***Sources and contamination routes of microbial pathogens to fresh produce during field cultivation: a review***

Oluwadara Oluwaseun Alegbeleye1, Ian Singleton2, Anderson S. Sant’Ana1

1Department of Food Science, Faculty of Food Engineering, University of Campinas, Campinas, São Paulo – Brazil.

2School of Applied Sciences, Sighthill Campus, Edinburgh Napier University, Edinburgh - UK.

\*Corresponding author: Prof. A.S. Sant’Ana: and@unicamp.br Address: Rua Monteiro Lobato, 80. CEP: 13083-862, Campinas, SP – Brazil

**Abstract**

Foodborne illness resulting from the consumption of contaminated fresh produce is a common phenomenon and has severe effects on human health together with severe economic and social impacts. The implications of foodborne diseases associated with fresh produce have urged research into the numerous ways and mechanisms through which pathogens may gain access to produce, thereby compromising microbiological safety. This review provides a background on the various sources and pathways through which pathogenic bacteria contaminate fresh produce; the survival and proliferation of pathogens on fresh produce while growing and potential methods to reduce microbial contamination before harvest. Some of the established bacterial contamination sources include contaminated manure, irrigation water, soil, livestock/ wildlife, and numerous factors influence the incidence, fate, transport, survival and proliferation of pathogens in the wide variety of sources where they are found. Once pathogenic bacteria have been introduced into the growing environment, they can colonize and persist on fresh produce using a variety of mechanisms. Overall, microbiological hazards are significant; therefore, ways to reduce sources of contamination and a deeper understanding of pathogen survival and growth on fresh produce in the field are required to reduce risk to human health and the associated economic consequences.

**Keywords:** On-farm food safety, soil, irrigation water, manure, foodborne pathogens, fruits and vegetables.

1. ***Introduction***

Foodborne diseases are rife in many regions of the world, with at least 1 in 10 people falling ill yearly from consumption of contaminated food and 420, 000 deaths occurring as a result, according to the World Health Organisation (WHO) (2015). Foodborne diseases have exerted pressure on medical services, contributed to economic and political distress, exacerbated malnutrition and led to human suffering. There are several agents such as chemicals, pathogens, and parasites, which may adulterate food at different points in the food production and preparation process (Allos et al., 2004). Many of these agents have been extensively characterized and investigated by numerous studies (Farber & Peterkin, 1991; Zhao et al., 2001; Le Loir et al., 2003; Ehling‐Schulz et al., 2004; Adzitey et al., 2013; Botana, 2014). Strategies and protocols to prevent occurrence (and outbreak) of foodborne diseases have been devised and implemented by many researchers, regulatory bodies, and governments. However, despite the considerable progress achieved scientifically, foodborne diseases continue to occur, representing a significant cause of morbidity and mortality globally (Mead et al., 1999; Murray et al., 2013). Although foodborne diseases are more common in developing countries particularly in Africa and South East Asia with specific groups of people such as children, the immunocompromised, pregnant and aged being particularly at risk, foodborne diseases are not limited to these regions or groups of people (WHO, 2007). For instance, according to the Centres for Disease Control and Prevention (CDC), between 2001 and 2009, there were 38.4 million episodes of domestically acquired foodborne gastroenteritis caused by unspecified agents in the United States alone (CDC, 2009). Approximately 17.8 million acute gastroenteritis occurred, and there were at least 473,832 hospitalizations in the US each year and 215 779 hospitalizations caused by the 24 known gastroenteritis pathogens. An estimated 5 072 persons died of acute gastroenteritis each year, of which 1 498 deaths were caused by the 24 known foodborne pathogens (Scallan et al., 2011). Health Canada (2011) estimates that 11-13 million cases of foodborne illnesses occur in Canada every year.

Although the conventional notion is that foodborne diseases typically originate from meat and poultry products, vegetables and fruits have been implicated in various foodborne outbreaks (Westrell et al., 2009; Lynch et al., 2009; [European Food Safety Authority (EFSA), 2013]. A significant increase in foodborne disease outbreaks or cases associated with consumption of fresh produce has been reported. This increase has been largely due to a general increase in produce consumption, globalization of the produce industry and more effective surveillance (Tauxe et al., 1997; Lederberg et al., 2003; Havelaar et al., 2010). Increased consumption of fresh produce is likely due to global government efforts to promote healthy eating, the associated health-promoting benefits of consuming fresh produce and ease of access to fresh local produce (Pollack 2001; Regmi, 2001; Berger et al., 2010; Painter, 2013). Since fresh produce is mostly eaten raw or after minimal processing, pathogen contamination constitutes a potential health risk (Callejón et al., 2015; Li et al., 2017). There are numerous factors capable of compromising the microbiological integrity of produce along the farm to fork continuum, all of which have potentially fatal outcomes. However, pre-harvest hazards to produce have been recognized as important because usually, once pathogen contamination is established in the field, it can be challenging to decontaminate produce. There are numerous circumstances that can undermine the safety of produce on farms. Many of these arise because agriculture has grown more intensive over the years, and produce fields are often located near animal production zones thus entwining the ecological connections between wild animals, livestock and produce (Strawn et al., 2013 a, b). This, in many cases, predisposes fruits and vegetables to pre-harvest hazards. Some important pre-harvest hazard sources to produce include the use of contaminated soil, irrigation water and manure for produce cultivation. Wild animals and insects have also been implicated as vehicles of pathogens to produce.

To ensure produce safety on a sustainable scale, it is imperative to correctly understand the routes of entry, fate, transport, establishment, and survival of pathogens in the agricultural environment such as soil, irrigation water and manure. The knowledge gap in this regard is being filled rapidly, as many studies have attempted to explain the behavior of foodborne pathogens in agricultural media and describe the associations among pathogens, produce and the agrarian environment. In this review, the extent of the produce contamination problem is discussed as well as the sources and routes of contamination of soil, irrigation water, fruits, and vegetables. Also, the various mechanisms and strategies through which bacterial pathogens become established on fruits and vegetables are briefly examined.

1. ***Overview of outbreaks associated with fresh produce***

The nutritional and health benefits of consuming fruits and vegetables have been recognized and widely publicized. This has elicited changes in human dietary habits, with many consumers incorporating more fruits and vegetables into their meals. Consequently, the global production of fruits and vegetables has surged exponentially in recent decades. The increased demand for produce has led to modifications such as increased use of soil amendments, utilization of alternative water sources and increased imports and exports in agriculture- spanning across agronomic practices, processing, preservation, packaging, distribution, and marketing (Beuchat, 2002). Some of these modifications, however, have great potential to compromise the safety of fruits and vegetables. The biological hazards that are most relevant to fresh produce safety are either zoonotic or human in origin and can be classified into spore-forming bacteria, non-spore forming bacteria, viruses, parasites and prions (James, 2006). Most studies/surveillance efforts have identified bacterial contaminants in produce-borne illness outbreaks. There is, therefore, a disproportionately higher abundance of information regarding bacterial contamination in the literature. This may be because bacterial species have in fact caused many more outbreaks, but other microbial groups- viruses and parasites have been understudied. The most commonly implicated etiologic agents are presented in Table 1. Although data and information available on outbreaks associated with fresh produce are diverse and patchy, the available research evidence indicates that the foodborne illness burden due to contaminated produce has increased, in recent decades. In the United States, between 1996 and 2010, approximately 23% of total foodborne illness outbreaks were produce related (Jung et al., 2014). In Europe, from 2007 to 2011, produce was linked with 10% of the outbreaks, 35% of the hospitalizations and 46% of the deaths (EFSA, 2017). In Australia, fresh produce was linked to 4% of all foodborne disease outbreaks informed from 2001 to 2005 (Lynch et al., 2009). Specific produce items are more commonly linked to foodborne illness incidents; for example, leafy greens such as lettuce and spinach, as well as fresh herbs such as parsley and basil are conventional sources of bacterial infections (WHO, 2008; Berger et al., 2010; Denis et al., 2016). Berries, green onions, melons, sprouted seeds, and tomatoes are similarly high-level priority produce items (Olaimat & Holley, 2012; Denis et al., 2016). In the US, between 2006 and 2014, 16 of 68 multistate foodborne outbreaks were associated with vegetables (CDC, 2014). A list of recent produce-related outbreaks is presented in Table 2.

Most industrialized nations especially the United States have extensive and exhaustive datasets indicating the magnitude of outbreaks, the extent of severity and casualties incurred, the implicated pathogen and produce item as well as documented preventive protocols to avoid future outbreaks. Unfortunately, however, the same is not true of many other countries especially African Countries, the majority of which are still grappling with other challenges and hence, lack the resources to efficiently track and trace foodborne illness incidents (WHO, 2000).

Many conventional foodborne detection methods are time consuming and laborious, and advanced techniques have therefore been developed and optimized as alternatives to or for use in combination with these traditional techniques. Many of these are rapid, sensitive, reliable and standardized. They can be categorized into nucleic acid based, biosensor-based and immunological based methods (Croci et al., 2008; Adzitey et al., 2013; Law et al., 2014). Typical examples include simple polymerase chain reaction (PCR), multiplex PCR, real-time PCR, nucleic acid sequence-based amplification (NASBA), loop-mediated isothermal amplification (LAMP) and oligonucleotide DNA microarray. Other examples are optical, electrochemical and mass-based biosensors, and enzyme-linked immunosorbent assay (ELISA) and lateral flow immunoassay (Law et al., 2014; Gilchrist et al., 2015). These advances in epidemiological investigation approaches and techniques have made it possible to explore the crucial associations between produce and pathogens. In spite of this, however, prompt identification of implicated produce vehicles, location or point of contamination in fresh produce associated outbreaks is still a significant challenge. One prime constraint is the relatively short shelf life of fresh produce, which is often discarded by the time an outbreak is identified (Strausbaugh and Herwaldt, 2000; Lynch et al., 2009). Therefore, most of the time, the real source of contamination is not ascertained causing investigators to speculate or assume a source. This is, however, dangerous because, in addition to the possibility of being wrong, there is empirical evidence that once a particular transmission pathway is identified, repeated investigations are bound to be biased in causation (Lynch et al., 2009). Another important consideration is that usually, outbreaks receive widespread attention if the event (i) has severe public health impacts (ii) is unusual or sudden (in that the etiological agent and/produce type are unanticipated; making the circumstances of the outbreak unique and (iii) poses a significant risk of international spread with consequences for international travel or trade. Invariably, the smaller, ‘less significant' outbreaks are never investigated. More importantly, foodborne illness incidents occur sporadically in populations, and these cannot be captured in routine epidemiological surveillance or outbreak investigations (Scallan et al., 2011). This means that the data available may not be a valid representation of the problem. It is likely that the foodborne illness burden related to consumption of contaminated produce is still largely underestimated.

1. ***Sources and Routes of Produce Contamination***

The possible routes and sources of produce contamination are numerous, and intensive efforts have been made to accurately understand the exact mechanisms through which pathogens are introduced into fresh produce (Kotzekidou, 2016). Sources and routes of produce contamination vary for different production zones. This is because each farm has a distinct combination of environmental risk factors such as topography, land-use interactions, and climate. Combinations of these peculiar environmental risk factors influence the frequency and transmission of foodborne pathogens and subsequently impact the risk of produce contamination (Strawn et al., 2013 b). Primarily, pathogens may contaminate produce ‘on-field’ via various routes including; atmospheric deposition, uptake from contaminated soils and groundwater (Harris et al. 2003; Lynch et al., 2009; Mei Soon et al., 2012), use of raw (or poorly treated) manure and compost, exposure to contaminated water (irrigation or flooding), transfer by insects, or by fecal contamination generated by livestock or wild animals (Cooley et al., 2007; Uyttendaele et al., 2015). A schematic representation of the main entry points for pathogens to humans via produce is provided in Figure 1.

* 1. ***Introduction of pathogens into soil via manure/compost application***

The use of organic materials such as livestock excreta, slurries, abattoir wastes, sewage sludge as well as municipal and industrial waste treatment residuals as soil amendments is widespread (Avery et al., 2005; Goss et al., 2013). Although these serve as a cost-effective source of nutrients for agricultural purposes, research demonstrates that raw manure as well as contaminated (or improperly treated) manure constitute a significant risk of pathogenic contamination for produce (James, 2006; Manyi-Loh et al., 2016). Public health relevant bacteria, viruses and parasites such as *E. coli* O157:H7, *Salmonella* spp*., L. monocytogenes, Campylobacter* spp.,porcine enteroviruses, bovine coronavirus, bovine virus diarrhoea *Cryptosporidium parvum* and *Giardia* have been isolated from raw/poorly treated manure (Derbyshire, 1973; Derbyshire & Brown, 1978; Sellers, 1981; Strauch 1991; Pell, 1997; Grewal et al., 2006). Pathogens may be spread through direct interaction of vegetable surfaces with manure, or by splashing of (contaminated) soil/manure particles from the soil on vegetables via rainfall and/overhead irrigation or by vectors. Additionally, manure piles stored next to growing areas may constitute contamination risk due to run-off (James, 2006; Warriner et al., 2009).

Manure application could be by broadcasting as a solid, semi-solid or liquid throughout the field or by the introduction of livestock or wildlife feces at distinct locations (Jung et al., 2014). In many parts of the world, organic cultivation systems use more manure than conventional growers, and chemical treatment against pathogens is prohibited in organic farming. There have thus been some assertions that organic produce represents a more significant safety risk than its non-organic counterpart, although, there is no unequivocal research evidence supporting this claim (Johannessen et al., 2005; Loncarevic et al., 2005; Warriner et al., 2009; Ivey, 2011; Maffei et al., 2016).

The survival of pathogens in manure and biosolids depends on factors such as the manure source, production process, and characteristics, treatment technique applied, physicochemical factors like pH and relative humidity, incidence of antagonists or predators, weather conditions, desiccation, aeration, soil type, degree of manure incorporation, amongst others (Ingham et al., 2004; Wood, 2013) (Table 3). The manure composition, which is determined in large part, by the feed formulation, dictates the profile of pathogens occurring in manure as well as their ability to persist even post-treatment (Franz et al., 2005). Certain workers have proposed that cattle diet may influence the incidence of representative bacterial species; *E. coli* O157:H7 and Salmonella in manure. These pathogens have been reported to persist longer in manure obtained from cattle fed diets rich in energy but low in fiber content such as high digestible grass silage and maize silage compared to animals that received diets with low energy and higher fiber content such as straw (Franz & van Bruggen, 2008). It has also been suggested that feeding cattle with hay may significantly reduce shedding of acid-resistant *E. coli* (Diez-Gonzalez et al., 1998; Franz & van Bruggen, 2008). How effective these strategies are in reducing pathogen load in (animal-derived) manure, is however not clear.

Manure treatment techniques such as composting, aerobic and anaerobic digestion, pelleting, alkaline stabilization, conditioning, dewatering and heat drying have been used to treat manure before application as fertilizer for a long time. While many of them are reasonably efficient, concerns have been raised about their ability to satisfactorily eliminate pathogenic bacteria (Day & Funk, 2002; Lu et al., 2012; Lorin et al., 2016). Tailing of pathogen inactivation curves, as well as apparent regrowth or recontamination of bacteria after treatment, have been reported. Many pathogens have been shown to be capable of withstanding manure treatment processes, thereby, constituting a major risk of contamination (Brackett, 1999). Composting is a popular manure treatment and composting temperatures that exceed 55ºC for three days are considered sufficient to kill most pathogens (Grewal et al., 2006). However, few studies have demonstrated that the heat-induced death of bacteria in composted materials is a complex phenomenon (Ingham et al., 2004; Gupta, 2012). Bacterial regrowth and recontamination in cooled compost have been reported (Hassen et al., 2001; Ingham et al., 2004). Pelletizing is another common treatment available and is commonly applied to chicken manure (chicken manure pellets). Pelletizing the manure reduces the off-odor and facilitates transport and storage. Although the process usually involves a thermal procedure, more studies are required to validate whether the process efficiently inactivates clinically relevant pathogens (Chen & Jiang, 2014; Jung et al., 2014). The use of a fish emulsion as fertilizer has raised similar concerns; although most preparation methods available include a thermal process, the ability of this to inactivate enteric bacteria and viruses needs to be rigorously validated (Jung et al., 2014).

Due to the diverse range of variables associated with manure composition, treatment, pre-application storage, application and incorporation, regulatory bodies have stipulated minimum manure-to-harvest time intervals necessary to ensure microbiological safety. The United States Department of Agriculture (USDA) ‘Organic production and handling’ specifies that unless composted, raw animal manure must be incorporated into the soil not less than 120 days prior to harvest of a product whose edible portion has direct contact with the soil surface or soil particles, or 90 days if there is no direct contact (USDA, 2015). Canadian authorities specify 3, 15 and 12 months for tree fruits and grapes, small fruits and vegetables respectively as the minimum time delay between manure application and harvest for these crops (Olaimat & Holley, 2012).

* 1. ***Irrigation water***

Irrigation water has been identified as a potential source of produce contamination (Benjamin, 2013; Uyttendaele et al. 2015; Faour-Klingbeil et al. 2016). Being a common and essential requirement for crop production, water must be supplied to plants when necessary, and irrigation water sources are used to supplement limited rainfall in many areas (Kirby et al. 2003). Epidemiological investigations of food poisoning outbreaks, experimental studies examining pathogen contamination of fruits and vegetables as well as observations of increased incidence of disease in areas practicing wastewater irrigation with little or no wastewater treatment indicate that contaminated irrigation water might indeed be a source of foodborne pathogens on fresh produce (Norman & Kabler, 1953; Hernández et al., 1997; Steele & Odumeru, 2004). For example, Hepatitis A outbreaks associated with lettuce (Seymour & Appleton, 2001) and spring onions (Josefson, 2003) were linked to sewage-contaminated irrigation water (Heaton and Jones, 2008).

Various factors including irrigation regime (method and timing of irrigation), irrigation water sources, type of crop and land use practices in the farm influence the extent and frequency of pathogenic contamination of produce (Figure 3) (Pereira et al. 2002; Pachepsky et al. 2011; Olaimat & Holley 2012). Other factors such as pathogen concentration, pathogen strain, weather patterns, plant state, and physiology also have significant implications for produce safety (Marvasi et al., 2013; Uyttendaele et al., 2015; Decol et al., 2017) (Table 4).

* + 1. ***Relationship between irrigation regime and contamination potential of produce***

There are several types of irrigation systems available, each of which is typically complex and has its own drawbacks. Most irrigation systems create complicated ecological environments with multiple potential sources and routes of pathogenic contamination (Pachepsky et al., 2011). Each irrigation subsystem: collection, replenishment, storage, conveyance, distribution off and on-farm, as well as on-farm application involve processes that have great potential to compromise the microbiological integrity of the irrigation water in unique ways. During transportation from the source to the field, water is susceptible to significant microbiological depreciation (Pachepsky et al., 2011). The prevailing deterioration dynamic will depend on the transportation mode. For instance, irrigation water transport via irrigation ditches and canals involves interaction with microbial reservoirs of bottom sediments, bank soils, algae and periphyton, whereas water transport via pipes involves interactions with biofilms in the transport pipes (Jjemba et al., 2010; Pachepsky et al., 2014). This sort of contamination is particularly prominent in reclaimed water distribution systems (Jjemba et al., 2010; Weinrich et al., 2010). The method of storage for irrigation water can have a profound effect on pathogen transmission. For example, certain studies have demonstrated that water quality is rapidly degraded in storage ponds and tanks due to inputs from avian species or other wildlife (Field & Samadpour, 2007; McLain & Williams, 2008; Higgins et al., 2009). Other storage systems such as check dams, impoundments, inter-basin transfer schemes, abstraction schemes and reservoirs have been identified as places where indicator and pathogenic microorganisms can survive and proliferate (Abbasi, 2001; Kirubel, 2015). The mode of application also has significant impacts on the risk of microbiological contamination (Berger et al., 2010). Compared with furrow and subsurface drip irrigation systems, sprinkler irrigation poses a higher risk of microbiological contamination (Kisluk & Yaron, 2012; Pachepsky et al., 2014). Surface furrow and drip irrigation systems minimize contact between edible portions of certain plants (leafy vegetables provide larger surface area for contact and possible microbial attachment) and irrigation water (Directorate, 2002; Fonseca et al., 2011; Mei Soon et al., 2012; Uyttendaele et al., 2015). Hydroponic growing systems also offer this advantage (Jung et al., 2014; Allende & Monaghan, 2015).

The irrigation application method has been determined to influence the internalization of some pathogens in produce such as spinach plants. According to some studies, the likelihood of internalizing pathogens increases when the organisms are introduced by water sprinkling systems as opposed to when the water is directly applied to the soil (Solomon et al., 2002; Stine et al., 2005; Mitra et al., 2009; Warriner et al., 2009; Erickson et al., 2010a; Kisluk & Yaron, 2012; Zheng et al. 2013). More details on pathogen internalization are provided in section 4 (below). Depending on the geographical location, the irrigation regime with respect to time of day, season and harvest time may influence the likelihood of pathogenic contamination. For example, Kisluk & Yaron, (2012) in a study conducted in Haifa, Israel demonstrated that night-time irrigation and irrigation during the winter season is more likely to contaminate plants with enteric bacteria. Contaminated irrigation water poses the most significant risk when crops are irrigated close to harvest time, because harvesting of produce containing viable pathogens is more likely. Therefore, an adequate time interval between irrigation and harvest should be conscientiously followed.

The microbial quality of irrigation water depends mostly on the source of the water. In order of increasing risk of microbial contamination hazard, irrigation water sources can be ranked as follows: potable or rainwater, deep groundwater, shallow groundwater, wells, surface water and raw or inadequately treated wastewater (James, 2006; Leifert et al., 2008; Pachepsky et al., 2011). The microbial quality of rainwater or rain-harvested water is relatively good. The quality and safety of use, however, depends largely on the collection, transportation and storage means. This can be illustrated with roof-harvested rainwater, which may become contaminated with pathogenic bacteria and protozoan parasites because of the occurrence of animal droppings on roofs, particularly immediately after relatively long periods of drought (Uyttendaele et al., 2015). Groundwater (or borehole water) is usually microbiologically safe, except if it has been contaminated with surface runoff or other sources of contamination close to the aquifer. Certain farm operations such as intensive dairying and border-strip irrigation (a type of surface irrigation, which is a hybrid of level basin and furrow irrigation) (Valipour et al., 2015) lead to leaching of pathogens such as *E. coli* and Campylobacter to shallow groundwater, thereby contaminating it (Close et al., 2008). Water from wells that are free from leaks and have sound casing are expected to be microbiologically safe. Factors such as the design of wells, nature of the substrate, depth to groundwater and rainfall may affect the microbial quality of good water (James, 2006; Gerba, 2009). Surface waters; which are the predominant source of irrigation waters in many countries, including open canals, ponds, lakes, rivers and streams are much more susceptible to pathogenic contamination compared to groundwater (Allende & Monaghan, 2015; Uyttendaele et al., 2015). Sewage discharges, septic tank contamination, storm drains, wild and livestock defecation, run-off from contaminated fields, industrial and municipal effluents can all potentially contaminate surface waters (Steele & Odumeru, 2004; James, 2006). Wastewater is usually of poor chemical and microbiological quality. Therefore, it requires extensive treatment before it can be safely used to irrigate crops. Water sources (other than rain) used to irrigate produce is usually only minimally treated or untreated in many cases (Steele & Odumeru, 2004; Jung et al., 2014). It is expensive and time-consuming to treat irrigation water up to drinking water standards, which is the ideal recommendation (Crook & Surampalli, 1996; Forslund et al., 2010).

* + 1. ***Pathogen survival in irrigation water***

Although awareness of the potential dangers of using microbiologically compromised water for irrigation has increased in recent times, scarcity of water resources in certain regions has contributed enormously to the use of sub-optimal supplementary irrigation water sources. In such cases, irrigation water represents a greater microbiological risk to produce (Sundström, et al., 2014). One of the most frequent pathogens implicated in water-related outbreaks is *E. coli* O157:H7 (CDC, 1999; Hilborn et al., 1999). The organism can survive for a protracted period in water (even in deionized water) depending on temperature conditions (Chalmers et al., 2000; Islam et al., 2004a). It also exhibits a remarkable ability to withstand extreme environmental conditions such as high acidity and extremely low-temperature conditions.

The ability of a pathogen to survive (or persist) in the environment (and on produce) is an essential determinant in the risk of human infection. The actual risks associated with pathogens occurring in irrigation water depend on numerous variables including environmental conditions such as temperature, pH and UV light (Sant'Ana et al., 2014). Other factors such as the excreted load of the pathogen, its latency period before it becomes infectious, its ability to efficiently multiply outside a mammalian host, its infectious dose for humans, inhibitory competition from the indigenous microflora as well as host response also play a relevant role (Steele & Odumeru, 2004). Bacteria and viruses survive for lengthier periods in groundwater compared to surface water because groundwater tends to be cooler, offers protection from sunlight, and has less biological activity (Steele & Odumeru, 2004). These groups of microbes only typically last no longer than 45 and 15 days in surface water and sewage, respectively. Conversely, parasites (eggs/cysts) may survive for as long as 60 days or even several months in surface water and wastewater (Lefler & Kott, 1974; Sagik et al., 1978; Bihn, 2011). This suggests that pathogenic microorganisms are capable of surviving for extended periods, which constitutes a profound threat to produce safety. Regardless of the source or route of exposure, one potentially fatal consequence of pathogen contamination of irrigation water is the repeated inoculation of plants with the pathogens. The fate and transport of these pathogens once introduced into the produce vary widely (Table 4). Some pathogens are capable of adhesion to surfaces of produce while some others can rapidly internalize into plant tissues under certain conditions, translocate and persist until consumed (Warinner et al., 2003; Bernstein et al., 2007a; Doyle & Erickson, 2008). This has rendered many conventional processing and chemical sanitizing methods ineffectual (Hong & Moorman, 2005) and is a growing public health concern.

* + 1. ***Irrigation water and pathogens: a summary***

Although the potential for produce contamination via irrigation water has been identified, it is difficult to estimate the magnitude of the problem (Groves et al., 2002; Antwi-Agyei et al., 2015). Despite the fact that numerous studies have linked poor microbiological quality of irrigation water with the incidence of human pathogens on fruits and vegetables, direct evidence of irrigation water causing foodborne disease is relatively rare (Harris et al., 2012). This is because a substantive “cause-effect” relationship is yet to be established as it is required that the same pathogenic strain is isolated from the patient, produce, and irrigation sources (Pachepsky et al., 2011). Furthermore, there must be a clear sequence of events connecting patient, produce, and irrigation source (Steele & Odumeru, 2004). This is difficult to achieve due to certain limitations such as an inability to promptly identify the locations associated with produce contamination and delays inherent in foodborne outbreak investigations (Pachepsky et al., 2011). In the absence of direct confirmation, the “cause-effect” relationship can only be deduced based on circumstantial or subjective evidence (Pachepsky et al., 2011). Also, it is apparent that there is no valid link between detected pathogen levels in irrigation waters and disease risk. Some studies have demonstrated a lack of correlation between pathogen prevalence in waters used for irrigation and disease incidence due to consumption of irrigated produce (Cooley et al. 2007; McEgan et al., 2013; McEgan et al., 2014). There is an abundance of laboratory studies elucidating potential mechanisms of produce contamination from waterborne pathogens. However, field studies showing the exact process of produce contamination via this medium are relatively scarce. It is thus expedient to generate more field data in this regard.

* 1. ***The soil environment as a natural habitat for (potential) bacterial pathogens***

Soils typically harbour an abundant consortium of microorganisms, some of which are human pathogens such as *B. cereus*, *Clostridium botulinum*, *C. perfringens*, *Listeria monocytogenes* and *Aeromonas* (Nicholson et al., 2005; Warriner et al., 2009; Jay, 2012). They may, therefore, serve as a medium of plant contamination through seeds, roots or surfaces. Many soil resident pathogens have adapted to survival in soil with spores persisting indefinitely. However, since many agricultural soils are predisposed to point and non-point sources of pathogenic contamination, allochthonous pathogens may continuously be introduced into soil environments (Santamaria and Toranzos, 2003). Some of the primary sources of pathogens into soil include the use of contaminated irrigation water and manure, animal grazing, municipal solid wastes and other effluents (Santamaria and Toranzos, 2003; Sant'Ana et al., 2014).

* + 1. ***Effect of soil properties and environmental variables on the incidence of pathogens in soils***

The fate, survival and recalcitrance of pathogens in soil depend on factors such as soil type, soil moisture, pH, temperature, nutrient availability, agronomic practices, as well as soil biological interactions (Table 5). Soil matric potential (moisture levels) is determined by soil properties and water inputs through precipitation and/irrigation and has been demonstrated to be one of the most critical factors influencing microbial transport and survival in soil (Leifert et al., 2008). Cool, moist environments are favorable for the survival of bacteria and viruses. Under dry soil conditions, a reduction in bacterial and viral population densities are usually observed (Santamaria and Toranzos, 2003; Ghorbani et al., 2008). *Escherichia coli* survival has been reported to be highest in organic soils under flooded conditions, and peak populations recorded after a rise in the water-table accompanying significant rainfall events (Tate, 1978; Hagedorn et al., 1978; Rochelle-Newall et al., 2016). Some pathogens such as *Streptococcus faecalis* have been proven to thrive poorly under low soil moisture conditions (Kibbey et al., 1978; Jamieson et al., 2002; Cabral, 2010). Increased rates of virus inactivation at low soil moisture levels have been demonstrated (Yeager & O’Brien 1979). Also, decreased recovery of viral (poliovirus type 1 and coxsackievirus B1) infectivity in dried soils was attributed to evaporation of soil water in the same study by Yeager & O’Brien (1979). In addition, experimentation by Hurst et al., (1978) correlated inactivation of enteroviruses [echovirus type 7 (strain Wallace), coxsackievirus B3 (strain Nancy) and poliovirus type 1 (strain LSc)] in sludge-amended soils with moisture loss in the sludge piles.

Soil pH influences microbial diversity and the biogeochemical processes, which they mediate (Fierer & Jackson, 2006; Nicol et al., 2008). Optimum pH for bacterial survival seems to be neutral, but fungi are known to be more tolerant of acidic conditions, compared to bacteria (Leahy & Colwell 1990). Amino acids (most viruses behave as proteins) have different pK values and so the ratio of positive to negative charges on proteins vary with pH (Yates et al., 1985). In an experiment that lasted 170 days using poliovirus type 1, echovirus 7, echovirus 9 and coxsackie B3, viruses were detected up till the 110th – 170th day at pH 7.5 while at pH 5.0, the viruses died off between the 25th and 60th day depending on virus type (Bagdasaryan, 1964).

Soil types vary depending on organic matter content, water release characteristics, particle size distribution and moisture retention capacity. These variations significantly influence the survival of enteric pathogens in soil (Jamieson et al., 2002; Atkinson et al., 2010). Clay soils support the adsorption of microorganisms onto soil particles, and this reduces microbial die-off rates (Reddy et al., 1981). Clays protect bacterial cells, and possibly viral particles, by creating a barrier against microbial predators and parasites (Santamaria & Toranzos, 2003).Viruses, which are mostly large proteins possessing various charges, are capable of forming numerous bonds with clay minerals (Stotzky 1986). For example, the survival of *E. coli* is prolonged in clay soils where adsorption of cells to the soil particles protects it against protozoa (Mosaddeghi et al., 2009). *Escherichia coli* can persist for up to 25 weeks in clay and loam soils, but for much less (8 weeks) in sandy soils (Lang and Smith, 2007). Results of a study that compared Rotavirus survival in three soil fractions (whole soil, sand and clay) at temperatures 4, 25 and 37ºC for 18 days showed least survival in sand fractions (Davidson et al., 2013). In the absence of soil particles, Rotavirus survived best at 4 ºC with survival decreasing, with an increase in temperature, except in whole soil, where it survived better over the entire temperature range and for more than a week at 37 ºC, indicating that whole soil offered some protective effect (Davidson et al., 2013). Conversely, though, there is a report of shorter survival duration of enteroviruses (poliovirus type 1, echovirus 7, echovirus 9 and coxsackie B3) in loamy soil than in sandy soil (Bagdasaryan, 1964).

A link between higher organic matter content and enteric pathogen persistence has been established (Jamieson et al., 2005; Williamson et al., 2005; Leifert et al., 2008). There is overwhelming research evidence in this regard, seeing that many of the studies that compared the persistence of enteric pathogens in top and sub-soils recorded higher survival rates in topsoil (Zhai, 1995; Wang et al., 2004; Nyberg et al., 2010). Research has also shown higher pathogen levels in organic soils after manure application compared to sandy soils (Tate, 1978; Jamieson et al., 2002). Therefore, the rates of pathogen survival are lower in sandy soils, which have a low water-holding capacity (Mubiru et al., 2000; Erickson et al., 2014a).

Lower temperatures are more suitable for bacterial and viral survival. The ultraviolet radiation from the sun inactivates viruses on the surface of the soil, but viruses in deeper soil strata are protected from this (Rodríguez-Lázaro et al., 2012; Zablocki et al., 2016). In loamy soil samples, at pH 7.5, poliovirus and echovirus were recovered after 110 – 130 days at 3 - 10 ºC compared to recovery 40 – 90 days at 18 - 23 ºC (Bagdasaryan, 1964). Similarly, Poliovirus Type 1 and coxsackievirus B 1 pfu were recovered for up to 12 days at 37 ºC whereas pfu were recovered from soil for up to 180 days at 4 ºC (temperature profiles tested were 4, 22 and 37 ºC) (Yeager & O’Brien, 1979). The persistence of poliovirus in sludge-amended soil was assessed in a field study where appropriately cultivated and irrigated plots were treated with virus-spiked effluents by flooding. This was done for 123 days spanning through spring, summer and winter seasons. Poliovirus survived best during winter (when it was detected after 96 days), but during summer, the longest survival period was 11 days (Tierney et al., 1977). Parasites seem to prefer warm temperature conditions. Prevalence of hookworms have been correlated to warm temperatures, relatively high rainfall and low clay content (sandy soils with clay content of less than 15%) (Mabaso et al., 2003).

 Nutrient availability is essential for the survival of microbes in the soil. The presence of organic matter promotes the survival, and in many cases, the regrowth of enteric bacteria (Jamieson et al., 2002; Looney et al., 2010). Organic matter improves nutrient retention, serves as carbon sources for bacterial species and enhances moisture retention (Gerba et al., 1975; Schoonover & Crim, 2015).

Apart from environmental stress responses, foreign enteric bacteria must compete with the endogenous microflora to become established in the soil environment (Jiang et al., 2002). Some autochthonous soil organisms have been shown to be resistant to newly introduced microorganisms in their environment (Ellis and McCalla, 1976). Also, certain bacteriophage, some protozoa, nematodes and free-living soil organisms such as Bdellovibrio can parasitize non-indigenous pathogens, thereby limiting their survival (Klein & Cassida, 1967; Goss & Richards, 2008). Additionally, increased pathogen survival, and regrowth in some instances, in sterile soils and soils with relatively low biological activity has been reported (Gerba et al., 1975; Tate, 1978). There is some research evidence that alien enteric pathogens compete poorly for nutrients and are thereby susceptible to inhibition by soil-borne bacteria (Jiang et al., 2002). The effects that this has on the persistence of pathogens (especially pathogens introduced via contamination) in soil is however not yet fully understood. The impacts that soil edaphic and biotic conditions have on the occurrence, fate and persistence of microorganisms in soils should not be underestimated. These factors can collectively or independently stifle or encourage foreign pathogens. For instance, members of Listeria possess advantageous intrinsic factors such as an extensive repertoire of transport systems (like phosphotransferase system and transcriptional regulators) which makes them capable of successfully persisting in the soil ecosystem (Newell et al., 2010). However, these species are highly sensitive to extrinsic factors and this affects their ability to survive in soil environments (Newell et al., 2010; Locatelli et al., 2013). Although studies have been conducted on the occurrence of *L. monocytogenes* in various ecological niches, including soil, more emphasis has been placed on the occurrence of *Listeria* spp. in fresh vegetables under storage conditions, food processing and packaging environments. The expression of genes and induction of proteins such as cold shock and cold acclimation proteins, as well as tolerance for low pH and high salt concentration in these environments have received much research attention. There is however, need for more research to understand the dynamics of Listeria survival in soils.

***3.3.2. Other factors affecting survival of pathogens in soil***

Agronomic practices such as soil improvement and manure application method influence the survival of pathogens in the soil (Table 5). Soil improvement strategies (inorganic and organic fertilizer, compost, biosolids and other residuals application), significantly enhance the nutrient loads of soils (Diacono & Montemurro, 2010). In varying degrees, these are important sources of primary nutrients such as N and P as well as secondary nutrients such as Ca, Mg and S to the soil. A ready supply of essential nutrients encourages the growth of pathogens. Compost application modifies the long-term soil conditions by increasing the pH steadily, this, therefore, affects pathogen survival in soil (Weller, 1988; Sharma & Reynnells, 2016). Bacteria tend to decline more rapidly when manure is applied superficially as opposed to when incorporated into the soil immediately after application (Solomon et al., 2002; Islam et al., 2004a). This is probably due to the elimination of drying conditions and exposure to UV at the soil surface (Schulze-Makuch & Irwin, 2006) or because incorporation of manure disrupts macropores and boosts soil-bacteria contact (Jamieson et al. 2002).

After manure application on land, if applied manure is contaminated, it is probable that the pathogens will move through the soil matrix, either vertically or horizontally. Vertical movement of pathogens through the soil is influenced by the amount and intensity of rainfall, climatic conditions as well as the season of application. Horizontal movement is known to be influenced by soil type, moisture levels, temperature, microbial activity, transport through plant roots, rainfall patterns, soil pH amongst other biophysical factors. It is, however, apparent that water flow is the most important dispersal factor for percolation of manure-derived pathogens in soils, regardless of type and structure although more quantitative information regarding this is desirable (Mawdsley et al., 1995; Jiang et al., 2002; Jamieson et al., 2002; Islam et al., 2004b; You et al., 2006; Leifert et al., 2008; Semenov et al., 2009).

The extent of movement will affect the distribution and eventual fate of the pathogens. Some will spread in soil and attach to roots. Others may be washed off to surface waters or percolate to aquifers, potentially contaminating irrigation water sources (Figure 2) (Jamieson et al. 2002; Vinten et al. 2002; Avery et al. 2004 a, b; Islam et al. 2004b). Pathogens occurring in contaminated manure, therefore, can be rapidly transported within soil systems (Gagliardi and Karns, 2000; Kisluk & Yaron 2012). The success of conveyance and distribution, however, further depends on inherent survival capabilities of the pathogen as well as the presence and structure of plant root systems (Figure 2) (Kemp et al., 1992; Mubiru et al., 2000; Avery et al., 2004a; Franz et al., 2008; Arthurson et al., 2010).

There is some evidence that pathogens may indeed survive longer in manure-amended soils than actual manure samples, and this has been illustrated for enteric species such as *S*. Typhimurium and *E. coli* O157:H7. *Salmonella* Typhimurium, has, however, exhibited superior persistence capabilities compared to *E. coli* O157:H7 in manure-amended soils (Islam et al., 2004b; You et al., 2006; Franz et al., 2008; Fremaux et al., 2008; Pornsukarom & Thakur 2016). There is a paucity of data on the persistence of pathogens in manure amended-soils in the tropics (Ongeng et al. 2015). One interesting study provides an insight into the survival of *E. coli* O157:H7 and *Salmonella* Typhimurium under tropical climatic conditions (Ongeng et al., 2011). The study showed that survival periods were mostly shorter than the observed record in temperate regions indicating that biophysical conditions in the tropics may be more injurious to these pathogens. It is, therefore, not prudent to predict the survival of *E. coli* and *S.* Typhimurium in tropical soils from data obtained in temperate locations.

The soil is the most important cultivation medium and represents a relevant risk for produce contamination. A myriad of studies regarding the behavior of pathogens in various kinds of soil ecosystems is available. However, validated consensus protocols for conducting and interpreting experimental studies as well as for evaluating the effects of environmental and soil characteristics on fate of pathogens in soils are not yet available. It is important to further understand the effects of soil types, environmental factors, biological processes and interactions, cultivation and management practices on the behavior of (indigenous and foreign) enteric pathogens in agricultural soils.

* 1. **Animals and Insects**

Apart from farm animals, whose roles as reservoirs of enteric pathogens has been established, wild animals such as birds, reptiles, rodents, amphibians, some helminths, and insects like flies and beetles can also serve as vehicles of pathogens to contaminate cultivation media and produce (Beuchat, 2006; Lim et al., 2014). Livestock and wild animals may gain access to cultivation areas either because of adjacent land use (livestock rearing) or by intrusion (Jay-Russel, 2013). Birds such as gulls, pigeons, chickens, starlings, Canada geese, migratory ducks and sandhill cranes (Pacha et al., 1998; Hald et al., 2004; Ekdahl et al., 2005; Humphrey et al., 2007) have been determined to be carriers of pathogens such as *E. coli*, Salmonella and Campylobacter (Wallace et al., 1997; Schmidt et al., 2000; Wani et al., 2004). Insects are typically ubiquitous in cultivation fields, and hence, have unrestricted access to produce. They are usually found in manure piles, feedlots and other habitats near cultivation fields, and so farms practicing mixed farming represent a more significant risk (Martínez-Vaz et al., 2014). Many bacterial species have evolved to exploit insects as hosts or vectors. Filth flies, fruit flies, cockroaches and other insects act as mechanical and biological vectors to contaminate fruits and vegetables on the field (Sasaki et al., 2000; Mpuchane et al., 2004; Alam & Zurek, 2004; Humphrey et al., 2007). Many pathogens use flies as vectors for cross-transmission. For example, the transient survival of *Pectobacterium carotovorum* subsp. *carotovorum* in the gut of the fruit fly Drosophila and subsequent transmission to other plants has been observed (Nadarasah & Stavrinides, 2011; Lim et al., 2014).

Under laboratory environment, direct bacterial transfer from contaminated flies to fruits or plant leaves was shown to occur (Sela et al., 2005; Talley et al., 2009; Lim et al., 2014). Members of Muscidae and Calliphoride which are usually abundant in production fields adjacent to cattle rearing lots have been associated with the transmission of *E. coli* O157:H7 (Talley et al., 2009). Insects that feed on plants also play significant roles in produce contamination by providing direct routes for internalizing pathogens from manure to plants in the field (Talley et al., 2009). Insect deterioration creates openings that aid the ingress of pathogens into inner plant tissues, thereby enhancing colonization of spoilage and pathogenic bacteria on produce (Warriner & Namvar, 2010; Lim et al., 2014). A seasonal trend to contamination by insects has been identified. There is increased insect and animal activity during the warmer months of the year. Moreover, peak incidences of pathogens have been reported during the warmer months (Liang et al., 2015).

Reptiles including snakes, lizards, chameleons, turtles, as well as other ophidians, saurians and chelonians have been found harboring enteric bacteria like Salmonella (Corrente et al., 2004; Beuchat, 2006). Many wild rodents are asymptomatic carriers of pathogens like Salmonella and Campylobacter. The occurrence of rodents on farms are often associated with infrastructural impairment, and although their destructive tendencies have been widely recognized, their zoonotic risks are often primarily underestimated. They are capable of amplifying the number of pathogens in the environment and transferring them to other farm animals and produce (Meerburg & Kijlstra, 2007). Commensal rodents (house mice and rats) pose a particular threat because of their ecology (they live close to livestock) and high fecundity (Brooks & Jackson, 1973; Witmer et al., 2014).

***4*.** ***Survival of pathogens on and within fresh produce***

Foodborne illness resulting from the consumption of contaminated produce is dependent on specific factors. First, the produce must be contaminated with a pathogen, which must survive until the time of consumption at levels sufficient to induce illness (Harris et al., 2003). The dose required to cause illness in many cases, is very low, which indicates that the microorganism needs only to contaminate the food to survive without necessarily reproducing. For instance, pathogenic parasites and viruses are not capable of multiplying outside a human or animal host and only need to survive in sufficient numbers to cause illness (Harris et al., 2003). The survival and or growth of pathogens is influenced by the kind of organism, produce type, on-field environmental conditions, as well as the physiological state of the plant and pathogen. The possible routes of entry into plant tissues include: natural apertures (such as stomata, lenticels, sites of lateral root emergence), wounds caused by biotic or abiotic circumstances and following the flow of water from roots to leaves, where pathogens can efficiently survive and multiply (Steele & Odumeru, 2004; Deering et al., 2012; Hirneisen et al., 2012). The popular opinion is that pathogens will survive but not thrive on intact (uninjured) outer surfaces of produce, primarily due to the protective effects of natural plant barriers (such as cell walls and wax layers) (Mathews 2006; Heaton & Jones, 2008). Survival and proliferation of enteric pathogens on produce is significantly enhanced if the protective barrier becomes compromised either by physical or biological damage (such as punctures or bruising), insect ruination or through degradation by plant pathogens. It is vital to understand the microbe-microbe and plant-microbe interactions that occur in the phyllosphere and rhizosphere which influence the adaptation, colonization, survival, growth, and persistence of foodborne pathogens on produce.

***4.1. Access to and establishment of pathogens in produce***

***4.1.1. Attachment***

Attachment is pre-requisite for the colonization and subsequent transmission of enteric pathogens throughout plants including the edible portions (Berger et al., 2010). It is important to note that attachment onto the surface of intact produce is limited in contrast to the attachment on other food commodities such as processed meat tissues (Erickson, 2010). However, the attachment does indeed occur and is facilitated by stomata, lenticels, broken trichomes, as well as bruises and cracks occurring on produce surfaces. The incidence of scars and cracks (which may set in late in the growing season while the fleshy portion is enlarging rapidly) in certain fruits also aids pathogen attachment (Bhagat et al., 2010). Cracks tend to occur in or on the weak areas on plant surfaces such as around lenticels and trichomes, and hence, these areas are more susceptible to invasion by pathogens. Cavities within the epidermis may also develop from cuticular cracks as the fruit develops, thereby entrapping pathogens and shielding them from desiccation and disinfection. The initial phase of bacterial attachment is a rapid process initiated once the bacteria establishes contact with the plant surface (phyllosphere) (Sant’Ana et al., 2014). The phyllosphere, also known as the aerial parts of plants pose challenges for microbial survival. Exposure to high UV doses, temperature and relative humidity fluctuations sabotage viability (Brandl et al., 2004; Heaton & Jones, 2008). Epiphytes that exist within the phyllosphere have, however, evolved specialized mechanisms to improve stress tolerance and nutrient acquisition. For instance, *Pseudomonas* spp. produce pigments to insulate against UV and pectolytic enzymes to gain nutrients (Heaton & Jones, 2008). The ability of the pathogen to persist on the phyllosphere improves the chances of a viable or infectious dose remaining post cultivation (Heaton & Jones, 2008). The successful attachment on the phyllosphere also depends on the crop and pathogen type. A classic illustration is Salmonella invasion of lettuce and tomatoes. Salmonella contamination of lettuce and tomatoes via soil is usually quite low, implying that Salmonella does not readily attach to or grow in the phyllosphere of these crops (Critzer & Doyle, 2010). Also, attachment of Salmonella and *E.coli* O157:H7 is observed more frequently with Brassicaceae compared to lettuce, carrots, and tomatoes, which has generated the theory of selective attachment, suggesting that certain produce types are more prone to contamination than others (Warriner & Namvar, 2010). Specific pathogens such as Salmonella have surface epitopes that can bind to plant structures such as stomata to aid attachment (Warriner & Namvar, 2010). Some also have higher capabilities to metabolize nutrients contained within the apoplastic fluid of plants (Warriner & Namvar, 2010). These traits significantly enhance their attachment abilities. Finally, hydrophobic interactions between a plants' epidermal layer and microbial cells are believed to play a major role in facilitating this initial phase of attachment (Burnett & Beuchat, 2001).

Surface colonization is the final phase of attachment during which biofilms may be formed. Biofilms are microbial colonies, which form when single microorganisms attach and aggregate on a hydrated surface and undergo a "lifestyle switch," giving up life as a single cell to live on a surface in an adhesive cell matrix with other microorganisms (Lemon et al., 2007). Cells in a biofilm have a better chance of adaptation and survival (especially during periods of stress) as they are protected within the matrix (Decho, 2000) and are usually resistant to antimicrobial agents (Lemon et al., 2007). Naturally occurring biofilms are present in many fruits and vegetables, but the ability of foodborne pathogens to associate with them and persist is not yet fully understood (Brackett, 1999; Ferreira et al., 2014; Larsen et al., 2014). Pathogen serovars that are strong biofilm producers have been shown to attach better to both intact and injured produce surface compared to strains that are weak biofilm producers (Lindow & Brandl, 2003; Kroupitski et al., 2009). The occurrence of biofilms improves the chances of transient occupants of leaf surfaces such as enteropathogens of becoming effectively incorporated into phyllosphere biofilms (Heaton & Jones, 2008). Bacterial appendages such as curli, pili, fimbriae, and flagella, as well as proteins in outer membranes and genes, may also facilitate the surface colonization by pathogens. Increases in the expression of fliC, flagellin-encoding gene have been observed in certain produce contamination studies. After attachment, it becomes very difficult to remove the pathogens from produce by surface washing (Beuchat & Scoutten, 2002). Overall, enteric soil pathogens may reach the edible portions of fruits and vegetables via numerous mechanisms and routes and these have been elucidated by several studies (Natvig et al. 2002; Johannessen et al. 2005; Barak and Liang, 2008; Tyler and Triplett, 2008). Some of these routes include germination of seeds in contaminated soils, which leads to bacterial colonization of roots and edible parts, direct transfer of pathogens within the soil to crops when heavy rain or water gun irrigation causes leaf splash, bacterial infiltration through roots, amongst others.

***4.1.2.******Internalization***

Attached pathogens can reach the interior of fruits and vegetables via a variety of pathways. The extent of internalization depends on factors such as the route and mechanism of entry, the type and age of the plant, the aerial and/ or root morphology and exudates, the soil type and biology and the strain and/serovar of bacteria (Hirneisen, 2012; Brandl, 2013; Lim et al., 2014). The mechanism could be either passive or active (Sant’Ana et al., 2014). Passive internalization involves the uptake of bacteria mainly through roots and seeds. Mechanistically though, enteric pathogens may be internalized via the root system and transported to edible tissues, but the risk of contamination by this route is likely low (Matthews et al. 2014). This is because in the environment, particularly areas that are not prone to contamination events, the levels of enteric pathogens are likely to be extremely low (Cooley et al. 2007; Matthews et al. 2014). In contaminated zones, however, human pathogens may indeed invade root tissues and subsequently translocate to edible portions (Solomon et al., 2002; Solomon & Matthews, 2005). Depending on the age of the plant, pathogens may invade external root surfaces (main and side roots, as well as root hairs) and subsequently internalize. The developmental stage of plant root systems when contamination occurs influences the capability of pathogens to interact with, penetrate plant roots and migrate to other tissues (Mootian et al., 2009). The physiological characteristics of the roots may also determine the success of internalization; for example, some root vegetables possess antimicrobial properties, which limits the growth and internalization of enteric bacteria (Hirneisen et al., 2012). Pathogens like *E. coli* O157:H7 have been demonstrated to survive longer in the soil in the presence of rye and alfalfa roots (Gagliardi & Karns 2002).

Other work has demonstrated that pathogens enter root tissues at sites of lateral root emergence or through damaged roots (Mendes et al., 2013). Salmonella and *E.coli* O157:H7 have penetrated Arabidopisis and lettuce plants’ roots, while *Klebsiella pneumoniae* have been detected on numerous plants’ roots (Tyler & Triplett, 2008). Other examples include the invasion as well as (endophytic and systemic) colonization of barley roots by *S.* Typhimurium, the shoots of black pepper stem cuttings by *Pseudomonas aeruginosa*, as well as roots and shoots of tomato seedlings by *P. aeruginosa* (Kutter et al., 2006; Kumar et al., 2013). It is, however, important to note that successful invasion of the root and shoot system may not guarantee translocation to the edible or foliar portions of produce. In some surveys, bacterial pathogens were detected in roots but not leaves of crops examined (Watchel et al., 2002; Warriner et al., 2003; Bernstein et al., 2007a; Mitra et al., 2009; Sharma et al., 2009).

A growing body of evidence suggests that seeds may serve as primary inoculum source in produce contamination. In the case of vegetables, seed sprouts have been implicated as the initial inoculum source, severally (Warriner et al., 2003; Deering et al., 2012; Kumar et al., 2013). In recent time, seeds have been recognized as a significant source of inoculum for foodborne illnesses associated with sprout consumption (Mahon et al., 1997; National Advisory Committee on Microbiological Criteria for Foods, 1999; Buck et al., 2003; Yang et al., 2013). It is possible that enteric bacteria may be transmitted from contaminated seeds to sprout to mature plants, throughout entire plant life cycle up to consumption. The contamination may be transferred from seed again, thus persisting in produce cultivation cycles, for a long time. There is a record of *E. coli* 0157:H7 adherence to outer surfaces and subsequent successful internalization of radish sprouts produced from contaminated seed during sprout growth (Itoh et al., 1998).

Rate and efficiency of uptake also depends on the type of produce, and the level of internalization varies widely among plants and even among different species of the same crop due to variations in intrinsic factors, which affect pathogen survival and proliferation (Golberg et al., 2011; Erickson, 2012). For instance, certain produce items, like fully ripe tomatoes are typically in the pH range (3.9 – 4.5) which conventionally impedes growth of most enteric bacteria, whereas, the pH of numerous vegetables, melons, and soft fruits is usually 4.6 or higher, which is conducive for bacterial growth (Beuchat, 2002; Gagliardi et al., 2003). Therefore, Gram-negative bacteria are more commonly associated with vegetables while molds and certain yeasts mostly occur on fruits, due to the differences in pH requirements of the respective groups of microbes (Jay, 2012). Members of the Brassicaceae family (radish, turnip and broccoli) were demonstrated to have a higher prevalence of Salmonella contamination than lettuce, tomatoes and carrots when grown in contaminated soil (Barak et al., 2008). Among leafy greens, radicchio and endive may be more likely to be contaminated than lettuce, spinach, parsley or cilantro (Barak et al., 2008). *Salmonella* Typhimurium has been demonstrated to internalize more efficiently in iceberg lettuce and arugula leaves compared to romaine, red lettuce, fresh basil, parsley and tomato leaves, which displayed only marginal internalization. *Listeria monocytogenes* seems to exhibit a selective preference for certain vegetables like radishes and potatoes, as certain studies reported that although *L. monocytogenes* successfully invaded tissues of a wide variety of vegetables, radishes and potatoes appeared to be more often and severely contaminated (Beuchat, 1996). It is also apparent that *L. monocytogenes* does not survive and internalize satisfactorily on fresh carrot, in fact, low doses of raw carrot juice have been demonstrated to inhibit the growth of the pathogen (Beuchat et al., 1990; Farber & Peterkin, 1991; Oh, 1993; Benkerroum, 2013).

Internalization is believed to be a plant-pathogen specific interaction, and therefore, internalization success varies from pathogen to pathogen (Erickson, 2012). A comparison of the internalization of *L. monocytogenes* to *S.* Typhimurium on inoculated seeds of cress, radish, spinach, lettuce, mustard, carrots, and tomatoes showed significant variations in the rate and efficiency of internalization by the pathogens. Under identical experimental conditions, *S.* Typhimurium internalized into the roots of the vegetables, whereas, *L. monocytogenes* did not (Jablasone et al., 2005). Similarly, while *S.* Typhimurium was found to be associated with the internal portions of barley sprouts, *L. monocytogenes*, *L. ivanovii* and *L. innocua* were not (Kutter et al., 2006). Furthermore, the degree of internalization is contingent on the serovar/strain (Larsen et al., 2014). Gene expression, metabolic and antimicrobial capacities vary among strains. Certain strains manifest up-regulation of peculiar genes like the *pdu,* *cob-cbi*, and *out* which improve carbon source utilization and may confer a competitive edge, thereby enhancing the survival and persistence of these strains (Fox et al., 2011)*.* Some *E. coli* 0157 strains possess metabolic capacities, which foster their survival in certain agroecosystems such as soils (Franz et al., 2011). In a bid to explain the strain-specific internalization dynamics, a five serovar Salmonella cocktail (Montevideo, Michigan, Poona, Hartford and Enteritidis) was inoculated into hydroponic growth substrates. Serotypes Montevideo and Michigan were most prevalent, while Enteritidis, Hartford and Poona were not detected in any of the tomato tissue samples (Guo et al., 2001). This is a quintessential illustration of internalization variation among serovars. Likewise, Salmonella serovars; Cubana, Infantis and Typhimurium exhibited varying capabilities to internalize and colonize alfalfa sprouts when seeds were inoculated under identical environmental conditions (Dong et al., 2003).

Some scholars have endeavored to compare the survival of two arguably most prominent foodborne pathogens: *E. coli* and Salmonella*.* Serovars of both can proficiently adapt to environmental stress; -numerous strains are known to become habituated to low pH conditions and subsequently manifest remarkable tolerance to stress conditions. *Escherichia coli* can perpetually evolve new varieties that have neither been previously reported nor characterized and which are capable of exploring and inhabiting previously unrecognized niches (Newell et al., 2010). Both seem to be capable of long-term survival in the agricultural environment and on produce, but it is quite apparent that Salmonella survives better than *E. coli* (Brandl, 2006; Mandrell, 2009; Newell et al., 2010; Schikora et al., 2012; Ongeng et al., 2015). Many Salmonella serovars bind to plants significantly better than *E. coli* strains. *Escherichia coli’*s inability to lower its metabolic rate to suit the low availability of accessible organic carbon and to competently cope with low nutrient conditions contributes significantly to its die-out in soils and on produce, and therefore, lowers its competitiveness (survival) compared to Salmonella (Beuchat, 2002; Franz et al., 2008; Franz & van Bruggen, 2008; Franz et al., 2011).

Internalization has been correlated with motility and chemotaxis. Flagella mutants (fliGHI:Tn10, cheY) deficient in motility and chemotaxis respectively have exhibited reduced attachment and penetration of lettuce leaves (Kroupitski et al., 2009; Lim et al., 2014). It has also been hypothesized that products of photosynthesis serve as nutrients to aid internalization of pathogens (Lim et al., 2014).

Active internalization typically involves the penetration of bacteria through natural openings. The ability of foodborne pathogens to internalize in produce represents a significant public health risk because internalized pathogens are protected against optimized disinfection modes (Meireles et al., 2016) except irradiation which seems capable of reasonably eradicating internalized pathogens in produce. The technique penetrates produce tissues to eliminate internalized pathogens, and Gram-negative bacteria are very susceptible to even low doses (Saroj et al., 2007; O’Bryan et al., 2008). However, treatment with irradiation may produce off flavors, colors and odors and may inactivate some of the nutrients (Fan & Sokorai, 2008). It is, therefore, not accepted and endorsed for produce treatment. There are other relatively new technologies such as modified atmosphere packaging, ozone, ultrasound and ultraviolet treatments, which seem promising in ensuring the microbiological safety of fresh fruits and vegetable products (Shayanfar & Pillai, 2014). However, limited commercial applications have been described for most of these new technologies. Electron beam technology is another up-and-coming treatment option, which according to experts, can play a pivotal role in mitigating some of the contemporary microbiological risks facing the produce industry (Shayanfar & Pillai, 2014; Lung et al., 2015). It is an environment friendly, cost and time effective decontamination strategy that uses low-dose ionizing radiation to treat crops (-as well as other food items), to eliminate microbial contamination. It is capable of inhibiting the germination of crops and controls the rate of ripening of fruits and vegetables, thereby extending their shelf life (Lung et al., 2015). It inhibits a variety of enteric pathogens without compromising food sensory and nutritional qualities and can be used in combination with other traditional or non-traditional food processing technologies (Lung et al., 2015). Regulatory authorities such as the US Food and Drug Administration have approved it, but the full import of the safety of use is not yet conclusive.

Given the amount of evidence indicating that enteric pathogens (that are not plant pathogens) can invade and be internalized into plants, it is important to understand how such microbes establish access to plant tissues, as this may facilitate the development of strategies to reduce internalization. For successful colonization, major interactions take place between pathogens and their plant hosts that determine the success of the pathogenic attack (Warriner & Namvar, 2010). Many enteric pathogens have devised mechanisms to overcome plants’ basal defense mechanisms and innate immune responses (Lim et al., 2014). Plants first line of response to foreign invasion is by the innate immune system. This consists of two main branches: PAMP-triggered immunity (PTI) and effector-triggered immunity (ETI). In the first stage, microorganism associated molecular patterns (PAMPs or MAMPs such as flagellin, peptidoglycan, lipopolysaccharide) are identified by plant host receptors popularly known as Pattern Recognition Receptors (PRRs) (Deering et al., 2012). These batteries of receptors deployed by the host are designed to curb the growth and spread of the pathogen (Ausubel, 2005). PTI response is broad-spectrum; sensitive to molecules familiar to many classes of microorganisms including non-pathogens. Upon recognition, plant defense signal pathways are activated among which, jasmonate, salicylic acid and ethylene play essential roles.

Virulent plant pathogens may through diverse strategies, such as the production and secretion of effectors, efficiently override PTI, for example, there are some ‘effectors' that can overcome PTI by interfering with MAMP detection and subsequent defense signaling (Kazan & Lyons, 2014). This results in effector-triggered susceptibility (ETS). For susceptible interactions, effectors produced and released by the microorganism are transferred into the plant cell through the TTSS (Type III Secretion System). Specific nucleotide-binding leucine-rich-repeat (NB-LRR) proteins encoded by resistance genes, resulting in ETI and limitation of pathogen transmission to other tissues, recognize these effectors. While PTI is considered the first line of defense against pathogenic infection, ETI is an accelerated and amplified response, the outcome of which is often a hyper-sensitive response (HR) (Spoel & Dong, 2012).

The ability of pathogenic bacteria to colonize a plant may also be influenced by their interactions with other microorganisms either positively or negatively (Deering et al., 2012). If other microorganisms supply carbon sources (via degradation of cell wall polymers or induced secretion of sugars), or sequester antimicrobials, this can enhance pathogen colonization (Bais et al., 2006; Warriner et al., 2009; Augimeri et al., 2015). Alternatively, plant pathogens that wound or destroy living tissue may create a microenvironment that is suitable for the survival and/replication of human pathogens (Rashid et al., 2016). Pathogens are often associated more with plants whose tissues have been damaged by soft-rot pathogens compared to those with healthy tissues (Brandl, 2008). Before pathogenic bacteria can colonize the surface or interior of a plant host, they have to contend with the naturally occurring microflora that is already established (Deering et al., 2012). The ability of the indigenous bacterial community to inhibit the growth of introduced enteric pathogens has been demonstrated by numerous studies (Liao & Fett, 2001; Matos & Garland, 2005; Schuenzel & Harrison, 2002; Cooley et al., 2003; Johnston et al., 2009).

There is direct evidence that the stomata play essential roles in internalization, host immunity and pathogen virulence of pathogens (Kroupitski et al., 2009; Zeng et al., 2010). Some researchers have reported that plant stomata close in response to plant pathogens and some human pathogens (Melotto et al., 2008; Roy et al., 2013). *Escherichia coli* O157:H7 has been reported to trigger stomatal closure even under high relative humidity, a stressful environmental condition that generally weakens plant defenses against bacteria in field and laboratory conditions (Roy et al., 2013).

 Stomata closure could be triggered by certain peptides such as flg22 produced by bacterial flagellin and lipopolysaccharides which are recognized by PAMPs or MAMPs in a salicylic acid-dependent manner. In the case of some plant pathogens such as *Xanthomonas* spp. and *Pseudomonas syringae*, virulence factors produced are capable of overcoming this innate immunity and counter stomata defense. For example, *Pst* DC3000 and several other pathovars of *Pseudomonas syringae*, produce coronatine (COR), a phytotoxin which can reverse stomatal closure induced by bacteria or MAMPs (Zeng et al., 2010). Stomatal immunity can diminish the penetration of human pathogens through the leaf epidermis, resulting in low bacterial titers in the plant apoplast (Roy et al., 2013). However, plant defense responses induced by pathogens vary and plants may recognize and respond to some human pathogens more effectively than others (Roy et al., 2013). For example, comparison of plant defense responses induced by *E. coli* O157:H7 and *S.* Typhimurium SL1344 in *Arabidopsis thaliana* and lettuce (*Lactuca sativa*) revealed some variations. While *E. coli* O157:H7 triggered stomatal closure, SL1344 only induced a transient stomatal immunity. Also, PR1 gene expression was significantly higher in Arabidopsis leaves infected with *E. coli* O157:H7 compared with SL1344 (Roy et al., 2013).

Although, numerous studies have examined the intricacies of internalization in fresh produce, many of these are laboratory based. The few available field studies, which have mostly studied *E. coli,* indicate that internalization of pathogens may be not be very common in field settings (Zhang et al., 2009; Erickson et al., 2010b; Erickson et al., 2013; Erickson et al., 2014b). More field studies are therefore, required to properly understand the potential/likelihood of enteric pathogens to internalize in fresh produce as well as the actual factors that influence the success of internalization.

1. ***Precautions to reduce bacterial contamination of produce in the field.***

To successfully achieve an acceptable level of microbiological safety for fresh produce, it is essential to control environmental contamination in the field by taking appropriate pre-harvest precautions. One fundamental factor to consider is the state or quality of the growing fields. Fields on which wild or domestic animals have been recently grazed that have been subjected to flooding or may have been previously contaminated with manure constitute an unacceptable microbiological risk (Turbé et al., 2010). Therefore, growers need to scrupulously investigate land history when selecting a location for produce cultivation (Islam et al., 2004a, b). Cultivation areas should be safeguarded from flooding, and fecal contamination and manure should be adequately treated (using popular methods like composting and aging) before application as fertilizer. Also, suitable buffer zones (physical barriers) such as mounds, diversion berms, vegetative buffers as well as ditches should be erected between animal grazing regions and produce cultivation areas (James, 2006; Olaimat & Holley, 2012). Appropriate livestock waste disposal and farm general waste management should be adopted to ensure safety.

Numerous experts have highlighted the need for monitoring, regulation and control of the microbiological quality of irrigation water. Several regional and international standards exist for irrigation water use and practices to prevent incidence of bacterial contamination. The use of potable water for irrigation (and other cultivation operations) is highly recommended. Certainly, this is not economical in many instances and may increase production costs, which will raise prices; it is however, pertinent to public health safety. In developing countries, a myriad of safety regulations exists such as cessation of irrigation prior to harvesting, lowering of watering cans to reduce splashes from (contaminated) soil, adoption of furrow irrigation system over the use of sprayers which expose edible portions of leafy vegetables directly to irrigation water, and so on (Keraita et al., 2010; Amoah et al., 2011; Uyttendaele, 2015). In cases where surface water is the irrigation water source, drainage of contaminated water into the surface water reservoir may be prevented by constructing ditches, buffer strips, as well as retention and drainage systems. Potential overflow points should be identified and eliminated. It is also important to determine (potential) points of contamination because control measures are bound to be more effective if focused on eliminating contamination at the source (Madramootoo et al., 1997; Pachepsky et al., 2011). Irrigation wells, functional septic, water and sewage systems should be installed and properly maintained especially during periods of excessive rainfall to prevent pathogen contamination (Buck et al., 2003; Olaimat & Holley, 2013). Surface and groundwater resources should be protected from any potential sources of contamination including wildlife, animal waste, agricultural run-off, human activity, sewage, or industrial effluents. Other management practices like; removal of riparian areas, erection of fences, and treatment of irrigation water (for example, using UV treatment) can be considered to enhance safety assurance of irrigation water. These precautions will minimize contamination risks on produce farms and should be applicable not just to supposed high-risk crops (such as leafy greens) but all produce (squash, and others) (Strawn et al., 2013 b). Implementing some of these may, however, be costly and have negative impacts on landscape health. Irrigation water sources should be routinely monitored to ensure microbiological safety (Brackett, 1999; Islam et al., 2004b). Ideally, there should be more regular reporting on the microbiological quality of irrigation waters in different world regions. Such surveys should reflect the true levels of actual pathogens rather than indicators, and bias should be avoided towards contaminated samples by intensively monitoring every irrigation source possible, and not just sites where extensive contamination has been known to occur (Stoeckel, 2009).

As part of a total package of hygiene measures to prevent the transfer of foodborne pathogens, wild animals, birds, flies and rodents should be controlled in cultivation areas. Interventions to mitigate wildlife intrusion of a farm may be costly and not entirely effective, especially if not done properly, thereby allowing certain animals direct access to crops. In many cases, it is not economical to fence large farms, but small farms can be fenced to restrict wild animals (Jung et al., 2014). Other mechanical/biological control methods include the use of scarecrows, reflective strips, monitoring of animal tracks and field intrusion as well as gunshots to ward off pests and animals. Mechanical traps and baits can be used to control mice and rodents. Overall, practical, cost-effective methods should be adopted to mitigate wild sources and routes of produce contamination.

Considering that, in many important outbreaks, vegetable seed sprouts have been implicated as the initial inoculum source, the elimination of bacteria from seeds before planting has become crucial (Buck et al., 2003). Chemical or physical treatment methods are usually used to decontaminate seeds, in a bid to reduce the risks of sprout borne disease outbreaks. However, this poses some challenges for growers, as the chosen decontamination method has to fulfill certain conditions. One important consideration is the preservation of seed viability. Selected treatment dosage should be able to inactivate pathogens without adversely affecting seed viability (Buck et al., 2003). Also, the treatment must be able to penetrate and access bacteria that may be residing in protected seed tissues, and finally, certain treatments may be inactivated by seeds, rendering them less effective (Buck et al., 2003). Nevertheless, the efficacy of chemical seed treatments for sprout seed including chlorine compounds (commonly calcium and sodium hypochlorite), ethanol, hydrogen peroxide, calcium EDTA, 4-hydroxybenzoic acid, ozonated water and other commercial disinfectants have been extensively documented. It is also possible to use gaseous chemicals and thermotherapy (e.g., hot water treatment), although excessively high temperatures may affect sprout vigor. Another potential issue with hot water treatment is that when treating large batches of seed, it is practically impossible to achieve temperature uniformity throughout the water bath. Therefore, while a portion of the seeds receives the appropriate temperature-time exposure, some will still contain viable bacteria after ‘treatment.' Also, there is a potent risk of cross-contamination with this technique. Other viable options include seed treatment with bacteriophage, combinations of thermotherapy with chlorine and the use of ionizing radiation. Radiation is particularly appealing because it can penetrate seed tissues and possibly eliminate bacteria localized within protected tissues (Buck et al. 2003). However, it has been postulated that high levels of irradiation may distort the physiology and organoleptic properties of seedlings, more research is therefore, needed to evaluate the prospects and risks of this approach. Other precautionary measures include testing seed lots for purity and germination rate prior to marketing, proper warehouse storage (in metal bins) until bagged, as well as ensuring general facility sanitation and employee hygiene (National Advisory Committee on Microbiological Criteria for Foods, 1999).

Safety criteria and regulations are mostly region specific, it is however, critical to enforce these regulations, ensure that growers adhere to such and there is a need to constantly improve standards; if new information becomes available, regulations should immediately be updated (Köpke et al., 2007). Most of the available data is from the developed world mainly from the US and certain parts of Europe. It is necessary to develop surveillance and tracking systems and generate robust databases for other regions as well. More studies should be conducted under field conditions, rather than laboratory or greenhouse simulations, as this will provide a better understanding of how enteric pathogens behave in agricultural production environments.

Finally, and more importantly, it is necessary to ensure producers are mindful of their roles in assuring food safety. Growers should be encouraged to adopt the best possible agricultural practices to ensure produce safety. It is also important to enlighten consumers about possible risks and appropriate mitigation strategies. There are wrong notions and misconceptions, which have to be corrected promptly, for example, many people believe it is not necessary to wash organically grown fruits and vegetables (Leifert et al. 2008).

1. ***Research recommendations***
	1. ***Epidemiology***

It is evident that epidemiologic investigations are worthwhile as public health directives and policies based on investigation output have averted impending foodborne disease crises in many cases. The relevance of epidemiological surveys globally and regionally, therefore, cannot be overemphasized. This means that epidemiological investigation tools and systems need to be objective, updated, precise, flexible and timely. While significant progress has been achieved in the area of epidemiology, there are still certain cracks that need to be addressed. The use of routine, optimized clinical pathogen identification techniques may mean that new pathogens may likely be missed. This is a potentially grave issue, because periodically, since the development of foodborne disease surveillance, the list of foodborne pathogens has continued to expand. Care should, therefore, be taken to avoid research bias since it is likely that produce items that have been previously associated with foodborne illness outbreaks and product recalls may receive particular scrutiny. New pathogens emerge due in part, to evolving ecology and technology while already recognized strains continue to evolve, potentially becoming smarter, evading and subverting detection, sanitization and plant host defenses. It is important to further understand the evolution dynamics and emergence of new pathogens, as well as develop and optimize methods to meet the emerging challenges.

* 1. ***Understudied pathogens***

Awareness and surveillance of viral and parasitic enteric pathogens need to be more robustly developed. Although Noroviruses, Hepatitis A, Rotaviruses as well as certain emerging viruses such as SARS are well known, they are rarely routinely screened for in fresh produce in most countries. Also, their ecology in fresh produce is poorly understood, for instance, the knowledge of the stability and persistence of human Norovirus in foods has been garnered mostly from the study of surrogate viruses. More importantly, their significance in foodborne disease incidence remains undetermined. Parasitic pathogens like Ascaris, Giardia, Entamoeba, Cyclospora, Cryptosporidia and Trichinella are recognized (Newell et al., 2010; Robertson et al., 2014), but not all are routinely monitored in produce.

* 1. ***A need for protocol consensus***

The roles that livestock and wildlife play in pathogenic contamination of fruits and vegetables as well as their epidemiology through the food chain is poorly understood. It is difficult to compare the available studies because some have used naturally contaminated animals, while others used experimentally inoculated animals. The exact transport/transfer mechanisms of pathogens from animal fecal material or contaminated manure/soil to fruits and vegetables via splash are not yet properly understood. For example, it will be helpful to understand the specific spatial factors that influence the transfer of pathogens from fecal pellets to fruits and vegetables. The survival times for pathogens in fecal contaminants, manure, and manure-amended soils are inconsistent, reflecting the varying conditions under which many of the available studies have been conducted (These variations are demonstrated in Tables 3, 4 & 5). The fate of pathogens on the soil surface, the relationship between manure-derived pathogens and soil particles, as well as the states in which pathogens occur in soil slurry or manure mixtures, should be further explored. The exact mechanisms of uptake or (transmission) of pathogens from contaminated manure or manure amended soils to plants, particularly in field settings should be studied. This will facilitate the design of scientifically sound produce safety standards. The majority of studies available on pathogen transport in soils have been conducted using homogenized natural soils in laboratory designed soil columns. These may not be a true representation of field conditions and diversifying the experimental conditions will aid the development of efficient, grower-level interventions that will effectively reduce the likelihood of on-field contamination of produce.

There are dissenting opinions among experts on a variety of issues pertinent to produce safety. With regards to the factors, mechanisms as well as principles that aid competent internalization and persistence of pathogens on produce, there are many variations. The available studies are difficult to compare largely because they have been conducted under varying physicochemical circumstances, types of microcosms, experimental conditions and used distinct strains (Shown in Tables 3, 4 & 5). Most studies were conducted under disparate environmental conditions, and accurate weather data necessary to interpret results from the varying sources is lacking. Study results for one crop variety may indeed not hold true for other varieties, for instance, data for apples may not necessarily apply to all pome fruit and data for romaine lettuce may not apply to all leafy greens. When possible, varieties exhibiting greater potential for pathogen survival should be selected for experimental investigations. Another relevant consideration for crop selection is preference for varieties that are indigenous to the region in question. Some other seemingly trivial controversial issues include whether outer leaves are significantly more likely than inner leaves to become contaminated via splash and whether or not the potential for survival on the abaxial side of leaves is higher than on the adaxial side. The implications of dormant, non-dividing ‘persister’ cells occurring in certain plant pathogens on the ability to withstand environmental stresses and extensive survival as well as the issues surrounding linked resistance is still an important research debate. Also, even though atmospheric deposition seems to be an uncommon route of pathogenic contamination for produce, it has been documented as a potentially important route (Beuchat & Ryu, 1997; Harris et al., 2003; Mei Soon et al., 2012). It will be worthwhile exploring how relevant this is for produce safety.

While many of the available studies have made stringent efforts to simulate produce cultivation circumstances, it is extremely challenging to create precise/accurate environmental conditions in a laboratory setting. Most studies are conducted under controlled laboratory conditions. Factors like the biological activity of the soil, manure, water and crops, soil and water chemistries as well as meteorological elements such as wind, UV intensity, temperature, rainfall are simply impossible to replicate under laboratory conditions. Laboratory scale model systems may provide important details about the roles of environmental variables on pathogen growth and survival in agricultural environments, but the slightest tweaks in experimental protocols can affect pathogen survival in agroecosystems. Unfortunately, actual field-based studies are subject to disruption from unforeseen environmental events such as weather extremes and damage triggered by biological agents including insects or onset of plant diseases.

More field studies (where typical agricultural practices and conditions are closely simulated) are therefore, highly desirable to further understand the persistence phenomenon. Safety and ethical issues however restrict the use of pathogens in the greenhouse and field-based research. Strategies to improve existing biocontainment and decontamination processes should be developed and optimized as soon as possible. Another possible solution is to develop and optimize strategies that will cater for the experimental variations in model system development. An assessment and identification of environmental variables that influence the fate of test organisms should be included in experimental designs. Despite meticulous planning however, a field trial may fail to yield serviceable results due to factors that are out of the researcher’s control. Consequently, more replicate trials may need to be conducted. Furthermore, agronomic and farm management practices are not uniform in all regions, and production practices significantly differ from region to region depending on seasons and weather patterns within the same region. These often depend on operation scale, type of farming practices et cetera. The risks associated with conventional cropping systems are bound to differ from those of systems that combine intensive livestock farming with arable farming. In addition to general studies, a case-by-case approach should be considered where possible (if financial and technical resources, as well as other circumstances, permit) because farming operations vary widely from farm to farm and this influences the potential for pathogen occurrence, survival, proliferation and dissemination.

1. ***Conclusions***

The potential of fresh produce to harbor pathogens is now well recognized, and fresh produce has been established as a vehicle of foodborne disease. The diverse and complex sources and routes of enteric pathogens to fruits and vegetables have been widely researched. The interplay of land use, water management, weather patterns and specific pathogen properties and sources have been illustrated to have significant consequences for the microbiological safety of fresh fruits and vegetables. Attempts have been made to understand the general microbial profile of fresh produce, the behavior, fate and transport of pathogens, as well as their location in and on plant parts. The facts gleaned from these studies have been the subject of many extensive reviews. There is abundant information about the factors that affect the contamination and persistence of pathogens on fresh produce. In light of the available evidence, significant effort must be made to efficiently monitor and illustrate recent trends in the occurrence of foodborne diseases associated with the consumption of fruits and vegetables. Partnerships and collaboration among all relevant stakeholders; commercial growers, public health practitioners, veterinary and food safety experts and field biologists is necessary in order to ensure the safety of fruits and vegetables delivered to consumers.

On a final note, the need to control all potential pathogen entry pathways has been established and is being continuously stretched by regulators and other specialists. There are numerous other factors along the food production chain that may predispose produce to microbial contamination. However, it is of utmost importance to avoid and control microbial contamination of produce at the pre-harvest stage. This is because contaminated manure, water and soil have been shown to indeed contaminate produce, and decontamination of produce, polluted arable soil and groundwater has proven to be a very challenging and expensive endeavour.

***Acknowledgements***

The authors are grateful to the National Council for Scientific and Technological Development (CNPq) (Grant #302763/2014-7) and the Coordination for the Improvement of Higher Education Personnel (CAPES) (Grant ##33003017027P1) for the financial support. Oluwadara Alegbeleye wishes to acknowledge the financial support of Conselho Nacional de Desenvolvimento Cientifico e Tecnológico (CNPq) through award grant number 148279/2017-1.

***Conflicts of interest***

The authors declare no conflicts of interest.

***8) References***

Abbasi, S. A. (2001). *Water Resources Projects and their Environmental Impacts*. Discovery Publishing House. ISBN- 978-81-7141-579-3. Pp 1-5.

Adzitey, F., Huda, N. and Ali, G.R.R., (2013). Molecular techniques for detecting and typing of bacteria, advantages and application to foodborne pathogens isolated from ducks. *3 Biotech*, *3*(2), 97-107.

Ahmed, A. U., & Sorensen, D. L. (1995). Kinetics of pathogen destruction during storage of dewatered biosolids. *Water Environment Research*, *67*(2), 143-150.

Alam, M. J. & Zurek, L. (2004). Association of *Escherichia coli* O157: H7 with houseflies on a cattle farm. *Applied and Environmental Microbiology*, *70*(12), 7578-7580.

Allende, A., & Monaghan, J. (2015). Irrigation water quality for leafy crops: a perspective of risks and potential solutions. *International Journal of Environmental Research and Public Health*, *12*(7), 7457-7477.

Allos, B. M., Moore, M. R., Griffin, P. M., & Tauxe, R. V. (2004). Surveillance for sporadic foodborne disease in the 21st century: the FoodNet perspective *Clinical Infectious Diseases*, 38(3), S115–S120.

Alvarez, M. E., Aguilar, M., Fountain, A., Gonzalez, N., Rascon, O., & Saenz, D. (2000). Inactivation of MS-2 phage and Poliovirus in groundwater. *Canadian Journal of Microbiology*, *46*(2), 159-165.

Amoah, P., Keraita, B., Akple, M., Drechsel, P., Abaidoo, R. C., & Konradsen, F. (2011). *Low-cost options for reducing consumer health risks from farm to fork where crops are irrigated with polluted water in West Africa*. 141, IWMI, 1 – 37.

Antwi-Agyei, P., Cairncross, S., Peasey, A., Price, V., Bruce, J., Baker, K., ... & Ensink, J. (2015). A farm to fork risk assessment for the use of wastewater in agriculture in Accra, Ghana. *PloS one*, *10*(11), e0142346.

Arrus, K. M., Holley, R. A., Ominski, K. H., Tenuta, M., & Blank, G. (2006). Influence of temperature on Salmonella survival in hog manure slurry and seasonal temperature profiles in farm manure storage reservoirs. *Livestock Science*, *102*(3), 226-236.

Arthurson, V., Sessitsch, A., & Jäderlund, L. (2010). Persistence and spread of *Salmonella* *enterica* serovar Weltevreden in soil and on spinach plants. *FEMS Microbiology Letters*, *314*(1), 67-74.

Atkinson, C. J., Fitzgerald, J. D., & Hipps, N. A. (2010). Potential mechanisms for achieving agricultural benefits from biochar application to temperate soils: a review. *Plant and Soil*, *337*(1-2), 1-18.

Augimeri, R. V., Varley, A. J., & Strap, J. L. (2015). Establishing a role for bacterial cellulose in environmental interactions: lessons learned from diverse biofilm-producing Proteobacteria. *Frontiers in Microbiology*, *6*, 1282, [10.3389/fmicb.2015.01282](https://dx.doi.org/10.3389/fmicb.2015.01282).

Ausubel, F. M. (2005). Are innate immune signaling pathways in plants and animals conserved?. *Nature Immunology*, *6*(10), 973-979.

Avery, L. M., Hill, P., Killham, K., & Jones, D. L. (2004)a. *Escherichia coli* O157 survival following the surface and sub-surface application of human pathogen contaminated organic waste to soil. *Soil Biology and Biochemistry*, *36*(12), 2101-2103.

Avery, S. M., Moore, A., & Hutchison, M. L. (2004)b. Fate of *Escherichia coli* originating from livestock faeces deposited directly onto pasture. *Letters in Applied Microbiology*, *38*(5), 355-359.

Avery, L. M., Killham, K., & Jones, D. L. (2005). Survival of *E. coli* O157: H7 in organic wastes destined for land application. *Journal of Applied Microbiology*, *98*(4), 814-822.

Avery, L. M., Williams, A. P., Killham, K., & Jones, D. L. (2008). Survival of *Escherichia coli* O157: H7 in waters from lakes, rivers, puddles and animal-drinking troughs. *Science of the Total Environment*, *389*(2), 378-385.

Bagdasaryan, G. A. (1964). Survival of Viruses of the Enterovirus Group (Poliomyelitis, ECHO, Coxsackie) in Soil and on Vegetables. *Journal of Hygiene, Epidemiology, Microbiology and Immunology*, *8*(4), 497-505.

Bais, H. P., Weir, T. L., Perry, L. G., Gilroy, S., & Vivanco, J. M. (2006). The role of root exudates in rhizosphere interactions with plants and other organisms. *Annual Review of Plant Biology*, *57*, 233-266.

Baloda, S. B., Christensen, L., & Trajcevska, S. (2001). Persistence of a *Salmonella* *enterica* serovar Typhimurium DT12 clone in a piggery and in agricultural soil amended with Salmonella-contaminated slurry. *Applied and Environmental Microbiology*, *67*(6), 2859-2862.

Banning, N., Toze, S., & Mee, B. J. (2002). *Escherichia coli* survival in groundwater and effluent measured using a combination of propidium iodide and the green fluorescent protein. *Journal of Applied Microbiology*, *93*(1), 69-76.

Banning, N., Toze, S., & Mee, B. J. (2003). Persistence of biofilm-associated *Escherichia coli* and *Pseudomonas aeruginosa* in groundwater and treated effluent in a laboratory model system. *Microbiology*, *149*(1), 47-55.

Benkerroum, N. (2013). Traditional fermented foods of North African countries: technology and food safety challenges with regard to microbiological risks. *Comprehensive Reviews in Food Science and Food Safety*, *12*(1), 54-89.

Bernstein, N., Sela, S., Pinto, R., & Ioffe, M. (2007)a. Evidence for internalization of *Escherichia coli* into the aerial parts of maize via the root system. *Journal of Food Protection*, *70*(2), 471-475.

Bernstein, N., Sela, S., & Neder-Lavon, S. (2007)b. Effect of irrigation regimes on persistence of *Salmonella enterica* serovar Newport in small experimental pots designed for plant cultivation. *Irrigation Science*, *26*(1), 1-8.

Barak, J. D., Liang, A., & Narm, K. E. (2008). Differential attachment to and subsequent contamination of agricultural crops by *Salmonella enterica*. *Applied and Environmental Microbiology*, *74*(17), 5568-5570.

Barak, J. D., & Liang, A. S. (2008). Role of soil, crop debris, and a plant pathogen in *Salmonella enterica* contamination of tomato plants. *PLoS One*, *3*(2), e1657.

Benjamin, L., Atwill, E. R., Jay-Russell, M., Cooley, M., Carychao, D., Gorski, L., & Mandrell, R. E. (2013). Occurrence of generic *Escherichia coli, E. coli* O157 and *Salmonella* spp. in water and sediment from leafy green produce farms and streams on the Central California coast. *International Journal of Food Microbiology*, *165*(1), 65-76.

Bernard, H., Faber, M., Wilking, H., Haller, S., Höhle, M., Schielke, A., ... & Hamouda, O. (2014). Large multistate outbreak of Norovirus gastroenteritis associated with frozen strawberries, Germany, 2012.

Berger, C. N., Sodha, S. V., Shaw, R. K., Griffin, P. M., Pink, D., Hand, P., & Frankel, G. (2010). Fresh fruit and vegetables as vehicles for the transmission of human pathogens. *Environmental Microbiology*, *12*(9), 2385-2397.

Beuchat, L. R., Berrang, M. E., & Brackett, R. E. (1990). Presence and public health implications of *Listeria monocytogenes* on vegetables. *Foodborne Listeriosis*, 175-181.

Beuchat, L. R. (1996). *Listeria monocytogenes*: incidence on vegetables. *Food Control*, *7*(4-5), 223-228.

Beuchat, L. R., & Ryu, J. H. (1997). Produce handling and processing practices. *Emerging Infectious Diseases*, *3*(4), 459 - 465.

Beuchat, L. R. (2002). Ecological factors influencing survival and growth of human pathogens on raw fruits and vegetables. *Microbes and Infection*, *4*(4), 413-423.

Beuchat, L. R., & Scouten, A. J. (2002). Combined effects of water activity, temperature and chemical treatments on the survival of Salmonella and *Escherichia coli* O157: H7 on alfalfa seeds. *Journal of Applied Microbiology*, *92*(3), 382-395.

Beuchat, L. R. (2006). Vectors and conditions for preharvest contamination of fruits and vegetables with pathogens capable of causing enteric diseases. *British Food Journal*, *108*(1), 38-53.

Bhagat, A., Mahmoud, B. S., & Linton, R. H. (2010). Inactivation of *Salmonella enterica* and *Listeria monocytogenes* inoculated on hydroponic tomatoes using chlorine dioxide gas. *Foodborne Pathogens and Disease*, *7*(6), 677-685.

Bihn, E. (2011). Survey of current water use practices on fresh fruit and vegetable farms and evaluation of microbiological quality of surface waters intended for fresh produce production.

Bitton, G., Farrah, S. R., Ruskin, R. H., Butner, J., & Chou, Y. J. (1983). Survival of pathogenic and indicator organisms in ground water. *Groundwater*, *21*(4), 405-410.

Bolton, D. J. (1999). The‐survival‐characteristics‐of‐a‐non‐toxigenic‐strain‐of‐*Escherichia coli*‐O157: H7. *Journal of Applied Microbiology*, *86*(3), 407-411.

Botana, L.M. ed., (2014). *Seafood and Freshwater toxins: Pharmacology, Physiology, and Detection*. CRC Press. ISBN- 978-1-4665-0514-8.

Brackett, R. E. (1994). Microbiological spoilage and pathogens in minimally processed refrigerated fruits and vegetables. *Minimally Processed Refrigerated Fruits and Vegetables*, 269-312.

Brackett, R. (1999). Incidence, contributing factors, and control of bacterial pathogens in produce. *Postharvest Biology and Technology*, *15*(3), 305-311.

Braden, C. R., & Tauxe, R. V. (2013). Emerging trends in foodborne diseases. *Infectious disease clinics of North America*, *27*(3), 517-533.

Brandl, M. T., Haxo, A. F., Bates, A. H., & Mandrell, R. E. (2004). Comparison of survival of *Campylobacter jejuni* in the phyllosphere with that in the rhizosphere of spinach and radish plants. *Applied and Environmental Microbiology*, *70*(2), 1182-1189.

Brandl, M. T. (2006). Fitness of human enteric pathogens on plants and implications for food safety. *Annual Review of Phytopathology*, *44*, 367-392.

Brandl, M. T. (2008). Plant lesions promote the rapid multiplication of *Escherichia coli* O157: H7 on postharvest lettuce. *Applied and Environmental Microbiology*, *74*(17), 5285-5289.

Brandl, M. T., Cox, C. E., & Teplitski, M. (2013). Salmonella interactions with plants and their associated microbiota. *Phytopathology*, *103*(4), 316-325.

Brooks, J. E., & Jackson, W. B. (1973). A review of commensal rodents and their control. *Critical Reviews in Environmental Science and Technology*, *3*(1-4), 405-453.

Buck, P., Grimsrud K, Waters J, Cardinal R, Talbot J, Anand C, et al. (1998). Would you like a little Salmonella with your sandwich? In: Program and abstracts of the 47th Annual Epidemic Intelligence Service Conference, International Night. Atlanta, GA:

Buck, J. W., Walcott, R. R., & Beuchat, L. R. (2003). Recent trends in microbiological safety of fruits and vegetables. *Plant Health Progress*, *10*(1), 1094.

Burnett, S. L., & Beuchat, L. R. (2001). Human pathogens associated with raw produce and unpasteurized juices, and difficulties in decontamination. *Journal of Industrial Microbiology & Biotechnology*, *27*(2), 104-110.

Buswell, C. M., Herlihy, Y. M., Lawrence, L. M., McGuiggan, J. T., Marsh, P. D., Keevil, C. W., & Leach, S. A. (1998). Extended survival and persistence of *Campylobacter* spp. in water and aquatic biofilms and their detection by immunofluorescent-antibody and-rRNA staining. *Applied and Environmental Microbiology*, *64*(2), 733-741.

Cabral, J. P. (2010). Water microbiology. Bacterial pathogens and water. *International Journal of Environmental Research and Public Health*, *7*(10), 3657-3703.

Calder, L., Simmons, G., Thornley, C., Taylor, P., Pritchard, K., Greening, G., & Bishop, J. (2003). An outbreak of hepatitis A associated with consumption of raw blueberries. *Epidemiology & Infection*, *131*(1), 745-751.

Callejón, R. M., Rodríguez-Naranjo, M. I., Ubeda, C., Hornedo-Ortega, R., Garcia-Parrilla, M. C., & Troncoso, A. M. (2015). Reported foodborne outbreaks due to fresh produce in the United States and European Union: trends and causes. *Foodborne Pathogens and Disease*, *12*(1), 32-38.

Centers for Disease Control and Prevention (CDC. (1999). Outbreak of *Escherichia coli* O157: H7 and Campylobacter among attendees of the Washington County Fair-New York, 1999. *MMWR. Morbidity and Mortality Weekly Report*, *48*(36), 803.

Centers for Disease Control and Prevention (CDC). (2002). Multistate outbreaks of Salmonella serotype Poona infections associated with eating cantaloupe from Mexico--United States and Canada, 2000-2002. *MMWR. Morbidity and Mortality Weekly Report*, *51*(46), 1044.

Centers for Disease Control and Prevention (CDC). (2005). Outbreaks of Salmonella infections associated with eating Roma tomatoes—United States and Canada, 2004. *Morbidity and Mortality Weekly Report*, 54:325-328.

Centers for Disease Control and Prevention. Preliminary FoodNet data on the incidence of infection with pathogens transmitted commonly through food—10 states, (2009). MMWR *Morbidity and Mortality Weekly Report* 2010;59:418–22.

Centers for Disease Control and Prevention (2013) Multistate outbreak of hepatitis A virus infections linked to pomegranate seeds from Turkey. CDC, Atlanta. <http://www.cdc.gov/hepatitis/outbreaks/2013/a1b-03-31/index.html> (Accessed 24 May 2017).

Centers for Disease Control and Prevention (2014). List of selected multistate foodborne outbreak investigations. <http://www.cdc.gov/foodsafety/outbreaks/multistate-outbreaks/outbreaks-list.html>. (Accessed 13 June, 2017).

Centers for Disease Control and Prevention (2016). Listeria outbreaks. Available online: https://www.cdc.gov/listeria/outbreaks/ (accessed on 26 December 2017).

Centers for Disease Control and Prevention. (2017). List of selected multistate foodborne outbreak investigations. *Centers for Disease Control and Prevention. http://www.* [*https://www.cdc.gov/foodsafety/outbreaks/multistate-outbreaks/outbreaks-list.html*](https://www.cdc.gov/foodsafety/outbreaks/multistate-outbreaks/outbreaks-list.html) (Accessed 17th April, 2017).

Chalmers, R. M., Aird, H., & Bolton, F. J. (2000). Waterborne *Escherichia coli* O157. *Journal of Applied Microbiology*, *88*(S1).

Chandler, D. S., & Craven, J. A. (1978). Environmental factors affecting *Escherichia coli* and *Salmonella* Typhimurium numbers on land used for effluent disposal. *Australian Journal of Agricultural Research*, *29*(3), 577-585.

Chandler, D. S., & Craven, J. A. (1981). A note on the persistence of *Salmonella* havana and faecal coliforms on a naturally contaminated piggery effluent disposal site. *Journal of Applied Microbiology*, *51*(1), 45-49.

Chen, Z., & Jiang, X. (2014). Microbiological safety of chicken litter or chicken litter-based organic fertilizers: a review. *Agriculture*, *4*(1), 1-29.

Close, M., Dann, R., Ball, A., Pirie, R., Savill, M., & Smith, Z. (2008). Microbial groundwater quality and its health implications for a border-strip irrigated dairy farm catchment, South Island, New Zealand. *Journal of Water and Health*, *6*(1), 83-98.

Cook, K. L., & Bolster, C. H. (2007). Survival of *Campylobacter jejuni* and *Escherichia coli* in groundwater during prolonged starvation at low temperatures. *Journal of Applied Microbiology*, *103*(3), 573-583.

Cooley, M. B., Miller, W. G., & Mandrell, R. E. (2003). Colonization of *Arabidopsis thaliana* with *Salmonella enterica* and enterohemorrhagic *Escherichia coli* O157: H7 and competition by *Enterobacter asburiae*. *Applied and Environmental Microbiology*, *69*(8), 4915-4926.

Cooley, M., Carychao, D., Crawford-Miksza, L., Jay, M. T., Myers, C., Rose, C., ... & Mandrell, R. E. (2007). Incidence and tracking of *Escherichia coli* O157: H7 in a major produce production region in California. *PloS one*, *2*(11), e1159.

Cools, D., Merckx, R., Vlassak, K., & Verhaegen, J. (2001). Survival of *E. coli* and *Enterococcus* spp. derived from pig slurry in soils of different texture. *Applied Soil Ecology*, *17*(1), 53-62.

Corrente, M., Madio, A., Friedrich, K. G., Greco, G., Desario, C., Tagliabue, S., ... & Buonavoglia, C. (2004). Isolation of Salmonella strains from reptile faeces and comparison of different culture media. *Journal of Applied Microbiology*, *96*(4), 709-715.

Côté, C., & Quessy, S. (2005). Persistence of *Escherichia coli* and Salmonella in surface soil following application of liquid hog manure for production of pickling cucumbers. *Journal of Food Protection*, *68*(5), 900-905.

Cotterelle, B., Drougard, C., Rolland, J., Becamel, M., Boudon, M., Pinede, S., ... & Espié, E. (2005). Outbreak of norovirus infection associated with the consumption of frozen raspberries, France, March 2005. *Euro Surveillance* *10*(4), E050428.

Critzer, F. J., & Doyle, M. P. (2010). Microbial ecology of foodborne pathogens associated with produce. *Current Opinion in Biotechnology*, *21*(2), 125-130.

Croci, L., Dubois, E., Cook, N., de Medici, D., Schultz, A. C., China, B., ... & Van der Poel, W. H. (2008). Current methods for extraction and concentration of enteric viruses from fresh fruit and vegetables: towards international standards. *Food Analytical Methods*, *1*(2), 73-84.

Crook, J., & Surampalli, R. Y. (1996). Water reclamation and reuse criteria in the US. *Water Science and Technology*, *33*(10-11), 451-462.

Danyluk, M. D., Nozawa‐Inoue, M., Hristova, K. R., Scow, K. M., Lampinen, B., & Harris, L. J. (2008). Survival and growth of Salmonella Enteritidis PT 30 in almond orchard soils. *Journal of Applied Microbiology*, *104*(5), 1391-1399.

Davidson, P. C., Kuhlenschmidt, T. B., Bhattarai, R., Kalita, P. K., & Kuhlenschmidt, M. S. (2013). Investigation of rotavirus survival in different soil fractions and temperature conditions. *Journal of Environmental Protection*, *4*(07), 1.

Day, D. L., & Funk, T. L. (2002). Processing manure: physical, chemical and biological treatment. *Animal Waste Utilization: Effective Use of Manure as a Soil Resource*, 243-282.

Dazzo, F., Smith, P., & Hubbell, D. (1973). The influence of manure slurry irrigation on the survival of fecal organisms in Scranton fine sand. *Journal of Environmental Quality*, *2*(4), 470-473.

Decol, L. T., Casarin, L. S., Hessel, C. T., Batista, A. C. F., Allende, A., & Tondo, E. C. (2017). Microbial quality of irrigation water used in leafy green production in Southern Brazil and its relationship with produce safety. *Food Microbiology*, *65*, 105-113.

Decho, A. W. (2000). Microbial biofilms in intertidal systems: an overview. *Continental Shelf Research*, *20*(10), 1257-1273.

Deering, A. J., Mauer, L. J., & Pruitt, R. E. (2012). Internalization of *E. coli* O157: H7 and *Salmonella* spp. in plants: a review. *Food Research International*, *45*(2), 567-575.

Denis, N., Zhang, H., Leroux, A., Trudel, R., & Bietlot, H. (2016). Prevalence and trends of bacterial contamination in fresh fruits and vegetables sold at retail in Canada. *Food Control*, *67*, 225-234.

Dentinger, C. M., Bower, W. A., Nainan, O. V., Cotter, S. M., Myers, G., Dubusky, L. M., ... & Bell, B. P. (2001). An outbreak of hepatitis A associated with green onions. *The Journal of Infectious Diseases*, *183*(8), 1273-1276.

Derbyshire J.B. (1973). - Viral pollution hazards of animal wastes. In Viruses in the environment and their potential hazards (M.S. Mahdy & B.J. Dutka, eds.). Canadian Centre for Inland Waters, Burlington, Ontario, 65-68.

Denny, J., Threlfall, J., Takkinen, J., Löfdahl, S., Westrell, T., Varela, C., ... & Straetemans, M. (2007). Multinational *Salmonella* Paratyphi B variant Java (*Salmonella* Java) outbreak, August–December 2007. *Euro Surveillance*, *12*(12), E071220.

Derbyshire, J. B., & Brown, E. G. (1978). Isolation of animal viruses from farm livestock waste, soil and water. *Epidemiology & Infection*, *81*(2), 295-302.

Diacono, M., & Montemurro, F. (2010). Long-term effects of organic amendments on soil fertility. A review. *Agronomy for Sustainable Development*, *30*(2), 401-422.

Diez-Gonzalez, F., Callaway, T. R., Kizoulis, M. G., & Russell, J. B. (1998). Grain feeding and the dissemination of acid-resistant *Escherichia coli* from cattle. *Science*, *281*(5383), 1666-1668.

Directorate, C. (2002). Risk Profile on the Microbiological Contamination of Fruits and Vegetables Eaten Raw. [http://www2.esb.ucp.pt/twt/seg\_alim/outros/Frutos=perigos\_microbiologi.pdf](http://www2.esb.ucp.pt/twt/seg_alim/outros/Frutos%3Dperigos_microbiologi.pdf) (Accessed on 17 December, 2017).

Dong, Y., Iniguez, A. L., Ahmer, B. M., & Triplett, E. W. (2003). Kinetics and strain specificity of rhizosphere and endophytic colonization by enteric bacteria on seedlings of *Medicago sativa* and *Medicago truncatula*. *Applied and Environmental Microbiology*, *69*(3), 1783-1790.

Donnison, A., & Ross, C. (2009). Survival and retention of *Escherichia coli* O157: H7 and Campylobacter in contrasting soils from the Toenepi catchment. *New Zealand Journal of Agricultural Research*, *52*(2), 133-144.

Dowd, S. E., & Pillai, S. D. (1997). Survival and transport of selected bacterial pathogens and indicator viruses under sandy aquifer conditions. *Journal of Environmental Science & Health Part A*, *32*(8), 2245-2258.

Dowe, M. J., Jackson, E. D., Mori, J. G., & Bell, C. R. (1997). *Listeria monocytogenes* survival in soil and incidence in agricultural soils. *Journal of Food Protection*, *60*(10), 1201-1207.

Doyle, M. P., & Erickson, M. C. (2008). Summer meeting 2007–the problems with fresh produce: an overview. *Journal of Applied Microbiology*, *105*(2), 317-330.

Ehling‐Schulz, M., Fricker, M., & Scherer, S. (2004). *Bacillus cereus*, the causative agent of an emetic type of food‐borne illness. *Molecular Nutrition & Food Research*, *48*(7), 479-487.

Ekdahl, K., Normann, B., & Andersson, Y. (2005). Could flies explain the elusive epidemiology of campylobacteriosis?. *BMC Infectious Diseases*, *5*(1), 11.

Ellis, J. R., & McCalla, T. M. (1978). Fate of pathogens in soils receiving animal wastes—a review. *Trans. ASAE*, *21*(2), 309-313.

Erickson, M. C. (2010). Microbial risks associated with cabbage, carrots, celery, onions, and deli salads made with these produce items. *Comprehensive Reviews in Food Science and Food Safety*, *9*(6), 602-619.

Erickson, M. C., Webb, C. C., Diaz-Perez, J. C., Phatak, S. C., Silvoy, J. J., Davey, L., ... & Doyle, M. P. (2010)a. Surface and internalized *Escherichia coli* O157: H7 on field-grown spinach and lettuce treated with spray-contaminated irrigation water. *Journal of Food Protection*, *73*(6), 1023-1029.

Erickson, M. C., Webb, C. C., Diaz-Perez, J. C., Phatak, S. C., Silvoy, J. J., Davey, L., ... & Doyle, M. P. (2010)b. Infrequent internalization of *Escherichia coli* O157: H7 into field-grown leafy greens. *Journal of food protection*, *73*(3), 500-506.

Erickson, M. C., Webb, C. C., Díaz-Pérez, J. C., Davey, L. E., Payton, A. S., Flitcroft, I. D., ... & Doyle, M. P. (2013). Internalization of *Escherichia coli* O157: H7 following spraying of cut shoots when leafy greens are regrown for a second crop. *Journal of Food Protection*, *76*(12), 2052-2056.

Erickson, M. C., Habteselassie, M. Y., Liao, J., Webb, C. C., Mantripragada, V., Davey, L. E., & Doyle, M. P. (2014)a. Examination of factors for use as potential predictors of human enteric pathogen survival in soil. *Journal of Applied Microbiology*, *116*(2), 335-349.

Erickson, M. C., Webb, C. C., Díaz-Pérez, J. C., Davey, L. E., Payton, A. S., Flitcroft, I. D., ... & Doyle, M. P. (2014)b. Absence of internalization of *Escherichia coli* O157: H7 into germinating tissue of field-grown leafy greens. *Journal of Food Protection*, *77*(2), 189-196.

Ethelberg, S., Lisby, M., Vestergaard, L., Enemark, H., & Mølbak, K. (2005). Cryptosporidiosis outbreak associated with eating in a canteen, Denmark, August 2005. *Euro Surveill*ance *10*(10), E051027.

Ethelberg, S., Lisby, M., Böttiger, B., Schultz, A. C., Villif, A., Jensen, T., ... & Muller, L. (2010). Outbreaks of gastroenteritis linked to lettuce, Denmark, January 2010. *Eurosurveillance*, *15*(6), 19484.

European Food Safety Authority (EFSA) (2013). Scientific opinion on the risk posed by pathogens in food of non-animal origin. Part 1: outbreak data analysis and risk ranking of food/pathogen combinations. EFSA J. 11 (1), 3025.

European Food Safety Authority (EFSA) (2017), The European Union summary report on trends and sources of zoonoses, zoonotic agents and food-borne outbreaks in 2016. European Centre for Disease Prevention and Control <http://onlinelibrary.wiley.com/doi/10.2903/j.efsa.2017.5077/full>

Falkenhorst, G., Krusell, L., Lisby, M., Madsen, S. B., Böttiger, B. E., & Mølbak, K. (2005). Imported frozen raspberries cause a series of Norovirus outbreaks in Denmark, 2005. *Weekly releases (1997–2007)*, *10*(38), 2795.

Fan, X., & Sokorai, K. J. B. (2008). Retention of Quality and Nutritional Value of 13 Fresh‐Cut Vegetables Treated with Low Dose Radiation. *Journal of Food Science*, *73*(7).

Farber, J. M., & Peterkin, P. I. (1991). *Listeria monocytogenes*, a food-borne pathogen. *Microbiological Reviews*, *55*(3), 476-511.

Faour-Klingbeil, D., Murtada, M., Kuri, V., & Todd, E. C. (2016). Understanding the routes of contamination of ready-to-eat vegetables in the Middle East. *Food Control*, *62*, 125-133.

[FDA] U.S. Food and Drug Administration. Sprouters Northwest, Inc. recalls alfalfa sprout products because of possible health concern. Available at http:==www.fda.gov=oc= po=firmrecalls=sprouters09\_08.html. Rockville, MD; FDA, 2008a.

Ferreira, V., Wiedmann, M., Teixeira, P., & Stasiewicz, M. J. (2014). *Listeria monocytogenes* persistence in food-associated environments: epidemiology, strain characteristics, and implications for public health. *Journal of Food Protection*, *77*(1), 150-170.

Fenlon, D. R., Ogden, I. D., Vinten, A., & Svoboda, I. (2000). The fate of *Escherichia coli* and *E. coli* O157 in cattle slurry after application to land. *Journal of Applied Microbiology*, *88* 149 - 156.

Field, K. G., & Samadpour, M. (2007). Fecal source tracking, the indicator paradigm, and managing water quality. *Water Research*, *41*(16), 3517-3538.

Fierer, N., & Jackson, R. B. (2006). The diversity and biogeography of soil bacterial communities. *Proceedings of the National Academy of Sciences of the United States of America*, *103*(3), 626-631.

Fongaro, G., García-González, M. C., Hernández, M., Kunz, A., Barardi, C. R., & Rodríguez-Lázaro, D. (2017). Different Behavior of Enteric Bacteria and Viruses in Clay and Sandy Soils after Biofertilization with Swine Digestate. *Frontiers in Microbiology*, *8*:74.

Fonseca, J. M., Fallon, S. D., Sanchez, C. A., & Nolte, K. D. (2011). *Escherichia coli* survival in lettuce fields following its introduction through different irrigation systems. *Journal of Applied Microbiology*, *110*(4), 893-902.

Forslund, A., Ensink, J. H. J., Battilani, A., Kljujev, I., Gola, S., Raicevic, V., ... & Dalsgaard, A. (2010). Faecal contamination and hygiene aspect associated with the use of treated wastewater and canal water for irrigation of potatoes (*Solanum tuberosum*). *Agricultural Water Management*, *98*(3), 440-450.

Fox, E. M., Leonard, N., & Jordan, K. (2011). Physiological and transcriptional characterisation of persistent and non-persistent *Listeria monocytogenes* isolates. *Applied and Environmental Microbiology*, AEM-05529.

Frank, C., Walter, J., Muehlen, M., Jansen, A., Van Treeck, U., Hauri, A. M., ... & Schreier, E. (2007). Major outbreak of hepatitis A associated with orange juice among tourists, Egypt, 2004. *Emerging Infectious Diseases*, *13*(1), 156.

Franz, E., van Diepeningen, A. D., de Vos, O. J., & van Bruggen, A. H. (2005). Effects of cattle feeding regimen and soil management type on the fate of *Escherichia coli* O157: H7 and *Salmonella enterica* serovar Typhimurium in manure, manure-amended soil, and lettuce. *Applied and Environmental Microbiology*, *71*(10), 6165-6174.

Franz, E., Semenov, A. V., Termorshuizen, A. J., De Vos, O. J., Bokhorst, J. G., & Van Bruggen, A. H. (2008). Manure amended soil characteristics affecting the survival of *E. coli* O157: H7 in 36 Dutch soils. *Environmental Microbiology*, *10*(2), 313-327.

Franz, E., & van Bruggen, A. H. (2008). Ecology of *E. coli* O157: H7 and *Salmonella enterica* in the primary vegetable production chain. *Critical Reviews in Microbiology*, *34*(3-4), 143-161.

Franz, E., van Hoek, A. H., Bouw, E., & Aarts, H. J. (2011). Variability of *Escherichia coli* O157 strain survival in manure-amended soil in relation to strain origin, virulence profile, and carbon nutrition profile. *Applied and Environmental Microbiology*, *77*(22), 8088-8096.

Fremaux, B., Delignette‐Muller, M. L., Prigent‐Combaret, C., Gleizal, A., & Vernozy‐Rozand, C. (2007)a. Growth and survival of non‐O157: H7 Shiga‐toxin‐producing *Escherichia coli* in cow manure. *Journal of Applied Microbiology*, *102*(1), 89-99.

Fremaux, B., Prigent‐Combaret, C., Delignette‐Muller, M. L., Dothal, M., & Vernozy‐Rozand, C. (2007)b. Persistence of Shiga toxin‐producing *Escherichia coli* O26 in cow slurry. *Letters in Applied Microbiology*, *45*(1), 55-61.

Fremaux, B., Prigent‐Combaret, C., Delignette‐Muller, M. L., Mallen, B., Dothal, M., Gleizal, A., & Vernozy‐Rozand, C. (2008). Persistence of Shiga toxin‐producing *Escherichia coli* O26 in various manure‐amended soil types. *Journal of Applied Microbiology*, *104*(1), 296-304.

Fukushima, H., Hoshina, K., & Gomyoda, M. (1999). Long-Term Survival of Shiga Toxin-Producing *Escherichia coli* O26, O111, and O157 in Bovine Feces. *Applied and Environmental Microbiology*, *65*(11), 5177-5181.

Gagliardi, J. V., & Karns, J. S. (2000). Leaching of *Escherichia coli* O157: H7 in diverse soils under various agricultural management practices. *Applied and Environmental Microbiology*, *66*(3), 877-883.

Gagliardi, J. V., & Karns, J. S. (2002). Persistence of *Escherichia coli* O157: H7 in soil and on plant roots. *Environmental Microbiology*, *4*(2), 89-96.

Gagliardi, J. V., Millner, P. D., Lester, G., & Ingram, D. (2003). On-farm and postharvest processing sources of bacterial contamination to melon rinds. *Journal of Food Protection*, *66*(1), 82-87.

Garcia, R., Baelum, J., Fredslund, L., Santorum, P., & Jacobsen, C. S. (2010). Influence of temperature and predation on survival of *Salmonella enterica* serovar Typhimurium and expression of invA in soil and manure-amended soil. *Applied and Environmental Microbiology*, *76*(15), 5025-5031.

Garner, D., & Kathariou, S. (2016). Fresh produce–associated Listeriosis outbreaks, sources of concern, teachable moments, and insights. *Journal of Food Protection*, *79*(2), 337-344.

Gaul, L. K., Farag, N. H., Shim, T., Kingsley, M. A., Silk, B. J., & Hyytia-Trees, E. (2012). Hospital-acquired Listeriosis outbreak caused by contaminated diced celery—Texas, 2010. *Clinical Infectious Diseases*, *56*(1), 20-26.

Gerba, C. P., Wallis, C., & Melnick, J. L. (1975). Fate of wastewater bacteria and viruses in soil. *Journal of Irrigation and Drainage Engineering*, *101*(ASCE# 11572 Proceeding).

Gerba, C. P. (2009). The role of water and water testing in produce safety. *Microbial Safety of Fresh Produce*, 129-142.

Gessel, P. D., Hansen, N. C., Goyal, S. M., Johnston, L. J., & Webb, J. (2004). Persistence of zoonotic pathogens in surface soil treated with different rates of liquid pig manure. *Applied Soil Ecology*, *25*(3), 237-243.

Ghorbani, R., Wilcockson, S., Koocheki, A., & Leifert, C. (2008). Soil management for sustainable crop disease control: a review. *Environmental Chemistry Letters*, *6*(3), 149-162.

Gilchrist, C. A., Turner, S. D., Riley, M. F., Petri, W. A., & Hewlett, E. L. (2015). Whole-genome sequencing in outbreak analysis. *Clinical Microbiology Reviews*, *28*(3), 541-563.

Golberg, D., Kroupitski, Y., Belausov, E., Pinto, R., & Sela, S. (2011). *Salmonella* Typhimurium internalization is variable in leafy vegetables and fresh herbs. *International Journal of Food Microbiology*, *145*(1), 250-257.

Gordon, C., & Toze, S. (2003). Influence of groundwater characteristics on the survival of enteric viruses. *Journal of Applied Microbiology*, *95*(3), 536-544.

Goss, M. J., Tubeileh, A., & Goorahoo, D. (2013). A review of the use of organic amendments and the risk to human health. *Advances in Agronomy*, *120*, 275-379.

Goss, M., & Richards, C. (2008). Development of a risk-based index for source water protection planning, which supports the reduction of pathogens from agricultural activity entering water resources. *Journal of Environmental Management*, *87*(4), 623-632.

Grewal, S. K., Rajeev, S., Sreevatsan, S., & Michel, F. C. (2006). Persistence of *Mycobacterium avium* subsp. paratuberculosis and other zoonotic pathogens during simulated composting, manure packing, and liquid storage of dairy manure. *Applied and Environmental Microbiology*, *72*(1), 565-574.

Groves, S., Davies, N., and Aitken,M. (2002). A Review ofthe Use ofWater in UK Agriculture and the Potential Risks to Food Safety. Report B17001. Food Standards Agency, London. http://www.foodbase.org.uk/results.php?f\_report\_id¼194.

Gutierrez, E. (1997). Japan prepares as 0157 strikes again. Lancet, 349(9059):1156.

Gupta, V. (2012). *Isolation and characterization of various microorganisms from composts; its value addition to control Fusarium wilt of Solanum lycopersicum L. & cloning and expression of heat stress resistance inducing candidate gene, ThPIL of Trichoderma harzianum* (Doctoral dissertation, GB Pant University of Agriculture and Technology, Pantnagar-263145 (Uttarakhand).

Guo, X., Chen, J., Brackett, R. E., & Beuchat, L. R. (2001). Survival of Salmonellae on and in tomato plants from the time of inoculation at flowering and early stages of fruit development through fruit ripening. *Applied and Environmental Microbiology*, *67*(10), 4760-4764.

Hagedorn, C., Hansen, D. T., & Simonson, G. H. (1978). Survival and movement of fecal indicator bacteria in soil under conditions of saturated flow. *Journal of Environmental Quality*, *7*(1), 55-59.

Hald, B., Skovgård, H., Bang, D. D., Pedersen, K., Dybdahl, J., Jespersen, J. B., & Madsen, M. (2004). Flies and Campylobacter infection of broiler flocks. *Emerging Infectious Diseases*, *10*(8), 1490-1492.

Harris, L.J., Farber, J.N., Beuchat, L.R., Parish, M.E., Suslow, T.V., Garrett, E.H. and Busta, F.F. (2003). Outbreaks associated with fresh produce: incidence, growth, and survival of pathogens in fresh and fresh‐cut produce. *Comprehensive Reviews in Food Science and Food Safety*, *2*(s1), 78-141.

Harris, L. J., Bender, J., Bihn, E. A., Blessington, T., Danyluk, M. D., Delaquis, P., ... & LeJeune, J. T. (2012). A framework for developing research protocols for evaluation of microbial hazards and controls during production that pertain to the quality of agricultural water contacting fresh produce that may be consumed raw. *Journal of Food Protection*, *75*(12), 2251-2273.

Hassen, A., Belguith, K., Jedidi, N., Cherif, A., Cherif, M., & Boudabous, A. (2001). Microbial characterization during composting of municipal solid waste. *Bioresource Technology*, *80*(3), 217-225.

Havelaar, A. H., Brul, S., De Jong, A., De Jonge, R., Zwietering, M. H., & Ter Kuile, B. H. (2010). Future challenges to microbial food safety. *International Journal of Food Microbiology*, *139*, S79-S94.

Health Canada (2011). Food-related illnesses. Available at: http://www.hc-sc.gc.ca/ fn-an/securit/ill-intox/index-eng.php (accessed 01/05/2017)

Heaton, J. C., & Jones, K. (2008). Microbial contamination of fruit and vegetables and the behaviour of enteropathogens in the phyllosphere: a review. *Journal of Applied Microbiology*, *104*(3), 613-626.

Heier, B. T., Nygard, K., Kapperud, G., Lindstedt, B. A., Johannessen, G. S., & Blekkan, H. (2009). sugar peas, May–June 2009. *rationing in Europe? 295• Implementation of a national electronic reporting system in Lithuania 298• VACSATC (Vaccine safety: attitudes, training and communication): Why such a project? 304*, 344.

Hernández, F., Monge, R., Jiménez, C., & Taylor, L. (1997). Rotavirus and hepatitis A virus in market lettuce (*Latuca sativa*) in Costa Rica. *International Journal of Food Microbiology*, *37*(2), 221-223.

Hess, T. F., Grdzelishvili, I., Sheng, H., & Hovde, C. J. (2004). Heat inactivation of *E. coli* during manure composting. *Compost Science & Utilization*, *12*(4), 314-322.

Heinonen-Tanski, H., Niskanen, E. M., Salmela, P., & Lanki, E. (1998). Salmonella in animal slurry can be destroyed by aeration at low temperatures. *Journal of Applied Microbiology*, *85*(2), 277-281.

Heywood, P., Cutler, J., Burrows, K., Komorowski, C., Marshall, B., & Wang, H. L. (2007). A community outbreak of travel-acquired hepatitis A transmitted by an infected food handler. *Canada communicable disease report= Releve des maladies transmissibles au Canada*, *33*(11), 16-22.

Higgins, J., Warnken, J., Teasdale, P. R., & Arthur, J. M. (2009). Decline in recycled water quality during short-term storage in open ponds. *Journal of Water and Health*, *7*(4), 597-608.

Hilborn, E. D., Mermin, J. H., Mshar, P. A., Hadler, J. L., Voetsch, A., Wojtkunski, C., ... & Glynn, M. K. (1999). A multistate outbreak of *Escherichia coli* O157: H7 infections associated with consumption of mesclun lettuce. *Archives of Internal Medicine*, *159*(15), 1758-1764.

Himathongkham, S., Bahari, S., Riemann, H., & Cliver, D. (1999). Survival of *Escherichia coli* O157: H7 and *Salmonella* Typhimurium in cow manure and cow manure slurry. *FEMS Microbiology Letters*, *178*(2), 251-257.

Hirneisen, K. (2012). *Enteric viral interactions on fresh produce*. University of Delaware.

Hirneisen, K. A., Sharma, M., & Kniel, K. E. (2012). Human enteric pathogen internalization by root uptake into food crops. *Foodborne Pathogens and Disease*, *9*(5), 396-405.

Hjertqvist, M., Johansson, A., Svensson, N., Abom, P. E., Magnusson, C., Olsson, M., ... & Andersson, Y. (2006). Four outbreaks of Norovirus gastroenteritis after consuming raspberries, Sweden, June-August 2006. *Euro Surveillance*, *11*(36), 3038.

Hoang, L. M. N., Fyfe, M., Ong, C., Harb, J., Champagne, S., Dixon, B., & Isaac-Renton, J. (2005). Outbreak of Cyclosporiasis in British Columbia associated with imported Thai basil. *Epidemiology & Infection*, *133*(1), 23-27.

Holley, R. A., Arrus, K. M., Ominski, K. H., Tenuta, M., & Blank, G. (2006). Survival in manure-treated soils during simulated seasonal temperature exposure. *Journal of Environmental Quality*, *35*(4), 1170-1180.

Hong, C. X., & Moorman, G. W. (2005). Plant pathogens in irrigation water: challenges and opportunities. *Critical Reviews in Plant Sciences*, *24*(3), 189-208.

Horswell, J., Hewitt, J., Prosser, J., Van Schaik, A., Croucher, D., Macdonald, C., ... & Speir, T. (2010). Mobility and survival of *Salmonella* Typhimurium and human adenovirus from spiked sewage sludge applied to soil columns. *Journal of Applied Microbiology*, *108*(1), 104-114.

Humphrey, T., O'Brien, S., & Madsen, M. (2007). Campylobacters as zoonotic pathogens: a food production perspective. *International Journal of Food Microbiology*, *117*(3), 237-257.

Hurst, C. J., Farrah, S. R., Gerba, C. P., & Melnick, J. L. (1978). Development of quantitative methods for the detection of enteroviruses in sewage sludges during activation and following land disposal. *Applied and Environmental Microbiology*, *36*(1), 81-89.

Hutchison, M. L., Walters, L. D., Moore, A., Crookes, K. M., & Avery, S. M. (2004). Effect of length of time before incorporation on survival of pathogenic bacteria present in livestock wastes applied to agricultural soil. *Applied and Environmental Microbiology*, *70*(9), 5111-5118.

Hutchison, M. L., Walters, L. D., Moore, A., & Avery, S. M. (2005). Declines of zoonotic agents in liquid livestock wastes stored in batches on‐farm. *Journal of Applied Microbiology*, *99*(1), 58-65.

Hutin, Y. J., Pool, V., Cramer, E. H., Nainan, O. V., Weth, J., Williams, I. T., ... & Alter, M. J. (1999). A multistate, foodborne outbreak of hepatitis A. *New England Journal of Medicine*, *340*(8), 595-602.

Ingham, S. C., Losinski, J. A., Andrews, M. P., Breuer, J. E., Breuer, J. R., Wood, T. M., & Wright, T. H. (2004). *Escherichia coli* contamination of vegetables grown in soils fertilized with noncomposted bovine manure: garden-scale studies. *Applied and Environmental Microbiology*, *70*(11), 6420-6427.

Ishii, S., Yan, T., Vu, H., Hansen, D. L., Hicks, R. E., & Sadowsky, M. J. (2010). Factors controlling long-term survival and growth of naturalized *Escherichia coli* populations in temperate field soils. *Microbes and Environments*, *25*(1), 8-14.

Insulander, M., De Jong, B., & Svenungsson, B. (2008). A food-borne outbreak of cryptosporidiosis among guests and staff at a hotel restaurant in Stockholm county, Sweden, September 2008. *Eurosurveillance*, *13*(51), 19071.

Islam, M., Doyle, M. P., Phatak, S. C., Millner, P., & Jiang, X. (2004)a. Persistence of enterohemorrhagic *Escherichia coli* O157: H7 in soil and on leaf lettuce and parsley grown in fields treated with contaminated manure composts or irrigation water. *Journal of Food Protection*, *67*(7), 1365-1370.

Islam, M., Morgan, J., Doyle, M. P., Phatak, S. C., Millner, P., & Jiang, X. (2004)b. Fate of *Salmonella enterica* serovar Typhimurium on carrots and radishes grown in fields treated with contaminated manure composts or irrigation water. *Applied and Environmental Microbiology*, *70*(4), 2497-2502.

Itoh, Y., Sugita-Konishi, Y., Kasuga, F., Iwaki, M., Hara-Kudo, Y., Saito, N., ... & Kumagai, S. (1998). Enterohemorrhagic *Escherichia coli* O157: H7 present in radish sprouts. *Applied and Environmental Microbiology*, *64*(4), 1532-1535.

Ivey, M. L. L. (2011). *Assessing Microbial Risks and Management Strategies in Vegetables*. The Ohio State University.

Jablasone, J., Warriner, K., & Griffiths, M. (2005). Interactions of *Escherichia coli* O157: H7, *Salmonella* Typhimurium and *Listeria monocytogenes* plants cultivated in a gnotobiotic system. *International Journal of Food Microbiology*, *99*(1), 7-18.

Jäderlund, L., Sessitsch, A., & Arthurson, V. (2010). Persistence of two *Campylobacter jejuni* strains in soil and on spinach plants. *Applied and Environmental Soil Science*, 1-7 doi:10.1155/2011/836271.

James, J. (2006). Overview of microbial hazards in fresh fruit and vegetables operations. *Microbial Hazard Identification in Fresh Fruit and Vegetables*, 1-36.

Jamieson, R. C., Gordon, R. J., Sharples, K. E., Stratton, G. W., & Madani, A. (2002). Movement and persistence of fecal bacteria in agricultural soils and subsurface drainage water: A review. *Canadian Biosystems Engineering*, *44*(1), 1-9.

Jamieson, R. C., Joy, D. M., Lee, H., Kostaschuk, R., & Gordon, R. J. (2005). Resuspension of Sediment-Associated in a Natural Stream. *Journal of Environmental Quality*, *34*(2), 581-589.

Jay, J. M. (2012). *Modern Food Microbiology*. Springer Science & Business Media.

Jay-Russell, M. T. (2013). What is the risk from wild animals in food-borne pathogen contamination of plants. *CAB Reviews*, *8*(040), 1-16.

Jiang, X., Morgan, J., & Doyle, M. P. (2002). Fate of *Escherichia coli* O157: H7 in manure-amended soil. *Applied and Environmental Microbiology*, *68*(5), 2605-2609.

Jjemba, P. K., Weinrich, L. A., Cheng, W., Giraldo, E., & LeChevallier, M. W. (2010). Regrowth of potential opportunistic pathogens and algae in reclaimed-water distribution systems. *Applied and Environmental Microbiology*, *76*(13), 4169-4178.

Johannessen, G. S., Bengtsson, G. B., Heier, B. T., Bredholt, S., Wasteson, Y., & Rørvik, L. M. (2005). Potential uptake of *Escherichia coli* O157: H7 from organic manure into crisphead lettuce. *Applied and Environmental Microbiology*, *71*(5), 2221-2225.

Johnston, M. A., Harrison, M. A., & Morrow, R. A. (2009). Microbial antagonists of *Escherichia coli* O157: H7 on fresh-cut lettuce and spinach. *Journal of Food Protection*, *72*(7), 1569-1575.

Jones, P. W. (1976). The effect of temperature, solids content and pH on the survival of Salmonellas in cattle slurry. *British Veterinary Journal*, *132*(3), 284-293.

Jones, P.W. (1986). Sewage sludge as a vector of Salmonellosis. p. 21–23. In J.C. Block et al. (ed.) Epidemiological studies of risks associated with the agricultural use of sewage sludge. Elsevier, London

Josefson, D. (2003). Three die in US outbreak of hepatitis A. *BMJ: British Medical Journal*, *327*(7425), 1188. [10.1136/bmj.327.7425.1188-c](https://dx.doi.org/10.1136/bmj.327.7425.1188-c)

Jung, Y., Jang, H., & Matthews, K. R. (2014). Effect of the food production chain from farm practices to vegetable processing on outbreak incidence. *Microbial Biotechnology*, *7*(6), 517-527.

Kazan, K., & Lyons, R. (2014). Intervention of phytohormone pathways by pathogen effectors. *The Plant Cell*, *26*(6), 2285-2309.

Kearney, T. E., Larkin, M. J., & Levett, P. N. (1993). The effect of slurry storage and anaerobic digestion on survival of pathogenic bacteria. *Journal of Applied Microbiology*, *74*(1), 86-93.

Kemp, J. S., Paterson, E., Gammack, S. M., Cresser, M. S., & Killham, K. (1992). Leaching of genetically modified *Pseudomonas fluorescens* through organic soils: influence of temperature, soil pH, and roots. *Biology and Fertility of Soils*, *13*(4), 218-224.

Keraita, B., Konradsen, F., Drechsel, P., & Abaidoo, R. C. (2007). Reducing microbial contamination on wastewater irrigated lettuce by cessation of irrigation before harvesting. *Tropical Medicine & International Health*, *12*(s2), 8-14.

Kibbey, H. J., Hagedorn, C., & McCoy, E. L. (1978). Use of fecal streptococci as indicators of pollution in soil. *Applied and Environmental Microbiology*, *35*(4), 711-717.

Kim, J., & Jiang, X. (2010). The growth potential of *Escherichia coli* O157: H7, *Salmonella* spp. and *Listeria monocytogenes* in dairy manure‐based compost in a greenhouse setting under different seasons. *Journal of Applied Microbiology*, *109*(6), 2095-2104.

Kirby, R.M., Bartram, J. and Carr, R., 2003. Water in food production and processing: quantity and quality concerns. *Food Control*, *14*(5), pp.283-299.

Kirubel, T. (2015). *Water Quality and Sanitation Status of Improved Drinking Water Sources in Selected Rural Areas of Southern Nations Nationalities Peoples Region, Ethiopia* (Doctoral dissertation, Addis Ababa University).

Kisluk, G., & Yaron, S. (2012). Presence and persistence of *Salmonella enterica* serotype Typhimurium in the phyllosphere and rhizosphere of spray-irrigated parsley. *Applied and Environmental Microbiology*, *78*(11), 4030-4036.

Klein, D. A., & Casida Jr, L. E. (1967). *Escherichia coli* die-out from normal soil as related to nutrient availability and the indigenous microflora. *Canadian Journal of Microbiology*, *13*(11), 1461-1470.

Köpke, U., Krämer, J., Leifert, C., Cooper, J., & Niggli, U. (2007). Pre-harvest strategies to ensure the microbiological safety of fruit and vegetables from manure-based production systems. *Handbook of Organic Food Safety and Quality*, 413-429.

Korsager, B., Hede, S., Boggild, H., Bottiger, B. E., & Molbak, K. (2005). Two outbreaks of Norovirus infections associated with the consumption of imported frozen raspberries, Denmark, May-June 2005. *Euro Surveillance* *10*(6), E050623.

Kotzekidou, P. (Ed.). (2016). *Food Hygiene and Toxicology in Ready to Eat Foods*. Academic Press.

Kozak, G. K., MacDonald, D., Landry, L., & Farber, J. M. (2013). Foodborne outbreaks in Canada linked to produce: 2001 through 2009. *Journal of Food Protection*, *76*(1), 173-183.

Kroupitski, Y., Pinto, R., Brandl, M. T., Belausov, E., & Sela, S. (2009). Interactions of *Salmonella enterica* with lettuce leaves. *Journal of Applied Microbiology*, *106*(6), 1876-1885.

Kudva, I. T., Blanch, K., & Hovde, C. J. (1998). Analysis of *Escherichia coli* O157: H7 survival in ovine or bovine manure and manure slurry. *Applied and Environmental Microbiology*, *64*(9), 3166-3174.

Kumar, A., Munder, A., Aravind, R., Eapen, S. J., Tümmler, B., & Raaijmakers, J. M. (2013). Friend or foe: genetic and functional characterization of plant endophytic *Pseudomonas aeruginosa*. *Environmental Microbiology*, *15*(3), 764-779.

Kapperud, G., Rørvik, L. M., Hasseltvedt, V., Høiby, E. A., Iversen, B. G., Staveland, K., ... & Andersson, Y. (1995). Outbreak of *Shigella sonnei* infection traced to imported iceberg lettuce. *Journal of Clinical Microbiology*, *33*(3), 609-614.

Kutter, S., Hartmann, A., & Schmid, M. (2006). Colonization of barley (*Hordeum vulgare*) with *Salmonella enterica* and *Listeria* spp. *FEMS Microbiology Ecology*, *56*(2), 262-271.

Lang, N. L., & Smith, S. R. (2007). Influence of soil type, moisture content and biosolids application on the fate of *Escherichia coli* in agricultural soil under controlled laboratory conditions. *Journal of Applied Microbiology*, *103*(6), 2122-2131.

Law, J. W. F., Ab Mutalib, N. S., Chan, K. G., & Lee, L. H. (2014). Rapid methods for the detection of foodborne bacterial pathogens: principles, applications, advantages and limitations. *Frontiers in Microbiology*, *5* <https://doi.org/10.3389/fmicb.2014.00770>.

Larsen, M. H., Dalmasso, M., Ingmer, H., Langsrud, S., Malakauskas, M., Mader, A., ... & Wallace, R. J. (2014). Persistence of foodborne pathogens and their control in primary and secondary food production chains. *Food Control*, *44*, 92-109.

Leahy JG, Colwell RR (1990) Microbial degradation of hydrocarbons in the environment. Microbiological Reviews 54(3), 305–315.

Lefler, E., & Kott, Y. (1974). Virus retention and survival in sand. *Virus Survival in Water and Wastewater Systems*, (7), 84.

Le Guyader, F. S., Mittelholzer, C., Haugarreau, L., Hedlund, K. O., Alsterlund, R., Pommepuy, M., & Svensson, L. (2004). Detection of Noroviruses in raspberries associated with a gastroenteritis outbreak. *International Journal of Food Microbiology*, *97*(2), 179-186.

Leifert, C., Ball, K., Volakakis, N., & Cooper, J. M. (2008). Control of enteric pathogens in ready‐to‐eat vegetable crops in organic and ‘low input’production systems: a HACCP‐based approach. *Journal of Applied Microbiology*, *105*(4), 931-950.

Le Loir, Y., Baron, F., & Gautier, M. (2003). *Staphylococcus aureus* and food poisoning. *Genetics and Molecular Research*, *2*(1), 63-76.

Lemon, K. P., Higgins, D. E., & Kolter, R. (2007). Flagellar motility is critical for *Listeria monocytogenes* biofilm formation. *Journal of Bacteriology*, *189* (12), 4418-4424.

Lewis, H. C., Kirk, M., Ethelberg, S., Stafford, R., Olsen, K., Nielsen, E. M., ... & Mølbak, K. (2007). Outbreaks of Shigellosis in Denmark and Australia associated with imported baby corn, August 2007—final summary. *Euro Surveillance* *12*(10), E071004.

Li, K., Weidhaas, J., Lemonakis, L., Khouryieh, H., Stone, M., Jones, L., & Shen, C. (2017). Microbiological Quality and Safety of Fresh Produce in West Virginia and Kentucky Farmers’ Markets and Validation of a Post-harvest Washing Practice with Antimicrobials to Inactivate Salmonella and *Listeria monocytogenes*. *Food Control* 79; 101-108.

Liang, G., Gao, X., & Gould, E. A. (2015). Factors responsible for the emergence of arboviruses; strategies, challenges and limitations for their control. *Emerging Microbes & Infections*, *4*(3), e18.

Liao, C. H., & Fett, W. F. (2001). Analysis of native microflora and selection of strains antagonistic to human pathogens on fresh produce. *Journal of Food Protection*, *64*(8), 1110-1115.

Lim, J. A., Lee, D. H., & Heu, S. (2014). The interaction of human enteric pathogens with plants. *The Plant Pathology Journal*, *30*(2), 109.

Lindow, S. E., & Brandl, M. T. (2003). Microbiology of the phyllosphere. *Applied and Environmental Microbiology*, *69*(4), 1875-1883.

Liu, Q., Tomberlin, J. K., Brady, J. A., Sanford, M. R., & Yu, Z. (2008). Black soldier fly (*Diptera: Stratiomyidae*) larvae reduce *Escherichia coli* in dairy manure. *Environmental Entomology*, *37*(6), 1525-1530.

Locatelli, A., Spor, A., Jolivet, C., Piveteau, P., & Hartmann, A. (2013). Biotic and abiotic soil properties influence survival of *Listeria monocytogenes* in soil. *PLoS One*, *8*(10), e75969.

Loncarevic, S., Johannessen, G. S., & Rørvik, L. M. (2005). Bacteriological quality of organically grown leaf lettuce in Norway. *Letters in Applied Microbiology*, *41*(2), 186-189.

Looney, E. E., Sutherland, K. P., & Lipp, E. K. (2010). Effects of temperature, nutrients, organic matter and coral mucus on the survival of the coral pathogen, Serratia marcescens PDL100. *Environmental Microbiology*, *12*(9), 2479-2485.

Lorin, H. E., Costa, M. S. D. M., COSTA, L. A., Pereira, D. C., & Carneiro, L. J. (2016). Stabilization of confined beef cattle manure: characteristics of produced fertilizers. *Engenharia Agrícola*, *36*(5), 877-885.

Lu, Q., He, Z. L., & Stoffella, P. J. (2012). Land application of biosolids in the USA: a review. *Applied and Environmental Soil Science*,1-11 doi:10.1155/2012/201462.

Lung, H. M., Cheng, Y. C., Chang, Y. H., Huang, H. W., Yang, B. B., & Wang, C. Y. (2015). Microbial decontamination of food by electron beam irradiation. *Trends in Food Science & Technology*, *44*(1), 66-78.

Lynch, M. F., Tauxe, R. V., & Hedberg, C. W. (2009). The growing burden of foodborne outbreaks due to contaminated fresh produce: risks and opportunities. *Epidemiology and Infection*, *137*(03), 307-315.

Mabaso, M. L. H., Appleton, C. C., Hughes, J. C., & Gouws, E. (2003). The effect of soil type and climate on hookworm (Necator americanus) distribution in KwaZulu‐Natal, South Africa. *Tropical Medicine & International Health*, *8*(8), 722-727.

Mäde, D., Trübner, K., Neubert, E., Höhne, M., & Johne, R. (2013). Detection and typing of Norovirus from frozen strawberries involved in a large-scale gastroenteritis outbreak in Germany. *Food and Environmental Virology*, *5*(3), 162-168.

Madramootoo, C. A., Johnston, W. R., & Willardson, L. S. (1997). *Management of Agricultural Drainage Water Quality* (Vol. 13). Food & Agriculture Org.. ISBN 978-92-5-104058-4

Maffei, D. F., Batalha, E. Y., Landgraf, M., Schaffner, D. W., & Franco, B. D. (2016). Microbiology of organic and conventionally grown fresh produce. *Brazilian Journal of Microbiology*, *47*, 99-105.

Mahon, B. E., Pönkä, A., Hall, W. N., Komatsu, K., Dietrich, S. E., Siitonen, A., ... & Griffin, P. M. (1997). An international outbreak of Salmonella infections caused by alfalfa sprouts grown from contaminated seeds. *Journal of Infectious Diseases*, *175*(4), 876-882.

Mailles, A., Capek, I., Ajana, F., Schepens, C., Ilef, D., & Vaillant, V. (2006). Commercial watercress as an emerging source of Fascioliasis in Northern France in 2002: results from an outbreak investigation. *Epidemiology & Infection*, *134*(5), 942-945.

Maunula, L., Roivainen, M., Keränen, M., Mäkelä, S., Söderberg, K., Summa, M., ... & Niskanen, T. (2009). Detection of human norovirus from frozen raspberries in a cluster of gastroenteritis outbreaks. *Eurosurveillance*, *14*(49), 19435.

Mandrell, R. E. (2009). Enteric human pathogens associated with fresh produce: sources, transport and ecology. *Microbial Safety of Fresh Produce*, 5-41.

Manyi-Loh, C. E., Mamphweli, S. N., Meyer, E. L., Makaka, G., Simon, M., & Okoh, A. I. (2016). An Overview of the Control of Bacterial Pathogens in Cattle Manure. *International Journal of Environmental Research and Public Health*, *13*(9), 843 [10.3390/ijerph13090843](http://dx.doi.org/10.3390/ijerph13090843).

Matthews, K. R. (2006). Microorganisms associated with fruits and vegetables. In *Microbiology of Fresh Produce*. American Society of Microbiology. (pp. 1-19).

Matthews, K. R., Sapers, G. M., & Gerba, C. P. (Eds.). (2014). *The produce contamination problem: causes and solutions*. Academic Press.

Martínez-Vaz, B. M., Fink, R. C., Diez-Gonzalez, F., & Sadowsky, M. J. (2014). Enteric pathogen-plant interactions: molecular connections leading to colonization and growth and implications for food safety. *Microbes and Environments*, *29*(2), 123-135.

Marvasi, M., Hochmuth, G. J., Giurcanu, M. C., George, A. S., Noel, J. T., Bartz, J., & Teplitski, M. (2013). Factors that affect proliferation of Salmonella in tomatoes post-harvest: the roles of seasonal effects, irrigation regime, crop and pathogen genotype. *PloS one*, *8*(12), e80871.

Matos, A., & Garland, J. L. (2005). Effects of community versus single strain inoculants on the biocontrol of Salmonella and microbial community dynamics in alfalfa sprouts. *Journal of Food Protection*, *68*(1), 40-48.

Maule, A. (2000). Survival of verocytotoxigenic *Escherichia coli* O157 in soil, water and on surfaces. *Journal of Applied Microbiology*, *88*(S1) 71S – 78S.

Mawdsley, J. L., Bardgett, R. D., Merry, R. J., Pain, B. F., & Theodorou, M. K. (1995). Pathogens in livestock waste, their potential for movement through soil and environmental pollution. *Applied Soil Ecology*, *2*(1), 1-15.

McEgan, R., Mootian, G., Goodridge, L. D., Schaffner, D. W., & Danyluk, M. D. (2013). Predicting Salmonella populations from biological, chemical, and physical indicators in Florida surface waters. *Applied and Environmental Microbiology*, *79*(13), 4094-4105.

McEgan, R., Chandler, J. C., Goodridge, L. D., & Danyluk, M. D. (2014). Diversity of Salmonella isolates from central Florida surface waters. *Applied and Environmental Microbiology*, *80*(21), 6819-6827.

McGee, P., Bolton, D. J., Sheridan, J. J., Earley, B., & Leonard, N. (2001). The survival of *Escherichia coli* O157: H7 in slurry from cattle fed different diets. *Letters in Applied Microbiology*, *32*(3), 152-155.

McLain, J. E., & Williams, C. F. (2008). Seasonal variation in accurate identification of *Escherichia coli* within a constructed wetland receiving tertiary-treated municipal effluent. *Water Research*, *42*(15), 4041-4048.

McLaughlin, H. P., Casey, P. G., Cotter, J., Gahan, C. G., & Hill, C. (2011). Factors affecting survival of *Listeria monocytogenes* and *Listeria innocua* in soil samples. *Archives of Microbiology*, *193*(11), 775-785.

Mead, P.S., Slutsker, L., Dietz, V., McCaig, L.F., Bresee, J.S., Shapiro, C., Griffin, P.M. and Tauxe, R.V., (1999). Food-related illness and death in the United States. *Emerging Infectious Diseases*, *5*(5), 607 - 625.

Melotto, M., Underwood, W., & He, S. Y. (2008). Role of stomata in plant innate immunity and foliar bacterial diseases. *Annual Review of Phytopathology*, *46*, 101-122.

Meerburg, B. G., & Kijlstra, A. (2007). Role of rodents in transmission of Salmonella and Campylobacter. *Journal of the Science of Food and Agriculture*, *87*(15), 2774-2781.

Mei Soon, J., Manning, L., Paul Davies, W., & Baines, R. (2012). Fresh produce-associated outbreaks: a call for HACCP on farms?. *British Food Journal*, *114*(4), 553-597.

Meireles, A., Giaouris, E., & Simões, M. (2016). Alternative disinfection methods to chlorine for use in the fresh-cut industry. *Food Research International*, *82*, 71-85.

Mendes, R., Garbeva, P., & Raaijmakers, J. M. (2013). The rhizosphere microbiome: significance of plant beneficial, plant pathogenic, and human pathogenic microorganisms. *FEMS Microbiology Reviews*, *37*(5), 634-663.

Mitra, R., Cuesta-Alonso, E., Wayadande, A., Talley, J., Gilliland, S., & Fletcher, J. (2009). Effect of route of introduction and host cultivar on the colonization, internalization, and movement of the human pathogen *Escherichia coli* O157: H7 in spinach. *Journal of Food Protection*, *72*(7), 1521-1530.

Mohle-Boetani, J. C., Farrar, J., Bradley, P., Barak, J. D., Miller, M., Mandrell, R., ... & Werner, S. B. (2009). Salmonella infections associated with mung bean sprouts: epidemiological and environmental investigations. *Epidemiology and Infection*, *137*(03), 357-366.

Mosaddeghi, M. R., Mahboubi, A. A., Zandsalimi, S., & Unc, A. (2009). Influence of organic waste type and soil structure on the bacterial filtration rates in unsaturated intact soil columns. *Journal of Environmental Management*, *90*(2), 730-739.

Mootian, G., Wu, W. H., & Matthews, K. R. (2009). Transfer of *Escherichia coli* O157: H7 from soil, water, and manure contaminated with low numbers of the pathogen to lettuce plants. *Journal of Food Protection*, *72*(11), 2308-2312.

Moynihan, E. L., Richards, K. G., Ritz, K., Tyrrel, S. F., & Brennan, F. P. (2013). Impact of soil type, biology and temperature on the survival of non-toxigenic Escherichia coli O157. In *Biology and Environment: Proceedings of the Royal Irish*  *Academy* Royal Irish Academy. (pp. 41-46).

Mpuchane, S., Gashe, B., Attotey, J., Matsheka, I., Simpanya, M., Coetzee, S., Jordaan, A. and Mrema, N. (2004), “Carriage of microorganisms by domestic cockroaches and implications for food safety”, New Tools for Improving Microbial Food Safety and Quality, Biotechnology and Molecular Biology Approaches, FoodMicro 2004, Book of Abstracts, p. 355.

Mubiru, D. N., Coyne, M. S., & Grove, J. H. (2000). Mortality of *Escherichia coli* O157: H7 in two soils with different physical and chemical properties. *Journal of Environmental Quality*, *29*(6), 1821.

Muller L, Jensen T, Petersen RF, Molbak K, Ethelberg S (2009). Imported fresh sugar peas as suspected source of an outbreak of Shigella sonnei in Denmark, April–May 2009. Euro Surveill. 2009;14:pii:19241.

Munch, B., Larsen, H. E., & Aalbæck, B. (1987). Experimental studies on the survival of pathogenic and indicator bacteria in aerated and non-aerated cattle and pig slurry. *Biological Wastes*, *22*(1), 49-65.

Murray, C. J., Vos, T., Lozano, R., Naghavi, M., Flaxman, A. D., Michaud, C., ... & Aboyans, V. (2013). Disability-adjusted life years (DALYs) for 291 diseases and injuries in 21 regions, 1990–2010: a systematic analysis for the Global Burden of Disease Study 2010. *The lancet*, *380*(9859), 2197-2223.

Nadarasah, G., & Stavrinides, J. (2011). Insects as alternative hosts for phytopathogenic bacteria. *FEMS Microbiology Reviews*, *35*(3), 555-575.

Naganandhini, S., Kennedy, Z. J., Uyttendaele, M., & Balachandar, D. (2015). Persistence of pathogenic and non-pathogenic *Escherichia coli* strains in various tropical agricultural soils of India. *PloS one*, *10*(6), e0130038.

Nasser, A. M., & Oman, S. D. (1999). Quantitative assessment of the inactivation of pathogenic and indicator viruses in natural water sources. *Water Research*, *33*(7), 1748-1752.

National Advisory Committee on Microbiological Criteria for Foods. (1999). Microbiological safety evaluations and recommendations on sprouted seeds. *International Journal of Food Microbiology*, *52*(3), 123-153.

Natvig, E. E., Ingham, S. C., Ingham, B. H., Cooperband, L. R., & Roper, T. R. (2002). *Salmonella enterica* serovar Typhimurium and *Escherichia coli* contamination of root and leaf vegetables grown in soils with incorporated bovine manure. *Applied and Environmental Microbiology*, *68*(6), 2737-2744.

Newell, D. G., Koopmans, M., Verhoef, L., Duizer, E., Aidara-Kane, A., Sprong, H., ... & van der Giessen, J. (2010). Food-borne diseases—the challenges of 20years ago still persist while new ones continue to emerge. *International Journal of Food Microbiology*, *139*, S3-S15.

Nicol, G. W., Leininger, S., Schleper, C., & Prosser, J. I. (2008). The influence of soil pH on the diversity, abundance and transcriptional activity of ammonia oxidizing archaea and bacteria. *Environmental Microbiology*, *10*(11), 2966-2978.

Nicholson, F. A., Groves, S. J., & Chambers, B. J. (2005). Pathogen survival during livestock manure storage and following land application. *Bioresource Technology*, *96*(2), 135-143.

Niemi, M. (1976). Survival of *Escherichia coli* phage T7 in different water types. *Water Research*, *10*(9), 751-755.

Niu, M. T., Polish, L. B., Robertson, B. H., Khanna, B. K., Woodruff, B. A., Shapiro, C. N., ... & Margolis, H. S. (1992). Multistate outbreak of hepatitis A associated with frozen strawberries. *Journal of Infectious Diseases*, *166*(3), 518-524.

Norman, N. N., & Kabler, P. W. (1953). Bacteriological study of irrigated vegetables. *Sewage and Industrial Wastes*, 605-609.

Nuorti, J. P., Niskanen, T., Hallanvuo, S., Mikkola, J., Kela, E., Hatakka, M., ... & Ruutu, P. (2004). A widespread outbreak of *Yersinia pseudotuberculosis* O: 3 infection from iceberg lettuce. *Journal of Infectious Diseases*, *189*(5), 766-774.

Nyberg, K. A., Vinnerås, B., Ottoson, J. R., Aronsson, P., & Albihn, A. (2010). Inactivation of *Escherichia coli* O157: H7 and *Salmonella* Typhimurium in manure-amended soils studied in outdoor lysimeters. *Applied Soil Ecology*, *46*(3), 398-404.

Nyberg, K. A., Ottoson, J. R., Vinnerås, B., & Albihn, A. (2014). Fate and survival of *Salmonella* Typhimurium and *Escherichia coli* O157: H7 in repacked soil lysimeters after application of cattle slurry and human urine. *Journal of the Science of Food and Agriculture*, *94*(12), 2541-2546.

Nygård, K., Andersson, Y., Lindkvist, P., Ancker, C., Asteberg, I., Dannetun, E., ... & Stenqvist, K. (2001). Imported rocket salad partly responsible for increased incidence of hepatitis A cases in Sweden, 2000-2001. *Euro surveillance: bulletin Europeen sur les maladies transmissibles= European communicable disease bulletin*, *6*(10), 151-153.

O'brien, R. T., & Newman, J. S. (1977). Inactivation of polioviruses and coxsackieviruses in surface water. *Applied and environmental microbiology*, *33*(2), 334-340.

O'bryan, C. A., Crandall, P. G., Ricke, S. C., & Olson, D. G. (2008). Impact of irradiation on the safety and quality of poultry and meat products: a review. *Critical Reviews in Food Science and Nutrition*, *48*(5), 442-457.

Oh, D. H. (1993). *Antimicrobial properties of glycerol monolaurate either alone or combined with selected organic acids against Listeria monocytogenes* (Doctoral dissertation, Louisiana State University, Baton Rouge).

Olaimat, A. N., & Holley, R. A. (2012). Factors influencing the microbial safety of fresh produce: a review. *Food Microbiology*, *32*(1), 1-19.

Oliveira, M., Viñas, I., Usall, J., Anguera, M., & Abadias, M. (2012). Presence and survival of *Escherichia coli* O157: H7 on lettuce leaves and in soil treated with contaminated compost and irrigation water. *International Journal of Food Microbiology*, *156*(2), 133-140.

Ongeng, D., Muyanja, C., Geeraerd, A. H., Springael, D., & Ryckeboer, J. (2011). Survival of *Escherichia coli* O157: H7 and *Salmonella enterica* serovar Typhimurium in manure and manure‐amended soil under tropical climatic conditions in Sub‐Saharan Africa. *Journal of Applied Microbiology*, *110*(4), 1007-1022.

Ongeng, D., Geeraerd, A. H., Springael, D., Ryckeboer, J., Muyanja, C., & Mauriello, G. (2015). Fate of *Escherichia coli* O157: H7 and *Salmonella enterica* in the manure-amended soil-plant ecosystem of fresh vegetable crops: a review. *Critical Reviews in Microbiology*, *41*(3), 273-294.

Ostrolenk, M., Kramer, N., & Cleverdon, R. C. (1947). Comparative studies of enterococci and *Escherichia coli* as indices of pollution. *Journal of Bacteriology*, *53*(2), 197 - 203.

Pacha, R. E., Clark, G. W., Williams, E. A., & Carter, A. M. (1988). Migratory birds of central Washington as reservoirs of *Campylobacter jejuni*. *Canadian Journal of Microbiology*, *34*(1), 80-82.

Pachepsky, Y., Shelton, D. R., McLain, J. E., Patel, J., & Mandrell, R. E. (2011). Irrigation Waters as a Source of Pathogenic Microorganisms in Produce: A Review. *Advances in Agronomy*, *113*(7), 75 - 141.

Pachepsky, Y. A., Blaustein, R. A., Whelan, G., & Shelton, D. R. (2014). Comparing temperature effects on *Escherichia coli*, Salmonella, and Enterococcus survival in surface waters. *Letters in Applied Microbiology*, *59*(3), 278-283.

Painter, J. A. (2013). Attribution of Foodborne Illnesses, Hospitalizations, and Deaths to Food Commodities by using Outbreak Data, United States, 1998–2008-Volume 19, Number 3—March 2013-Emerging Infectious Disease journal-CDC.

Pell, A. N. (1997). Manure and microbes: public and animal health problem?. *Journal of Dairy Science*, *80*(10), 2673-2681.

Pereira, L. S., Oweis, T., & Zairi, A. (2002). Irrigation management under water scarcity. *Agricultural Water Management*, *57*(3), 175-206.

Piveteau, P., Depret, G., Pivato, B., Garmyn, D., & Hartmann, A. (2011). Changes in gene expression during adaptation of *Listeria monocytogenes* to the soil environment. *PLoS One*, *6*(9), e24881.

Platz, S. (1980). Studies on survival of *Salmonella* Typhimurium in different types of soils under outdoor climatic conditions (author's transl). *Zentralblatt fur Bakteriologie, Mikrobiologie und Hygiene. 1. Abt. Originale B, Hygiene*, *171*(2-3), 256-268.

Pollack, S. L. (2001). Consumer demand for fruit and vegetables: the US example. *Changing Structure of Global Food Consumption and Trade*, *6*, 49-54.

Ponka, A., Maunula, L., Von Bonsdorff, C. H., & Lyytikainen, O. (1999). Outbreak oof calicivirus gastroenteritis associated with eating frozen raspberries. *Euro surveillance: bulletin Europeen sur les maladies transmissibles= European Communicable Disease Bulletin*, *4*(6), 66-69.

Pornsukarom, S., & Thakur, S. (2016). Assessing the Impact of Manure Application in Commercial Swine Farms on the Transmission of Antimicrobial Resistant Salmonella in the Environment. *PloS one*, *11*(10), e0164621.

Public Health England, UK Government. *E. coli* O157 national outbreak update (2016). Available online: https://www.gov.uk/government/news/update-as-e-coli-o157-investigation-continues (accessed 22 December 2017)

Rashid, M. I., Mujawar, L. H., Shahzad, T., Almeelbi, T., Ismail, I. M., & Oves, M. (2016). Bacteria and fungi can contribute to nutrients bioavailability and aggregate formation in degraded soils. *Microbiological Research*, *183*, 26-41.

Ravva, S. V., Sarreal, C. Z., Duffy, B., & Stanker, L. H. (2006). Survival of *Escherichia coli* O157: H7 in wastewater from dairy lagoons. *Journal of Applied Microbiology*, *101*(4), 891-902.

Reddy, K. R., Khaleel, R., & Overcash, M. R. (1981). Behavior and transport of microbial pathogens and indicator organisms in soils treated with organic wastes. *Journal of Environmental Quality*, *10*(3), 255-266.

Regmi, A. (2001). Changing structure of global food consumption and trade: an introduction. *Changing Structure of Global Food Consumption and Trade. Anita Regmi*, 1, 1-3.

Renterghem, B. V., Huysman, F., Rygole, R., & Verstraete, W. (1991). Detection and prevalence of *Listeria monocytogenes* in the agricultural ecosystem. *Journal of Applied Microbiology*, *71*(3), 211-217.

Robertson, L. J., Sprong, H., Ortega, Y. R., van der Giessen, J. W., & Fayer, R. (2014). Impacts of globalisation on foodborne parasites. *Trends in Parasitology*, *30*(1), 37-52.

Rochelle-Newall, E. J., Ribolzi, O., Viguier, M., Thammahacksa, C., Silvera, N., Latsachack, K., ... & Hmaimum, N. (2016). Effect of land use and hydrological processes on *Escherichia coli* concentrations in streams of tropical, humid headwater catchments. *Scientific Reports*, *6*. doi:10.1038/srep32974.

Rodríguez-Lázaro, D., Cook, N., Ruggeri, F. M., Sellwood, J., Nasser, A., Nascimento, M. S. J., ... & Bosch, A. (2012). Virus hazards from food, water and other contaminated environments. *FEMS Microbiology Reviews*, *36*(4), 786-814.

Roy, D., Panchal, S., Rosa, B. A., & Melotto, M. (2013). *Escherichia coli* O157: H7 induces stronger plant immunity than *Salmonella enterica* Typhimurium SL1344. *Phytopathology*, *103*(4), 326-332.

Sant'Ana, A.S., Silva, F.F.P., Maffei, D.F., Franco, B.D.G.M., (2014). Introduction. In: Batt, C.A., Tortorello, M.L. (Eds.), Encyclopedia of Food Microbiology, vol 1. Elsevier Ltd, Academic Press, pp. 972–982. ISBN: 9780123847300

Sagik, B. P., Moore, B. E., & Sorber, C. A. (1978). Infectious disease potential of land application of wastewater. *State of Knowledge in Land Treatment of Wastewater*, *1*, 35-46.

Santamaria, J. and Toranzos, G.A., (2003). Enteric pathogens and soil: a short review. *International Microbiology*, *6*(1), 5-9.

Saroj, S. D., Hajare, S., Shashidhar, R., Dhokane, V., Sharma, A., & Bandekar, J. R. (2007). Radiation processing for elimination of *Salmonella* Typhimurium from inoculated seeds used for sprout making in India and effect of irradiation on germination of seeds. *Journal of Food Protection*, *70*(8), 1961-1965.

Sasaki, T., Kobayashi, M., & Agui, N. (2000). Epidemiological potential of excretion and regurgitation by *Musca domestica* (Diptera: Muscidae) in the dissemination of *Escherichia coli* O157: H7 to food. *Journal of Medical Entomology*, *37*(6), 945-949.

Saunders, O., Harrison, J., Fortuna, A. M., Whitefield, E., & Bary, A. (2012). Effect of anaerobic digestion and application method on the presence and survivability of *E. coli* and fecal coliforms in dairy waste applied to soil. *Water, Air, & Soil Pollution*, *223*(3), 1055-1063.

Scallan, E., Hoekstra, R.M., Angulo, F.J., Tauxe, R.V., Widdowson, M.A., Roy, S.L., Jones, J.L. and Griffin, P.M., (2011). Foodborne illness acquired in the United States—major pathogens. *Emerging Infectious Diseases*, *17*(1), 7 - 15.

Schmidt, H., Scheef, J., Morabito, S., Caprioli, A., Wieler, L. H., & Karch, H. (2000). A new Shiga toxin 2 variant (Stx2f) from *Escherichia coli* isolated from pigeons. *Applied and Environmental Microbiology*, *66*(3), 1205-1208.

Schikora, A., Garcia, A. V., & Hirt, H. (2012). Plants as alternative hosts for Salmonella. *Trends in Plant Science*, *17*(5), 245-249.

Schoonover, J. E., & Crim, J. F. (2015). An introduction to soil concepts and the role of soils in watershed management. *Journal of Contemporary Water Research & Education*, *154*(1), 21-47.

Schuenzel, K. M., & Harrison, M. A. (2002). Microbial antagonists of foodborne pathogens on fresh, minimally processed vegetables. *Journal of Food Protection*, *65*(12), 1909-1915.

Schulze-Makuch, D. and Irwin, L.N. (2006) Exotic forms of life in the Universe. *Naturwissenschaften* 93,155–172.

Sela, S., Nestel, D., Pinto, R., Nemny-Lavy, E., & Bar-Joseph, M. (2005). Mediterranean fruit fly as a potential vector of bacterial pathogens. *Applied and Environmental Microbiology*, *71*(7), 4052-4056.

Sellers R.F. (1981). - Absolute safety. In Communicable diseases resulting from storage, handling, transport and landspreading of manures (J.R. Walton & E.G. White, eds.). Offic. Publ. Europ. Comm., Luxemburg, 239-250.

Semenov, A. V., Van Overbeek, L., & Van Bruggen, A. H. (2009). Percolation and survival of *Escherichia coli* O157: H7 and *Salmonella enterica* serovar Typhimurium in soil amended with contaminated dairy manure or slurry. *Applied and Environmental Microbiology*, *75*(10), 3206-3215.

Semenov, A. V., van Overbeek, L., Termorshuizen, A. J., & van Bruggen, A. H. (2011). Influence of aerobic and anaerobic conditions on survival of *Escherichia coli* O157: H7 and *Salmonella enterica* serovar Typhimurium in Luria–Bertani broth, farm-yard manure and slurry. *Journal of Environmental Management*, *92*(3), 780-787.

Seymour, I. J., & Appleton, H. (2001). Foodborne viruses and fresh produce. *Journal of Applied Microbiology*, *91*(5), 759-773.

Sharma, M., Ingram, D. T., Patel, J. R., Millner, P. D., Wang, X., Hull, A. E., & Donnenberg, M. S. (2009). A novel approach to investigate the uptake and internalization of *Escherichia coli* O157: H7 in spinach cultivated in soil and hydroponic medium. *Journal of Food Protection*, *72*(7), 1513-1520.

Sharma, M., Millner, P. D., Hashem, F., Camp, M., Whyte, C., Graham, L., & Cotton, C. P. (2016). Survival and persistence of nonpathogenic *Escherichia coli* and attenuated *Escherichia coli* O157: H7 in soils amended with animal manure in a greenhouse environment. *Journal of Food Protection*, *79*(6), 913-921.

Sharma, M., & Reynnells, R. (2016). Importance of Soil Amendments: Survival of Bacterial Pathogens in Manure and Compost Used as Organic Fertilizers. *Microbiology Spectrum*, *4*(4), PFS-0010-2015. [10.1128/microbiolspec.PFS-0010-2015](https://doi.org/10.1128/microbiolspec.PFS-0010-2015) .

Shayanfar, S., & Pillai, S. D. (2014). Future trends in electron beam technology for food processing. *Electron Beam Pasteurization and Complementary Food Processing Technologies*, 295.

Shepherd Jr, M. W., Liang, P., Jiang, X., Doyle, M. P., & Erickson, M. C. (2007). Fate of *Escherichia coli* O157: H7 during on-farm dairy manure–based composting. *Journal of Food Protection*, *70*(12), 2708-2716.

Shi, X., Namvar, A., Kostrzynska, M., Hora, R., & Warriner, K. (2007). Persistence and growth of different Salmonella serovars on pre-and postharvest tomatoes. *Journal of Food Protection®*, *70*(12), 2725-2731.

Singh, R., Kim, J., Shepherd, M. W., Luo, F., & Jiang, X. (2011). Determining thermal inactivation of *Escherichia coli* O157:H7 in fresh compost by simulating early phases of the composting process. *Applied and Environmental Microbiology*, *77*(12), 4126-4135.

Smolinski, M. S., Hamburg, M. A. & Lederberg, J. (Eds.). (2003). *Microbial Threats to Health:* *Emergence, Detection, and Response* National Academies Press, Washington DC.

Sobsey, M. D., Shields, P. A., Hauchman, F. H., Hazard, R. L., & Caton, L. W. (1986). Survival and transport of hepatitis A virus in soils, groundwater and wastewater. *Water Science and Technology*, *18*(10), 97-106.

Solomon, E. B., Yaron, S., & Matthews, K. R. (2002). Transmission of *Escherichia coli* O157: H7 from contaminated manure and irrigation water to lettuce plant tissue and its subsequent internalization. *Applied and Environmental Microbiology*, *68*(1), 397-400.

Solomon, E. B., & Matthews, K. R. (2005). Use of fluorescent microspheres as a tool to investigate bacterial interactions with growing plants. *Journal of Food Protection*, *68*(4), 870-873.

Spoel, S. H., & Dong, X. (2012). How do plants achieve immunity? Defence without specialized immune cells. *Nature Reviews Immunology*, *12*(2), 89-100.

Steele, M. and Odumeru, J., (2004). Irrigation water as source of foodborne pathogens on fruit and vegetables. *Journal of Food Protection*, *67*(12), 2839-2849.

Strauch, D. (1991). Survival of pathogenic microorganisms and parasites in excreta, manure and sewage sludge. Revue Scientifique et Technique (International Office of Epizootics) *10*(3), 813-846.

Strausbaugh, L. J., & Herwaldt, B. L. (2000). *Cyclospora cayetanensis*: A review, focusing on the outbreaks of cyclosporiasis in the 1990s. *Clinical Infectious Diseases*, *31*(4), 1040-1057.

Strawn, L. K., Gröhn, Y. T., Warchocki, S., Worobo, R. W., Bihn, E. A., & Wiedmann, M. (2013)a. Risk factors associated with Salmonella and *Listeria monocytogenes* contamination of produce fields. *Applied and Environmental Microbiology*, *79*(24), 7618-7627.

Strawn, L. K., Fortes, E. D., Bihn, E. A., Nightingale, K. K., Gröhn, Y. T., Worobo, R. W., ... & Bergholz, P. W. (2013)b. Landscape and meteorological factors affecting prevalence of three food-borne pathogens in fruit and vegetable farms. *Applied and Environmental Microbiology*, *79*(2), 588-600.

Stine, S. W., Song, I., Choi, C. Y., & Gerba, C. P. (2005). Application of microbial risk assessment to the development of standards for enteric pathogens in water used to irrigate fresh produce. *Journal of Food Protection*, *68*(5), 913-918.

Stotzky, G. (1986). Influence of soil mineral colloids on metabolic processes, growth, adhesion, and ecology of microbes and viruses. *Interactions of Soil Minerals with Natural Organics and Microbes*, (interactionsofs), 305-428.

Stoeckel, D. M. (2009). Fecal contamination of irrigation water: Keep it off the dinner table. In *Proceedings of the 54th New Jersey Annual Vegetable Meeting*, pp. 100-102.

Sundström, J. F., Albihn, A., Boqvist, S., Ljungvall, K., Marstorp, H., Martiin, C., ... & Magnusson, U. (2014). Future threats to agricultural food production posed by environmental degradation, climate change, and animal and plant diseases–a risk analysis in three economic and climate settings. *Food Security*, *6*(2), 201-215.

Takkinen, J., Kangas, S., Hakkinen, M., Nakari, U. M., Henttonen, H., Siitonen, A., & Kuusi, M. (2004). *Yersinia pseudotuberculosis* infections traced to raw carrots in Finland. *Eurosurveillance*, *8*, 07.

Talley, J. L., Wayadande, A. C., Wasala, L. P., Gerry, A. C., Fletcher, J., DeSilva, U., & Gilliland, S. E. (2009). Association of *Escherichia coli* O157: H7 with filth flies (Muscidae and Calliphoridae) captured in leafy greens fields and experimental transmission of *E. coli* O157: H7 to spinach leaves by house flies (Diptera: Muscidae). *Journal of Food Protection*, *72*(7), 1547-1552.

Tannock, G. W., & Smith, J. M. (1972). Studies on the survival of *Salmonella* Typhimurium and *Salmonella* bovis-morbificans on soil and sheep faeces. *Research in Veterinary Science*, *13*(2), 150.

Tate, R. L. (1978). Cultural and environmental factors affecting the longevity of *Escherichia coli* in histosols. *Applied and Environmental Microbiology*, *35*(5), 925-929.

Tauxe, R., Kruse, H., Hedberg, C., Potter, M., Madden, J., & Wachsmuth, K. (1997). Microbial Hazards and Emerging Issues Associated with Produce† A Preliminary Report to the National Advisory Committee on Microbiologic Criteria for Foods. *Journal of Food Protection*, *60*(11), 1400-1408.

Taylor, R. J., & Burrows, M. R. (1971). The survival of *Escherichia coli* and *Salmonella* Dublin in slurry on pasture and the infectivity of S. Dublin for grazing calves. *British Veterinary Journal*, *127*(11), 536-543.

Temple, K. L., Camper, A. K., & McFeters, G. A. (1980). Survival of two Enterobacteria in feces buried in soil under field conditions. *Applied and Environmental Microbiology*, *40*(4), 794 -797.

Terzieva, S. I., & McFeters, G. A. (1991). Survival and injury of *Escherichia coli*, *Campylobacter jejuni*, and *Yersinia enterocolitica* in stream water. *Canadian Journal of Microbiology*, *37*(10), 785-790.

Tierney, J. T., Sullivan, R., & Larkin, E. P. (1977). Persistence of poliovirus 1 in soil and on vegetables grown in soil previously flooded with inoculated sewage sludge or effluent. *Applied and Environmental Microbiology*, *33*(1), 109-113.

Tiquia, S. M., Tam, N. F. Y., & Hodgkiss, I. J. (1998). Salmonella elimination during composting of spent pig litter. *Bioresource Technology*, *63*(2), 193-196.

Topp, E., Welsh, M., Tien, Y. C., Dang, A., Lazarovits, G., Conn, K., & Zhu, H. (2003). Strain‐dependent variability in growth and survival of *Escherichia coli* in agricultural soil. *FEMS Microbiology Ecology*, *44*(3), 303-308.

Turbé, A., De Toni, A., Benito, P., Lavelle, P., Lavelle, P., Camacho, N.R., Van Der Putten, W.H., Labouze, E. and Mudgal, S., (2010). Soil biodiversity: functions, threats and tools for policy makers.

Turnbull, P. C. B., & Snoeyenbos, G. H. (1973). The roles of ammonia, water activity, and pH in the salmonellacidal effect of long-used poultry litter. *Avian Diseases*, *17*(1) 72-86.

Turner, C. (2002). The thermal inactivation of *E. coli* in straw and pig manure. *Bioresource Technology*, *84*(1), 57-61.

Twisselmann, B. (2000). Outbreak of Listeria gastroenteritis in Italy caused by contaminated corn salad. *Weekly Releases (1997–2007)*, *4*(18), 1610.

Tyler, H. L., & Triplett, E. W. (2008). Plants as a habitat for beneficial and/or human pathogenic bacteria. *Annual Review of Phytopathology*, *46*, 53-73.

USDA National Organic Program (2015) 7 CFR Part 2015, as of October 26, 2015. Pp 1- 54, <https://www.nofany.org/files/NOP_Organic_Regulations.10.26.15.pdf> (Accessed on 10 January, 2018).

Uyttendaele, M., Jaykus, L. A., Amoah, P., Chiodini, A., Cunliffe, D., Jacxsens, L., ... & Medema, G. (2015). Microbial hazards in irrigation water: Standards, norms, and testing to manage use of water in fresh produce primary production. *Comprehensive Reviews in Food Science and Food Safety*, *14*(4), 336-356.

Valipour, M., Sefidkouhi, M. A. G., & Eslamian, S. (2015). Surface irrigation simulation models: a review. *International Journal of Hydrology Science and Technology*, *5*(1), 51-70.

VanderZaag, A. C., Campbell, K. J., Jamieson, R. C., Sinclair, A. C., & Hynes, L. G. (2010). Survival of *Escherichia coli* in agricultural soil and presence in tile drainage and shallow groundwater. *Canadian Journal of Soil Science*, *90*(3), 495-505.

Van Overbeek, L. S., Franz, E., Semenov, A. V., De Vos, O. J., & Van Bruggen, A. H. C. (2010). The effect of the native bacterial community structure on the predictability of *E. coli* O157: H7 survival in manure‐amended soil. *Letters in Applied Microbiology*, *50*(4), 425-430.

Vinten, A. J. A., Lewis, D. R., Fenlon, D. R., Leach, K. A., Howard, R., Svoboda, I., & Ogden, I. (2002). Fate of *Escherichia coli* and *Escherichia coli* O157 in soils and drainage water following cattle slurry application at 3 sites in southern Scotland. *Soil Use and Management*, *18*(3), 223-231.

Watchel, M. R., Whitehand, L. C., & Mandrell, R. E. (2002). Association of *Escherichia coli* O157: H7 with preharvest leaf lettuce upon exposure to contaminated irrigation water. *Journal of Food Protection*, *65*(1), 18-25.

Wadamori, Y., Gooneratne, R., & Hussain, M. A. (2017). Outbreaks and factors influencing microbiological contamination of fresh produce. *Journal of the Science of Food and Agriculture*, *97*(5), 1396-1403.

Wallace, J. S., Cheasty, T., & Jones, K. (1997). Isolation of Vero cytotoxin‐producing *Escherichia coli* O157 from wild birds. *Journal of Applied Microbiology*, *82*(3), 399-404.

Wang, G., Zhao, T., & Doyle, M. P. (1996). Fate of enterohemorrhagic *Escherichia coli* O157: H7 in bovine feces. *Applied and Environmental Microbiology*, *62*(7), 2567-2570.

Wang, H., Magesan, G. N., & Bolan, N. S. (2004). An overview of the environmental effects of land application of farm effluents. *New Zealand Journal of Agricultural Research*, *47*(4), 389-403.

Wang, H., Zhang, T., Wei, G., Wu, L., Wu, J., & Xu, J. (2014). Survival of *Escherichia coli* O157: H7 in soils under different land use types. *Environmental Science and Pollution Research*, *21*(1), 518-524.

Wani, S. A., Samanta, I., Bhat, M. A., & Nishikawa, Y. (2004). Investigation of shiga toxin‐producing *Escherichia coli* in avian species in India. *Letters in Applied Microbiology*, *39*(5), 389-394.

Warriner, K., Ibrahim, F., Dickinson, M., Wright, C., & Waites, W. M. (2003). Internalization of human pathogens within growing salad vegetables. *Biotechnology and Genetic Engineering Reviews*, *20*(1), 117-136.

Warriner, K., Huber, A., Namvar, A., Fan, W., & Dunfield, K. (2009). Recent advances in the microbial safety of fresh fruits and vegetables. *Advances in Food and Nutrition Research*, *57*, 155-208.

Warriner, K., & Namvar, A. (2010). The tricks learnt by human enteric pathogens from phytopathogens to persist within the plant environment. *Current Opinion in Biotechnology*, *21*(2), 131-136.

Weinrich, L. A., Jjemba, P. K., Giraldo, E., & LeChevallier, M. W. (2010). Implications of organic carbon in the deterioration of water quality in reclaimed water distribution systems. *Water Research*, *44*(18), 5367-5375.

Weller, D. M. (1988). Biological control of soilborne plant pathogens in the rhizosphere with bacteria. *Annual Review of Phytopathology*, *26*(1), 379-407.

Welshimer, H. J. (1960). Survival of *Listeria monocytogenes* in soil. *Journal of bacteriology*, *80*(3), 316 - 320.

Werner, S., Boman, K., Einemo, I., Erntell, M., Helisola, R., de Jong, B., ... & Ohlen, G. Outbreak of *Salmonella* Stanley in Sweden Associated with Alfalfa Sprouts Outbreak of *Salmonella* Stanley in Sweden associated with alfalfa sprouts, July-August 2007.

Westrell, T., Ciampa, N., Boelaert, F., Helwigh, B., Korsgaard, H., Chriél, M., ... & Mäkelä, P. (2009). Zoonotic infections in Europe in 2007: a summary of the EFSA-ECDC annual report. *Euro surveillance: bulletin Europeen sur les maladies transmissibles= European Communicable Disease Bulletin*, *14*(3), 785-794.

Wheeler, C., Vogt, T. M., Armstrong, G. L., Vaughan, G., Weltman, A., Nainan, O. V., ... & Lee, T. M. (2005). An outbreak of hepatitis A associated with green onions. *New England Journal of Medicine*, *353*(9), 890-897.

Wiley, B. B., & Westerberg, S. C. (1969). Survival of human pathogens in composted sewage. *Applied Microbiology*, *18*(6), 994-1001.

Williamson, K. E., Radosevich, M., & Wommack, K. E. (2005). Abundance and diversity of viruses in six Delaware soils. *Applied and Environmental Microbiology*, *71*(6), 3119-3125.

Williams, A. P., Avery, L. M., Killham, K., & Jones, D. L. (2007). Survival of *Escherichia coli* O157: H7 in the rhizosphere of maize grown in waste‐amended soil. *Journal of Applied Microbiology*, *102*(2), 319-326.

Witmer, G. W., Pitt, W. C., & Howald, G. (2014). Invasive rodent ecology, impacts, and management with an emphasis on the United States, pp.15 - 20.

Wood, J. L. (2013). *Examination of microbiological quality of in-field leafy vegetables and identification of on-farm generic Escherichia coli transmission dynamics* (Doctoral dissertation, University of British Columbia).

World Health Organization. (2000). WHO report on global surveillance of epidemic-prone infectious diseases. http://apps.who.int/iris/bitstream/10665/66485/1/WHO\_CDS\_CSR\_ISR\_2000.1.pdf

World Health Organization (2007). Food Safety. Global Burden of Foodborne Diseases <http://www.who.int/foodsafety/areas_work/foodborne-diseases/ferg/en/>

World Health Organization (2008). Microbiological hazards in fresh fruits and vegetables: Meeting report. M i c r o b i o l o g i c a l R i s k a s s e s s m e n t s e r i e s. <http://www.who.int/foodsafety/publications/micro/MRA_FruitVeges.pdf>. Accessed December 21, 2017

World Health Organization. (2015). Food Safety. Fact sheet N°399 http://www.who.int/mediacentre/factsheets/fs399/en/

Yang, Y., Meier, F., Ann Lo, J., Yuan, W., Lee Pei Sze, V., Chung, H. J., & Yuk, H. G. (2013). Overview of recent events in the microbiological safety of sprouts and new intervention technologies. *Comprehensive Reviews in Food Science and Food Safety*, *12*(3), 265-280.

Yates, M. V., Gerba, C. P., & Kelley, L. M. (1985). Virus persistence in groundwater. *Applied and Environmental Microbiology*, *49*(4), 778-781.

Yates, M. V., Stetzenbach, L. D., Gerba, C. P., & Sinclair, N. A. (1990). The effect of indigenous bacteria on virus survival in ground water. *Journal of Environmental Science & Health Part A*, *25*(1), 81-100.

Yeager, J. G., & O'Brien, R. T. (1979). Enterovirus inactivation in soil. *Applied and Environmental Microbiology*, *38*(4), 694-701.

You, Y., Rankin, S. C., Aceto, H. W., Benson, C. E., Toth, J. D., & Dou, Z. (2006). Survival of *Salmonella* enterica serovar Newport in manure and manure-amended soils. *Applied and Environmental Microbiology*, *72*(9), 5777-5783.

Zablocki, O., Adriaenssens, E. M., & Cowan, D. (2016). Diversity and ecology of viruses in hyperarid desert soils. *Applied and Environmental Microbiology*, *82*(3), 770-777.

Zeng, W., Melotto, M., & He, S. Y. (2010). Plant stomata: a checkpoint of host immunity and pathogen virulence. *Current Opinion in Biotechnology*, *21*(5), 599-603.

Zhai, Q., Coyne, M. S., & Barnhisel, R. I. (1995). Mortality rates of fecal bacteria in subsoil amended with poultry manure. *Bioresource Technology*, *54*(2), 165-169.

Zhang, G., Ma, L., Beuchat, L. R., Erickson, M. C., Phelan, V. H., & Doyle, M. P. (2009). Lack of internalization of *Escherichia coli* O157: H7 in lettuce (*Lactuca sativa* L.) after leaf surface and soil inoculation. *Journal of Food Protection*, *72*(10), 2028-2037.

Zhang, T., Wang, H., Wu, L., Lou, J., Wu, J., Brookes, P. C., & Xu, J. (2013). Survival of *Escherichia coli* O157: H7 in soils from Jiangsu Province, China. *PloS one*, *8*(12), e81178.

Zhao, S., White, D. G., Ge, B., Ayers, S., Friedman, S., English, L., ... & Meng, J. (2001). Identification and characterization of integron-mediated antibiotic resistance among Shiga toxin-producing *Escherichia coli* isolates. *Applied and Environmental Microbiology*, *67*(4), 1558-1564.

Zheng, J., Allard, S., Reynolds, S., Millner, P., Arce, G., Blodgett, R. J., & Brown, E. W. (2013). Colonization and internalization of *Salmonella enterica* in tomato plants. *Applied and Environmental Microbiology*, *79*(8), 2494-2502.

Zibilske, L. M., & Weaver, R. W. (1978). Effect of environmental factors on survival of *Salmonella* Typhimurium in soil. *Journal of Environmental Quality*, *7*(4), 593-597.

***Figure captions***

***Figure 1:*** Environmental risk factors for pre-harvest produce contamination.

***Figure 2***: The fate of pathogens in manure amended soil.

***Figure 3***: Factors affecting the survival of pathogens in produce cultivation media..