly, bacteria may readily spread ARGs via mobile genetic elements due to the existence of horizontal gene transfer (Figure 3). Both animal dung and sewage sludge have been shown to be hotspots for bacteria that transport mobile genetic elements, which increases horizontal gene transfer in soil and plant microbiomes when applied as organic fertiliser (Zhu et al., 2017). For instance, it has been observed that some pathogenic strains that contain ARGs, including *sul1* and *sul2*, are likely capable of transferring ARGs from the soil or manure to the plant microbiome. Sun et al. (2020) and McEwen & Collignon (2018). The hazards of ARG spread associated with agricultural organic fertilisation have been the subject of several investigations. One significant discovery was that lettuce grown organically has around eight times as many ARGs than lettuce grown conventionally using mineral fertilisers (Zhu et al., 2017). Therefore, improving nutrient recycling techniques is crucial for more sustainable agricultural production. According to a recent research on the wastewater treatment plant, readily biodegradable materials like sodium acetate (NaAc) may dramatically lower the quantity of human bacterial pathogens, mobile genetic element-mediated ARGs, and antibiotics (Zhang et al., 2022). When used in organic fertiliser composting, biochar, a popular soil supplement, has also been shown to be successful in lowering the possibility of ARG spread (Chen et al., 2018). The potential environmental risks in the microbial loop and the ecological and biological mechanisms underpinning the ARG reduction should be further assessed.

The emerging materials and approaches have great potential for developing sustainable and effective agronomic practices to reduce the transfer of ARGs in the future.

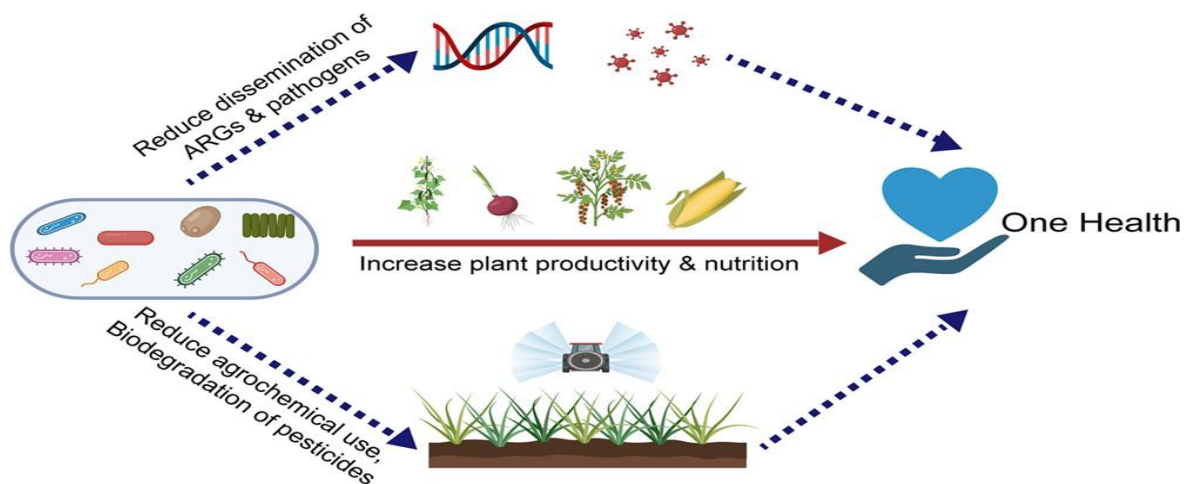
#### **4 | IMPACTS OF CHEMICAL PESTICIDES ON HUMAN AND ENVIRONMENTAL HEALTH**

Agrochemicals have been used excessively in traditional agronomic procedures to fulfil the ever-increasing demand for food. The detrimental effects of agrochemicals, especially chemical pesticides—a class of chemicals used to shield plants from insects, weeds, or harmful microorganisms—on the environment and human health make this problematic (Nicolopoulou-Stamati et al., 2016). According to Nicolopoulou-Stamati et al. (2016), occupational and unintentional skin, ingestion, or inhalation contact are the most frequent ways that chemical pesticides may harm human health. Due to the widespread presence of pesticide residues in food and drink (such as fruits, vegetables, wine, and water), food intake is another significant way that humans are exposed to chemical pesticides (Nicolopoulou-Stamati et al., 2016). Numerous studies have shown that exposure to popular chemical pesticide types is linked to a variety of long-term health problems (Table 3). The majority of nations have prohibited or limited the use of chemical pesticides that have been linked to serious health impacts (Yadav et al., 2015), yet the public health risks connected with these pesticides remain. In soil environments, pesticides may be stable and take months to years to degrade (Cremlyn, 1978). Organo-chlorine insecticides, for instance, have half-lives of many decades and are quite stable (Cremlyn, 1978). The chemical makeup of the pesticide, microbial and photochemical modification, sorption, and plant absorption are some of the elements that control how long chemical pesticides remain in soil (Gevao et al., 2003). According to estimates, even very low pesticide concentrations may linger in agricultural soil and have detrimental impacts on human health (Yadav et al., 2015). Because the majority of chemical pesticides are lipophilic, they may bioaccumulate in the human body via food cultivated in pesticide-polluted soils, including in blood, fatty tissue, and breast milk (Yadav et al., 2015). The insecticide dichlorodiphenyl-trichloroethane (DDT), which is widely distributed in nearly all organisms on Earth due to its long-persistent and slow biodegrading properties, is a well-known example of an organochlorine pesticide. It is acknowledged as the cause of numerous environmental and human health problems. According to Beard and Collaboration (2006), organochlorine pesticides generally cause endocrine disorders, disrupt the reproductive system, cause cancer, and affect lipid metabolism (Eskenazi et al., 2006; Karami-Mohajeri & Abdollahi, 2011; Loomis et al., 2015; Saiyed et al., 2003; Tiemann, 2008; Turusov et al., 2002). Organophosphorus is a significant class of chemical pesticides. Organophosphorus insecticides were first used in agricultural production as a greener substitute for organochlorines. Organophosphorus, however, has also been linked to a number of detrimental health effects, such as endocrine and neurotoxic effects, effects on nutrient metabolism, and genotoxic effects (Ezzi et al., 2016; Fritschi et al., 2015; Karami-Mohajeri & Abdollahi, 2011; McKinlay et al., 2008). Similar to this, other chemical pesticide groups including triazines and carbamates have also been linked to major health issues (Goad et al., 2004; Karami-Mohajeri & Abdollahi, 2011; Kniewald et al., 2000; Liu et al., 2006; Wen et al., 2021). Excessive use of chemical pesticides not only directly affects human health but also indirectly impedes the achievement of One Health ideals by harming environmental health, including biodiversity loss and detrimental effects on soil health. Glyphosate, a herbicide that has been deemed safe, is an excellent example. But according to current research, glyphosate is linked to changes in the microbial community compositions of soil, rhizosphere, and plant endosphere (Hirt, 2020; Van Bruggen et al., 2018). Furthermore, glyphosate treatment decreased plant growth-promoting microbes including mycorrhizal fungi and nitrogen-fixing bacteria, even at a lower than advised dosage, according to another recent research (Van Bruggen et al., 2018). Furthermore, eating glyphosate-contaminated food may impede healthy human gut microbes including *Enterococcus* and *Bifidobacterium* (Van Bruggen et al., 2018). Furthermore, the loss of crucial symbiotic bacteria for plant nutrients may result from chemical pesticides' documented detrimental effects on soil microbial diversity, which might have an influence on crop quality (Hirt, 2020). Captured

**TABLE 3** Commonly used chemical pesticides and their chronic health effects

| Chemical class   | Example                               | Direct impact on human          | Reference                               |
|------------------|---------------------------------------|---------------------------------|-----------------------------------------|
| Organochlorine   | Dichlorodiphenyltrichloroethane (DDT) | Carcinogenic                    | Turusov et al. (2002)                   |
|                  |                                       | Disruption endocrine system     | Turusov et al. (2002)                   |
|                  |                                       | Neurodevelopmental effects      | Eskenazi et al. (2006)                  |
|                  | Endosulfan                            | Interfere sex hormone synthesis | Saiyed et al. (2003); Sun et al. (2020) |
|                  | Lindane                               | Carcinogenic                    | Loomis et al. (2015)                    |
|                  |                                       | Impact development embryonic    | Tiemann (2008)                          |
| Organophosphates | Tris (4-chlorophenyl methanol (TCPM)  | Impact development embryonic    | Tiemann (2008)                          |
|                  | Methoxychlor                          | Impact development embryonic    | Tiemann (2008)                          |
|                  | Glyphosate                            | Probably carcinogenic           | Fritschi et al. (2015)                  |
|                  |                                       | Endocrine disruptors            | Fritschi et al. (2015)                  |
|                  | Chlorpyrifos                          | Genotoxic                       | Ezzi et al. (2016)                      |
|                  | Malathion                             | Probably carcinogenic           | Fritschi et al. (2015)                  |
|                  |                                       | Genotoxic                       | Moore et al. (2010)                     |
|                  |                                       | Cytotoxic                       | Moore et al. (2010)                     |
|                  | Diazinon                              | Probably carcinogenic           | Fritschi et al. (2015)                  |
|                  | Parathion                             | Possibly carcinogenic           | Fritschi et al. (2015)                  |
| Carbamates       | Tetrachlorvinphos                     | Possibly carcinogenic           | Fritschi et al. (2015)                  |
|                  | Carbofuran                            | Endocrine disruptors            | Goad et al. (2004)                      |
|                  |                                       | Impacting reproductive system   | Karami and Abdollahi (2011)             |
| Triazines        | Ziram                                 | Inhibit sperm mobility          | Wen et al. (2021)                       |
|                  | Atrazine                              | Cause reproductive disorder     | Kniewald et al. (2000)                  |
|                  |                                       | Cytotoxic                       | Liu et al. (2006)                       |

## 5 ANT MICROBIOMES TO IMPROVE SUSTAINABLE AGRICULTURAL PRODUCTION



In order to achieve sustainable agricultural output while limiting toxic impacts on human health, we propose that using soil and plant microbiomes might be a major contribution (Figure 4). By boosting plant yield and nutritional quality while simultaneously reducing the environmental impact of agricultural production, soil and plant microbiomes may directly contribute to food production (Singh & Trivedi, 2017). Increasing agricultural yield by manipulation of soil and rhizosphere microbiomes has been proposed by a number of research. targeted implementation of

#### **FIGURE 4**

A framework to show how microorganisms might be used to enhance agricultural production's sustainability and accomplish One Health's goals. Increasing crop yield and nutrient quality by direct manipulation of soil and plant microbiomes may contribute to food security. Increased soil microbial diversity may indirectly aid in the biodegradation of pesticide residues and lessen the risks to human health posed by the spread of soil-borne human diseases and antibiotic resistance genes (ARGs). Plant development and nutrient absorption have been shown to be enhanced by beneficial microorganisms that promote plant growth (Egamberdiyeva, 2007; Fiorentino et al., 2018). For instance, it has been shown that inoculating a variety of plants, such as tomatoes, onions, cucumbers, and tea plants, with Arbuscular mycorrhizal fungi can improve their quality and productivity (Gashaw Deressa & Schenk, 2008; Hu et al., 2013; Ortas et al., 2013; Watts-Williams et al., 2014). Furthermore, ecological processes that are essential to the long-term sustainability of food systems and human well-being are significantly influenced by the functioning of the soil microbiome (Chen et al., 2019a; Wagg et al., 2014). According to Delavaux et al. (2017), targeted management of soil microbiomes is likely to change soil microbial interactions with plants and with each other, which are linked to improvements in soil stability, aggregation, and moisture dynamics as well as plant resistance to biotic and abiotic stresses. However, there has been relatively little effective use of microbial manipulation in outdoor settings so far. The intricate soil-plant microbial interaction involved in using soil microorganisms to maximise sustainable agricultural production techniques still need research. Because soil microbiomes may be able to address the main obstacles to sustainable agriculture production, they may also indirectly support the objectives of One Health principles. One of the most important issues facing food cultivation is the development and spread of ARGs. Although it is linked to the danger of ARG diffusion, animal manure is often used as an organic fertiliser in sustainable agricultural production to recycle nutrients and reduce the usage of artificial fertilisers (Chen et al., 2017). The proliferation and selection for ARGs in the soil environment were found to be negatively correlated with the diversity of soil indigenous microorganisms (Chen et al., 2019b; Klümper et al., 2019), suggesting that increasing soil microbial biodiversity by reintroducing indigenous microbes to agricultural soils could be a potential solution to this problem. The capacity of various soil microorganisms to function as biological barriers to stop the invasion of manure-borne antibiotic resistance bacteria by raising the cost of resistance may be the underlying mechanism for such findings (Chen et al., 2019b). The success of invasion and survival of the enterohemorrhagic human pathogen *E. Coli* O157:H7 was also shown to be inversely correlated with greater soil microbial diversity (Van Elsland et al., 2003). This implies that lowering AMR and pathogen burdens may be facilitated by increasing soil microbial diversity. Furthermore, microbial degradation may be a viable way to mitigate the issues related to the usage of chemical pesticides. Certain bacteria may use chemical pesticides as sources of nutrients in natural or agricultural settings (Kanissery & Sims, 2011). The pesticide issue in industrial agricultural production, particularly the issues related to persistent pesticide residuals, cannot be solved by the rate of natural microbial breakdown. In order to promote microorganisms to break down chemical pesticide residues more quickly, several modifications to soil microbial populations are necessary. As an alternative, booting many pesticide-degrading

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