|  |  |  |  |
| --- | --- | --- | --- |
| **Bacteria** | **Viruses** | **Parasites** | **Fungi** |
| *Salmonella* spp. | Hepatitis A virus | *Cyclospora* | *Alternaria* sp. |
| *Escherichia coli* | Rotavirus | *Cryptosporidium parvum* | *Fusarium* sp. |
| *Campylobacter* spp. | Norovirus | *Giardia* sp. | *Aspergillus niger* |
| *Vibrio* spp. | Norwalk & Norwalk-like | *Trichinella* spp. |  |
| *Listeria monocytogenes* | Sapovirus | *Ascaris* spp. |  |
| *Bacillus cereus* | Calicivirus | *Trichuris trichiuria* |  |
| *Shigella* spp. |  | *Toxoplasma gondii* |  |
| *Clostridium* spp. |  |  |  |
| *Yersinia* spp. |  |  |  |
| *Pseudomonas* spp. |  |  |  |
| *Aeromonas* sp. |  |  |  |
| *Staphylococcus* spp. |  |  |  |
| *Enterobacter* spp. |  |  |  |
| *Brucella* spp |  |  |  |

***Table 1:*** The most commonly implicated etiological agents in fresh produce borne illnesses (Brackett, 1994; Beuchat, 2002; Buck et al., 2003; Heaton & Jones, 2008; Jung et al., 2014; Callejón et al.2015).

***Table 2****:* Produce related foodborne outbreaks between 1997 and 2017

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **Food vehicle** | **Country** | **Pathogen** | **Number of cases** | **Number of hospitalizations** | **Deaths** | **Ref** |
| Sprouts (Alfalfa, raw clover) | US | *Escherichia coli* | 59 | 17 | 0 | CDC, 2017 |
| RTE salads | US | *E. coli* | 33 | 7 | 0 | CDC, 2017 |
| Spinach and spring mix | US | *E. coli* | 33 | 13 | 0 | CDC, 2017 |
| Lettuce | US | *E. coli* | 84 | 45 | 0 | CDC, 2016 |
| Hazelnuts | US | *E. coli* | 8 | 4 | 0 | CDC, 2017 |
| Fresh spinach | US | *E. coli* | 199 | 102 | 3 | CDC, 2017 |
| Radish sprout | Japan | *E. coli* O157:H7 | 126  9451c | NS | 13 | Gutierrez, 1997 |
| Spinach | Canada | *E. coli* O157:H7 | 1 | NS | NS | Kozak et al., 2013 |
| Lettuce (romaine) | Canada | *E. coli* O157:H7 | 29 | NS | NS | Kozak et al., 2013 |
| Spanish onions | Canada | *E. coli O157:H7* | 235 | NS | NS | Kozak et al., 2013 |
| Watercress | UK | *E. coli* 0157 | NS | NS | NS | Wadamori et al., 2017 |
| Imported salad | UK | *E. coli* O157:H7 | 161 | 60 | 2 | Public health England, 2016 |
| Lettuce, cucumber | UK | *E. coli* 096 | 50 | NS | NS | Wadamori et al., 2017 |
| Packaged salads | US | *Listeria monocytogenes* | 19 | 19 | 1 | CDC, 2017 |
| Apples | US | *L. monoctogenes* | 35 | 34 | 7 | CDC, 2017 |
| Bean sprouts | US | *L. monocytogenes* | 5 | 5 | 2 | CDC, 2017 |
| Cantaloupe | US | *L. monocytogenes* | 147 | 143 | 33 | CDC, 2017 |
| Diced celery | US | *L. monocytogenes* | 10 | NS | 5 | Gaul et al., 2012 |
| Melons | US | *L. monocytogenes* | 147 | NS | 33 | CDC, 2016 |
| (pre packaged) caramel apples | US | *L. monocytogenes* | 35 | 31 | 7 | Garner &Kathariou 2016, |
| Corn salad | Italy | *L. monocytogenes* | 1 566 | 292 | 0 | Twisselmann 2000 |
| Sprouts (Alfalfa, raw clover) | US | *Salmonella* spp. | 506 | 65 | 0 | CDC, 2017 |
| Pistachios | US | *Salmonella* spp*.* | 11 | 2 | 0 | CDC, 2017 |
| Cucumbers | US | *Salmonella* spp. | 991 | 221 | 6 | CDC, 2017 |
| Bean sprouts | US | *Salmonella* spp. | 115 | NS | 0 | CDC, 2017 |
| Mangoes | US | *Salmonella* spp. | 127 | 33 | 0 | CDC, 2017 |
| Pine nuts | US | *Salmonella* spp*.* | 43 | 2 | 0 | CDC, 2017 |
| Papayas | US | *Salmonella* | 106 | 10 | 0 | CDC, 2017 |
| Maradol papaya | US | *Salmonella* Urbana | 7 | 4 | 0 | CDC, 2017 |
| Maradol papaya | US | *Salmonella* Newport & Infantis | 4 | 2 | 0 | CDC, 2017 |
| Maradol Papaya | US | *Salmonella* Anatum | 14 | 5 | 1 | CDC, 2017 |
| Maradol papaya | US | Salmonella | 210 | 67 | 1 | CDC, 2017 |
| Raw produce (Jalepenos and Serrano peppers) | US | *Salmonella* sp. | 1442 | 286 | 2 | CDC, 2017 |
| Cantaloupe | US | *Salmonella* sp. | 332 | 113 | 3 | CDC, 2017 |
| Tomatoes | US | *Salmonella* | 111 | 22 | 0 | CDC, 2017 |
| Tomatoes/peppers | US & Canada | *Salmonella* | 1442 | NS | NS | Warriner & Namvar, 2010 |
| Salads | UK | *S.* Singapore | 4 | NS | NS | Wadamori et al., 2017 |
| Sprouts (Alfalfa) | Australia | *Salmonella* | 100 | NS | NS | Warriner & Namvar, 2010 |
| Rock melon | Australia | *S.* Hvittingfoss | 97 | NS | NS | Wadamori et al., 2017 |
| (pre-packaged) lettuce | Australia | *S.* Anatum | 144 | NS | NS | Wadamori et al., 2017 |
| Sprouts (Alfalfa) | Canada | *Salmonella* | NS | NS | NS | Warriner & Namvar, 2010 |
| Fruit salad | Canada | *Salmonella* | NS | NS | NS | Warriner & Namvar, 2010 |
| Lettuce | Canada | *E. coli* | 34 | NS | NS | CDC, 2017 |
| Cantaloupes | Canada | *Salmonella* | NS | NS | NS | CDC, 2017 |
| Onion sprouts | Canada | *S.* Cubana | 20 | NS | NS | Kozak et al., 2013 |
| Sprouts (Alfalfa) | Canada | *S.* Meleagridis | 78 | NS | NS | Buck et al., 1998 |
| Cantaloupes | Canada | *S.* Poona | 2 | NS | NS | CDC, 2002 |
| Cucumbers | Canada | *S.* Brandenberg | 12 | NS | NS | Kozak et al., 2013 |
| Roma tomatoes (suspected) | Canada | *S.* Javiana | 7 | NS | NS | CDC, 2005 |
| Mung bean sprouts (suspected) | Canada | *S.* Enteritidis | 84 | NA | NS | Kozak et al., 2013 |
| Mung bean sprouts | Canada | *S.* Enteritidis | 8 | NS | NS | Kozak et al., 2013 |
| Baby spinach | Sweden | *Salmonella* Java | 177 | 46 | 0 | Denny et al., 2007 |
| Alfalfa sprouts | Sweden | *Salmonella* Stanley | 51 | 0 | 0 | Werner et al., 2007 |
| Baby carrots | Canada | *Shigella sonnei* | 4 | NS | NS | Warriner & Namvar, 2010 |
| Spinach | Canada | *Shigella sonnei* | 31 | NS | NS | Kozak et al., 2013 |
| Snow peas | Sweden | *Shigella dysentriae* | 35 | 0 | 0 | Mei soon et al., 2012 |
| Iceberg lettuce | Norway | *Shigella sonnei* | 110 | 0 | 0 | Kapperud et al. 1995 |
| Fresh sugar peas | Norway & Denmark | *Shigella sonnei* | 14 | 0 | 0 | Heier et al., 2009; Muller et al., 2009 |
| Baby corn (originated in Thailand) | Denmark | *Shigella sonnei* | 201 | 0 | 0 | Lewis et al. 2007 |
| Fresh vegetables (suspected) | New Zealand | *Yersinia pseudotuberculosis* | 334 | 65 | NS | Wadamori et al., 2017 |
| Raw carrots | Finland | *Y. pseudotuberculosis* | 125 | 0 | 0 | Takkinen et al., 2004 |
| Iceberg lettuce | Finland | *Y. pseudotuberculosis* | 47 | 16 | 1 | Nuorti et al., 2004 |
| Raspberries (imported from China) | Sweden | Norovirus | 433  30 c | 0 | 0 | Le Guyader et al., 2004;  Hjertqvist et al., 2006 |
| Lettuce | Denmark | Norovirus | 260 | 0 | 0 | Ethelberg et al., 2010 |
| Frozen raspberries | Denmark | Norovirus | 561  1, 043c | 0  0 | 0  0 | Korsager et al., 2005; Falkenhorst et al., 2005 |
| Frozen raspberries | France | Norovirus | 75 | 0 | 0 | Cotterelle et al., 2005 |
| Raspberries | Finland | Norovirus | ~200 | NS | NS | Maunula et al., 2009 |
| Strawberries | Germany | Norovirus | ~11 000 | NS | NS | Mäde et al., 2013;  Bernard et al., 2014 |
| Strawberries | US | Hepatitis A | ~1400  213 c | NS | NS | Niu et al., 1992;  Hutin et al., 1999 |
| Green onions | US | Hepatitis | 43  600 c | NS | NS | Dentinger et al., 2001; Frank et al., 2007 |
| Pomegranates | US | Hepatitis A | >150 | NS | NS | CDC 2013 |
| Blueberries | New Zealand | Hepatitis A | 81 | NS | NS | Calder et al., 2003 |
| Multiple produce | Canada | Hepatitis A | 3 | NS | NS | Kozak et al., 2013 |
| RTE leafy greens | Canada | Hepatitis A | 16 | NS | NS | Heywood et al., 2007 |
| Green onions | US | Hepatitis A | 111 (inconclusive) | - | - | Wheeler et al., 2005 |
| Rucola salad | Sweden | Hepatitis A | 54 | 0 | 0 | Nygard et al., 2001 |
| Frozrn raspberries | Finland | Calicivirus | 509b | 0 | 0 | Ponka et al., 1999 |
| Basil (imported from Thailand via the US) | Canada | *Cyclospora cayetanensis* | 17 | NS | NS | Hoang et al., 2005 |
| Cilantro (suspected) | Canada | *C. cayetanensis* | 11 | NS | NS | Kozak et al., 2013 |
| Mango/Basil (suspected) | Canada | *C. cayetanensis* | 17 | NS | NS | Kozak et al., 2013 |
| Basil | Canada | *C. cayetanensis* | 200 | NS | NS | Kozak et al., 2013 |
| Fresh parsley in sauce | Sweden | *Cryptosporidium* sp*.* | 21 | 3 | 0 | Insulander et al., 2008 |
| Whole carrots used in salad | Denmark | *Cryptosporidium hominis* | 78 | 0 | 0 | Ethelberg et al., 2005 |
| Cantaloupes | Mexico | *Salmonella* | NS | NS | NS | CDC,2017 |
| Basil | United Kingdom | *Salmonella* | 32 | NS | NS | Warriner & Namvar, 2010 |
| Raw water cress | France | *Fasciola hepatica* | 18 | NS | NS | Mailles et al., 2006; WHO, 2008 |

Keynote: NS- Not Specified, US- United States of America, RTE- Ready-to-eat, b- reported gastrointestinal symptoms, c- figures from 2 separate outbreaks

**Table 3:** Survival of foodborne pathogens in manure.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Pathogen** | **Media** | **Concentration inoculated** | **Experimental conditions** | **Main findings** | **References** |
| *E. coli* 0149 | Slurry | NS | Cattle & pig slurry, Aerated & non-aerated, 18 - 20 ºC, 6 - 9 ºC. 10 – 14 W, pH (6.9 – 7.8) | Exponential reduction during storage. At both temperatures, inactivation was faster in aerated than in non-aerated slurry batches | Munch et al., 1987 |
| *E. coli* O157:H7 | Bovine feces | 103 & 105 cfu/g | 5, 22 & 37 ºC, pH (6.8 – 7.4), | Survived for up to 70 d, depending on temperature | Wang et al., 1996 |
| *E. coli* O157:H7 | Manure | 105 - 108 cfu/g | Non aerated ovine manure, aerated ovine manure, and aerated bovine manure, 20, 4, 10, 23, 37, 45 & 70 ºC, 100 d | Survived for up to 21 months | Kudva et al., 1998 |
| *E. coli* O26, O111, O157 | Bovine feces | 101, 103, 105 cfu/g | 5, 15 & 25 ºC, | Strains survived for up to 18 W depending on inoculum concentration and temperature | Fukushima et al., 1999 |
| *E. coli* O157:H7 | Cattle manure  Manure slurry | 106 – 108 cfu/g | Stored at 4, 20, 37 ºC, pH (7.42 at the beginning, 7.10 – 9.47, by the end), | Capable of long term survival | Himathong  Kham et al., 1999 |
| *E. coli* O157:H7 | Cattle slurry | 106 cfu/g | Survival in slurry from cattle fed different diets (an entire silage diet & a silage + concentrate diet) was compared. 10 ºC, 84 d, pH (7.6 & 7.12) for silage and silage + concentrate respectively. | Can persist in slurry for an extended time period. Approximately 3.5 – 5.5 log reduction in numbers in slurry from cattle fed a silage and cattle fed a silage + concentrate diet respectively over 84 d | McGee et al., 2001 |
| *E. coli* 11943 | (Pig) Farm yard manure | NS | 50 & 55 ºC, 72 h | Survival depended on substrate composition, moisture content & duration of incubation. Temperatures in excess of 55 ºC for 2 h are required for inactivation. | Turner, 2002 |
| *E. coli* O157:H7 | Bovine derived manure | 102 - 106 cfu/g | Compared the survival of laboratory grown vs bovine derived *E. coli* O157:H7. 40 - 50 ºC, 50 - 60 ºC, >60 ºC, composted in lab scale bioreactors | With increase in temperature, survival declined | Hess et al., 2004 |
| *E. coli* O157:H7 | Slaughterhouse waste  Raw & treated sewage  Bovine slurry | 107 CFU/cm3 | 10 ºC, pH (4.44 – 12.42), | Gradual decline in cell count in all waste types, long-term storage may be an effective means of reducing pathogen loads in wastes before land application | Avery et al., 2005 |
| *E. coli* O157 | Pig slurries  Cattle slurries  Dirty water | 106 cfu/g | Laboratory controlled conditions, pH (6.20 – 7.70, summertime, 5.40 – 7.73, winter), average waste temperature- 12.4 & 4.3 ºC in summer & winter respectively. | Slow population decline generally. More rapid decline in dirty water than in pig slurry. Season of waste deposition & storage as well as dry matter content of the wastes did not affect the rate of decline. | Hutchison et al., 2005 |
| *E. coli* (non O157:H7, STEC) | Cow manure | 106 – 107 cfu/g | Survival compared in unturned & turned manure heaps, moisture content- 42% - 76.5% in turned heaps, 77.5% - 37% in unturned heaps. | Capable of long term survival | Fremaux et al., 2007a |
| *E. coli* 026 | Cow slurry | 106 cfu/mL in 15 L of cow slurry | pH (8.5 – 9.5), 113 d | Detected for up to 3 months . Capable of survival for an extended period. | Fremaux et al., 2007b |
| *E. coli* O157:H7 | Dairy manure based compost | 107 & 105 cfu/g | pH (7.9 & 8.0), % moisture content- 63.6 & 56.5, | Survived at heap’s surface for up to 4 months. | Shepherd et al., 2007 |
| *E. coli* ER2566 | Dairy manure | NS | Ability of black soldier fly (Diptera stratiomyidae) to reduce counts was assessed. The effect of temperature was examined. 72 h, 23, 27, 31, 35 ºC | Concentrations significantly reduced in all treatments. Better reduction in cells with an increase in temperature | Liu et al., 2008 |
| *E. coli* O157:H7 | Dairy compost | 103, 108.4 cfu/g for autoclaved and non autoclaved samples respectively | 10 – 50% moisture levels, greenhouse conditions, ‘room’ temperature, compared sterilized and non-sterilized compost | Better growth recorded when background microflora was low. | Kim & Jiang 2010 |
| *E. coli* O157:H7 | FYM &  Slurry | 107 cfu/g | Aerobic and anaerobic conditions compared, 16 ºC, 12 d | Significantly longer survival under anaerobic conditions compared to aerobic conditions. Effect of anaerobic storage on survival more pronounced in FYM than slurry | Semenov et al., 2011 |
| *E. coli* O157:H7 | (Fresh) dairy compost | 107 cfu/g | Moisture- 40/50%, 50, 55 & 60 ºC | Initial moisture levels in compost affects inactivation. Survival for 72, 48 & 24 h in compost with 40% moisture & 72, 24, 24 h in compost with 50% moisture at 50, 55 & 60 ºC | Singh et al., 2011 |
| *Salmonella (*Thompson, Typhimurium, Senftenberg | Litter & dry droppings | 1010 cfu/g | Effect of ammonia on survival rate was assessed. Moisture % by wt (0 – 22.0), pH (6.3 – 8.65), | Death rates increased with increase in aw. addition of ammonia accelerated the death rates. | Turnbull & Snoeyenbos, 1973 |
| *Salmonella* Dublin (HWS5I,  859/65, 2415)  Typhimurium (2337/65, A665) Stanley(S8o4/7)Choleraesuis (SI346/72)  Choleraesuis var Kunzedorf (S140/72) | Cattle slurry | 105, 106 cfu/g | pH (7.5) 5, 1020, 30 ºC, | Survived for up to 132 d at 5 ºC. | Jones, 1976 |
| *S.* Typhimurium0035 | Cattle slurry | 107 cfu/g | 135 d, 4 & 17 ºC | Reduction in viable numbers during slurry storage period. | Kearney et al., 1993 |
| *Salmonella* Infantis *a* | Slurry | 104 cfu/g | The effect of aeration on survival was investigated- in laboratory experiemnts and in farm scale slurry tanks. ‘Room temperature’, 6 – 39.4 ºC, | Sensitive to aeration, exponential decline in aerated slurry within 2 – 5 W | Heinonen-Tanski,et al., 1998 |
| *Salmonella a* | Spent pig litter (partially decomposed pig manure + sawdust) | NS | Effect of composting on elimination of Salmonella was investigated. Moisture content- 60%, 91 d, | Temperature has an effect on the elimination of Salmonella from the spent litter. Temperature from 64 -67 ºC sufficiently killed the pathogens during windrow composting. | Tiquia et al., 1998 |
| *Salmonella* Typhimurium | Cattle manure  Manure slurry | 106 – 108 cfu/g | Stored at 4, 20, 37 ºC, pH (7.42 at the beginning, 7.10 – 9.47, by the end), | Population reduction time ranged from 6 d to 3W in manure & 2 d to 5 W in manure slurry | Himathong  Kham et al 1999 |
| *Salmonella* Typhimurium, Agona, Hadar, Oranienburg | Hog manure | 107 cfu/mL | 4, 25, 37 ºC, ≤ 16 months, pH (7 – 7.5) | Cell numbers declined during storage. At 4 ºC, survival was >300 d. | Arrus et al., 2006 |
| *Salmonella* Newport | Dairy manure | 107.12 cfu/g | Used 2 strains- MDR & DS strains, 184 d, pH (6.7), moisture content- 86%, | Below the detection limit of the direct plating method | You et al., 2006 |
| *S.* Newport | Sewage sludge | 109 cfu/g | 43 h of composting, 60 C, | No viable cells detected after composting. | Wiley & Westerberg, 1969 |
| *Salmonella* spp. | Dairy compost | 101 cfu/g | Autoclaved and non-autoclaved compost compared, moisture levels of 10 – 50% | Increase in population within 3 d in autoclaved compost at 40% moisture. No growth in non-autoclaved compost observed. | Kim & Jiang 2010 |
| *Salmonella* Typhimurium | FYM & slurry | 107 cfu/g | Aerobic and anaerobic conditions compared, 16 ºC, 12 d | No significant difference in survival under aerobic & anaerobic conditions | Semenov et al., 2011 |
| *Listeria monocytogenes* | Cattle slurry | 108 cfu/g | 84 d, 4/17 ºC, | Decline in viable numbers is temperature dependent. More rapid decline was observed at 17 ºC than at 4 ºC. | Kearney et al., 1993 |
| *L monocytogenes* | Cattle slurry | 106 cfu/g | pH (6.9) moisture 12.1% | Decline at similar rates during summer and winter. | Hutchison et al., 2004 |
| *L. monocytogenes* | Dairy compost | 101 cfu/g | Initial moisture levels of 10 – 50%, greenhouse conditions, | Increase in population in compost with initial moisture content of 30%. Detected for up to 28 d in all seasons. Temperature, light intensity and moisture affected growth potential & survival. | Kim & Jiang, 2010 |
| *Campylobacter jejuni* | Cattle slurry | 104 cfu/ml | 112 d, 4/17 ºC, | Storage period was insufficient to reduce viable numbers. | Kearney et al., 1993 |
| *C. jejuni* | Biosolids | 106, 107, 108 cfu/g | 5, 22, 38, 49.5 ºC, 62d, pH (5.5 – 6.3), 3 batches, | Cells were sensitive to temperature, | Ahmed & Sorensen 1995 |
| *C. jejuni* | Pig slurries  Cattle slurries  Dirty waters | 106 cfu/g | Laboratory controlled conditions, pH (6.20 – 7.70, summertime, 5.40 – 7.73, winter), average waste temperature- 12.4 & 4.3 ºC in summer & winter respectively | Rapid population decline, not affected by season of waste deposition and storage. | Hutchison et al., 2005 |
| *Yersinia enterocolitica* | Cattle slurry | 109 cfu/g | 142 d, stored at 4/17 ºC, | Anaerobic digestion had little effect in reducing the viable numbers. | Kearney et al., 1993 |
| *Y. enterocolitica* | Biosolids | 108, 109 cfu/g | 5, 22, 38, 49.5 ºC, aerobic & anaerobic conditions, 62 d | Destruction at all temperature profiles, but destruction improved with increase in temperature. Oxygen did not have a significant impact on survival | Ahmed & Sorensen, 1995 |

Key: M- Months, FYM- Farm Yard Manure, h- hours, vs- versus, d- day(s), NS-Not specified

**Table 4:** Foodborne pathogens survival in water.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Pathogen** | **Water type** | **Concentration inoculated** | **Experimental conditions** | **Main findings** | **References** |
| *Campylobacter jejuni* | Stream (agricultural surface water) | 106 - 108 cfu/mL | pH (7.75), 6 & 16 ºC, Conductivity- 164 | No significant difference in survival between 6 & 16 ºC | Terzieva & McFeters (1991). |
| *Campylobacter* spp*.* | Water microcosm | 106 cfu/mL | 4 - 37 ºC, varying oxygenation levels (aerobic, microaerobic, anaerobic) | Influence of temperature on survival time was highly significant. Better survival recorded at 4 & 10 ºC | Buswell et al., 1998 |
| *Campylobacter jejuni* | Groundwater | 107 cfu/mL | Filter sterilized groundwater mesocosm, 470 d, 4 ºC, | Survival depends on water composition | Cook & Bolster, 2007 |
| *Escherichia coli* | Groundwater | NS | pH (7.6), 22 ºC, 15 d. (Strong H2S odor observed) | Exhibited remarkable stability in groundwater | Bitton et al., 1983 |
| *E. coli* 078:H11, 078:H12 | Stream (Agricultural surface water) | 105 – 106 cfu/mL  106 - 108 cfu/mL | pH (7.75), 6 & 16 ºC | Persistence prolonged at 6 ºC | Terzieva & McFeters, 1991. |
| *E. coli* O157:H7 | Surface water(s) (Lake, puddle, river, trough waters) | 8 × 104 cfu/mL | Lake, puddle, river, and animal drinking trough water were compared. 10 ºC, pH (6.2 – 8.9) | Persistence enhanced by water aeration and prior sterilization. No correlation between water chemistry and die-off times in any water type. Better survival in lake and puddle waters compared to river or drinking trough waters | Avery et al., 2008 |
| *E. coli a*  (NAR) | Groundwater | 104 cfu/mL | Manure application and heavy rainfall, percolation from soil assessed. 4 & 20 ºC, pH (5.6 ± 0.3, 5.4 ± 0.4) for field & riparian zones respectively. -15 - 25 ºC | Detected in samples throughout the year, both before and after manure application. However, presence and abundance was not strongly correlated to timing of manure application. | VanderZaag et al., 2010. |
| *E. coli* phage T7 | Groundwater  River water  Pulp waste water  Lake water  Brackish water  Mains water | 5 × 109 pfu/mL | 64d, 3 & 20 ºC,pH (4.7 – 8.7) | Generally good survival, inactivation rates varied depending on water type | Niemi 1976 |
| *E. coli* (H 10407 (078:H 1 1), TX432 (078:H 12), 09:K35:K99 | Agricultural surface water | 106 cfu/mL | Controlled laboratory conditions, pH (7.75), 6 & 16 ºC | Persistence prolonged at 6 ºC | Terzieva & McFeters, 1991 |
| *E. coli* DH5α | Groundwater | NS | 28 ºC, pH (7.2/7.7) for sterile and non-sterile samples respectively. 132 d. | Long term survival demonstrated under sterilized conditions. | Banning et al., 2002 |
| *E. coli* (ATCC 11775) | Groundwater | 1010 cfu/mL | pH (7.16 ± 0.2), effect of biofilm development on survival assessed. | It was suggested that *E. coli* can be outcompeted by indigenous bacteria in environments where biofilm development is enhanced. | Banning et al., 2003 |
| *E. coli* (ACM 1803) | groundwater | 106 cfu/mL | 15 & 28 ºC, | Better die off in the presence of indigenous microorganisms than in the absence. | Gordon & Toze, 2003 |
| *E. coli* O157:H7 | Wastewater (Dairy lagoon) microcosms | 103 – 107 cfu/mL | 23 ± 2 ºC, | Failure to be established & proliferate in dairy wastewater microcosm. Relationship between decline & inoculum load was observed. | Ravva et al., 2006 |
| *Salmonella* Typhimurium | Groundwater | NS | pH (7.6), 22 ºC, 15 d. (Strong H2S odor observed) | Exhibited remarkable stability in groundwater | Bitton et al., 1983 |
| *S.* Typhimurium | Groundwater | NS | pH (7.3), 21 ºC, 32 d | Rapid decline of culturable populations. >5 log units to below detection limits in 12 days. | Dowd & Pillai 1997 |
| *Y. enterocolitica* | Stream (Agricultural surface water) | 106 - 108 cfu/mL | pH (7.75), 6 & 16 ºC | Survived well at both 6 ºC & 16 ºC. Temperate conditions more suitable for growth | Terzieva & McFeters 1991 |
| Poliovirus 1 & 3 | River water | 104 – 106 pfu/ml | 12 M, pH (8.3), 4 - 27 ºC, | Inactivation rate affected by water temperature. | O’Brien & Newman 1977 |
| Poliovirus 1 | Groundwater | 104 – 106 pfu/ml | pH (6.0 – 8.3), 37 ºC, conducted in an atmosphere supplemented with 4% CO2 | Temperature was the main predictor of persistence. | Yates et al., 1985 |
| Hepatitis A virus | Groundwater | 105 pfu/ml | Survival at 8, 12, 16 W compared, pH (7.0), 5 & 25 ºC, | Survived for atleast 12 W, survived best at 25 ºC, | Sobsey et al., 1986 |
| Coliphage MS 2 | Groundwater | 104 - 106 pfu/ml | 12 - 30 ºC, pH (6.8 – 7.9), 30 d, | Temperature consistently and significantly correlated with survival | Yates et al., 1990 |
| Poliovirus 1 | Groundwater | 7.2 × 105 pfu/ml | pH (7.4), 4, 10, 20, 30, 37 ºC | Negligible inactivation rate at 4 & 10 ºC. Significant inactivation rate at 20 ºC & 30 ºC | Nasser & Oman, 1999 |
| Coxsackievirus | groundwater | 106 pfu/ml | Anoxic conditions, 15 & 28 ºC, | Temperature did not have a significant effect on die off in filtered groundwater. In the presence of indigenous species, decay was observed. | Gordon & Toze, 2003 |
| MS-2 Phage | groundwater | 107 – 108 pfu/ml | Sterile (filtered) groundwater, 4 ºC, 27 ºC, | Absolute inactivation in 8 days at 27 ºC, reactivation three days after temperature adjustment to 4 ºC (for crude lysates). When purified lysates were added to groundwater, no reactivation was observed. | Alvarez et al., 2000 |
| Poliovirus | Groundwater | 105 - 106 pfu/ml | 4 & 27 ºC | Inactivation at 27 ºC, but no reactivation was observed at 4 ºC | Alvarez et al., 2000 |

**Key:** M- months, NS- not specified, NAR- strain resistant to nalidixic acid, *a* – studies did not provide test serotype

**Table 5:** Survival of foodborne pathogens in soil.

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Pathogen** | **Soil type** | **Concentration inoculated** | **Experimental conditions** | **Main findings** | **References** |
| *Salmonella* Dublin | NS | 107 cfu/g | Soil amended with dairy slurry, 5 months, | Persisted for up to 12 W in soil. | Taylor & Burrows 1971 |
| *S.* Typhimurium & Bovis-mobificans | NS | 107 cfu/g | Amended with sheep manure, field conditions | Survived for up to 42 d after summer application | Tannock & Smith 1972 |
| *S.* Enteritidis | Scranton fine sand | 105 cfu/g | Amended with dairy manure slurry | DRT = 2 d in the absence of manure, 3.5 – 6 d in the presence of manure | Dazzo et al., 1973 |
| *S.* Typhimurium | Clay  Fine sandy loam | 0.5 g | 5, 22 & 39 ºC, 0, 0.5 & >22 moisture, 12 weeks | Death occurred within 17 d in dry soil incubated at 39 ºC. Similar survival profiles observed at 5 and 22 ºC and usually longer than at 39 ºC, up to 42 days in some cases. | Zibilske & Weaver, 1978 |
| *S.* Typhimurium | Sand  Loam  Clay | 104 cfu/g | 0.6, 3.2 & 14 ºC | 32, 46.8, 3.3 d at 14, 3.2 & 0.6 ºC | Platz 1980 |
| *S.* Typhimurium | Mountain field sites | 105 cfu/g | Feces – soil samples, by burying feces in soils. 8 W, | Initial rise in cell counts, decline by the 8th W. | Temple et al., 1980 |
| *S.* Havana | Silty clay loam | NS | Amended with contaminated slurry | Survived 8 months in soil after hog manure application z | Chandler & Craven, 1981 |
| *S.* Typhimurium | Garden soil  Sand | 105 cfu/g | 8, 20 ºC | Survived for 131 d and 102 d at 20 ºC in sandy soil and for 96 d in 8 and 54 d at 20 ºC in garden soil | Tamasi 1981 |
| *Salmonella* sp. | - | NS | Amended with cattle slurry | Survived for up to 300 d after manure application in summertime | Jones 1986 |
| *S.* Typhimurium | Agricultural soil | NS | Augmented with hog slurry, natural & lab conditions compared | Isolated up till 14 d and 299 d under lab and natural conditions respectively. | Baloda et al., 2001 |
| *Salmonella* cocktail (Montevideo, Michigan, Poona, Hartford & Enteritidis) | ‘moist’ soil | 108 cfu/g | 20 ºC, 70% relative humidity | < 2 log reduction after 45 d at 20 ºC | Guo et al., 2001 |
| *S.* Typhimurium | Silty clay loam  Loamy sand | 107 cfu/g | Amended with bovine manure | Survived 119 d after spring application on loamy sand, 3 log reduction in 63 d | Natvig et al., 2002 |
| *Salmonella* sp. | Sandy loam  Loamy sand | 103 - 104 cfu/g | Amended with hog manure, 5 - 30 ºC | Detected up till 27 d and 54 d after application in sandy loam and loamy sand soils respectively | Côté & Quessy 2005 |
| *S.* Anatum | Fine loamy | 105 cfu/100 ml of manure | Amended with swine manure, 6.7 - 15 ºC, soil temperature- 10 - 16 ºC | Manure application led to higher pathogen populations. Survived 7 d. | Gessel et al., 2004 |
| *S.* Typhimurium | Agricultural soil | 107 cfu/g | Amended with cattle manure poultry manure and dairy cattle manure compost, natural conditions | Survived 203 – 231 d | Islam et al., 2004b |
| *S.* Typhimurium | Agricultural soil (sandy loam) | 107 cfu/g (theoretical)  106 cfu/g (measured) | Amended with FYM & slurries from dairy cattle, poultry & pigs pH (6.9), % moisture-12.1 | Survived for up to 120 d (average one summer and winter season) | Hutchison et al., 2004 |
| *S.* Typhimurium | Sandy  loamy | 107 cfu/g | pH (7.1 & 7.3) for sand and loam respectively | Steady decline but still detected 56 days after inoculation | Franz, Diepeningen, Vos, & Bruggen, 2005 |
| *S.* Newport | Silt loam  Fine loam  Mixed, mesic typic hapludalf | 106.86 cfu/g | pH(6.5), 24.5 ± 1.4 ºC, 80% soil moisture, comparison of survival in sterilized and non sterilized soils | Persistence for 332 and 405 days in manure amended non sterilized and manure amended sterilized soils respectively | You et al., 2006 |
| *Salmonella* cocktail (Agona, Hadar, Heidelberg, Montevideo, Oranienburg & Typhimurium) | Loamy Sand  Clay | 105 cfu/ml | (hog) manure amended, Moisture- 60 – 80% FC, 180 d, -18, 4, 10, 25, 30 ºC, pH (7.6) | Improved moisture, manure addition and storage in the clay soil boosted survival of all serovars. Survived more than 180 d in manure amended (both soil types). | Holley et al., 2006 |
| *Salmonella* Newport | Experimental pot soil intended for cultivation | 106 cfu/g | Effect of irrigation regimes on survival were evaluated, greenhouse conditions, 23 ± 0.4 ºC & 35 ± 0.6 ºC at night and day respectively | Ability to withstand desiccation demonstrated | Bernstein et al., 2007b |
| *S. enterica*  (Baildon & Enteritidis) | Fallow supersoil-enriched potting soil). | 103, 105, 107 cfu/ml of irrigation water | pH (5.5 – 6.5), 18 ºC & 26 ºC, humidity 75%, 6 W | Was not stable and declined with time, but survived and remained capable of plant attachment and contamination atleast 6 W after introduction by irrigation. | Barak & Liang 2008 |
| *S.* Enteritidis | Clay loam  Sandy loam | 106 cfu/g | 12 months, 20 ± 2, 35 ± 2 ºC, | Capable of extended survival (at least 180 d). soil moisture did not influence survival. And soil type had only a minor impact. Temperature identified as an important factor influencing long-term survival | Danyluk et al., 2008 |
| *S*. Typhimurium | Sandy | 108.1 cfu/g  107.1 cfu/g | Comparison of substrate treatment (manure/slurry) | Equally high survival with both manure and slurry. | Semenov et al., 2009 |
| *Salmonella* Typhimurium | ‘Top’ soil | 108 cfu/g | 5, 15, 25 ºC, pH (7.2), 85% WHC, 42 d | Significantly better survival in soil incubated at 5 compared to 25 ºC | Garcia et al., 2010 |
| *Salmonella enterica* Weltevreden | Clay loam | 106 cfu/g | pH(6.6), amended with cattle manure slurry | Capable of persisting in soil | Arthurson et al., 2010 |
| *S*. Typhimurium | ‘fresh’ loamy | 104 cfu/g  107 cfu/g | pH (6.4), ≥80% moisture, 16 - 42 ºC. | Survival for 6 and 14 weeks at low and high inoculum density respectively, under tropical conditions | Ongeng et al., 2011 |
| *S.* Typhimurium | Silty clay topsoil overlying clay subsoil | 108 cfu/g | Amended with anaerobically digested, dewatered sewage sludge | The presence of sewage sludge can significantly influence transport & survival in soils, probably because of the presence of organic matter. | Horswell et al., 2010 |
| *S.* Typhimurium | Sandy loam  Silty clay | 108 cfu/ml | Amended with cattle slurry & human urine, Below 0 - 25 ºC, 180 d. pH (6.8, 7.2) for sandy loam & silty clay soils respectively. | Rapid cell reduction when amended with both as opposed to when amended with only cattle slurry. Longer survival with cattle slurry amendment compared to human urine amendment. | Nyberg et al., 2014 |
| *S.* Typhimurium | Clay  Sandy | 107 cfu/g | Applied 10 – 20 cm deep, 23 ± 2 ºC, 120 d, | Survival lower in clay soil than in sandy soil- this was attributed to higher organic matter & nutrient content, as well as more alkaline pH. | Fongaro et al., 2017 |
| *E. coli a* | NS | 10-2 - 10-7 cfu/g | Chicken manure amended soil, 160 d, | Persisted up till the 66th day | Ostrolenk et al., 1947 |
| *E. coli* OI39:K 82 (B) | NS | 106 cfu/g | Soil amended with dairy slurry, | Survived for up to 7 or 8 days | Taylor & Burrows, 1971 |
| *E.coli* 078 | Clay loam | 104 cfu/g | Amended with piggery effluent, soil temperature-13.5 - 16 ºC, daily maximum temperature- 27 & 29 ºC, rainfall- 4 – 13 mm, | Persisted for atleast 8 W after inoculation | Chandler & Craven 1978 |
| *E.coli* ATCC 15597 | Organic  Muck & sand | 107 cfu/g | 9 d, pH(6.16, 6.64), moisture 63 & 17%, 30 ºC for the muck and sand respectively | Capable of extensive survival in organic soils. Survival in muck soils atleast threefold greater than in sand. | Tate, 1978 |
| *E. coli e* | Mountain field soils | 106 cfu/g | 8 W, soil moisture range: 1 - 198 | Initial rise in cell counts, and then decline by the 8th W | Temple et al., 1980 |
| *E. coli* O157:H7 | Grassland soil (texture not specified) | 108 - 109 cfu/g | Amended with cattle effluents, 6.5 – 19.6 ºC | Extended survival in bovine feces &/ contaminated grassland | Bolton, 1999 |
| *E. coli* O157:H7 | Clay  Loam  Clay | 106 cfu/g | 6 months, amended with dairy cattle slurry | Sandy soil was least conducive to survival (56 d), in loam & clay soils, survival times were considerably longer. Survived for at least 175 d. | Fenlon et al., 2000 |
| *E. coli* O157 | Laboratory based soil and grass microcosms (texture not specified) | 108 cfu/g | 4 ºC,18 ºC, 130d, | Efficient survival in soil cores containing rooted grass. | Maule 2000 |
| *E. coli* O157:H7 | Silt loam [Pope (coarse loamy & Zanesville (fine silty)] | NA | Survival of non-pathogenic strain and pathogenic O157:H7 was compared. pH (5.6 & 5.5 for pope (with twice as much clay, more exchangeable bases, soil organic matter & Nitrogen) Zanesville respectively. 8 W | Soil matric potential could influence the survival of *E.coli* in soils. Better survival of non-pathogenic strain compared to O157:H7. Both strains exhibited greater mortality rates in pope silt loam soil. | Mubiru et al., 2000 |
| *E.coli a* | Sandy  Loam  Loamy sand | 103 cfu/g | 80 d, 5, 15 & 25 ºC, 60, 80 & 100% soil moisture field capacity. pH (4.6, 6.7 & 5.2) for sandy, loam & loamy sand respectively. | Impressive survival at 5 ºC, with gradual decline in cell growth, reaching detection limit by the 68th d. At 25 ºC, cell growth rapidly declined and reached detection limit by day 26. Low incubation temperature and high soil moisture content favor survival. Sandy soil proved best for survival. | Cools et al., 2001 |
| *E. coli* O157:H7 | Fallow soils (sandy-loam, clay-loam, silt- loam) | 106 cfu/g | Amended with dairy manure | Persisted for 25 – 41 d in fallow soils, manure did not seem to affect persistence, clay seemed to improve pathogen persistence and activity | Gagliardi & Karns 2002 |
| *E. coli* O157:H7 | Sandy loam | 107 cfu/g | Manure-amended, autoclaved and manure amended unautoclaved, 5 ºC, 15 ºC, 21 ºC | Survived for up to 77, 226 and 231 days respectively. More rapid decline in pathogen populations in unautoclaved soils attributed to the antagonistic interactions with soil autochthonous microbes | Jiang et al., 2002 |
| *E. coli a* | Manure amended  (loam, sandy loam & clay loam) | 106 cfu/g | Soil amended wit swine manure slurry (pH 8.5)Survival of two strains were compared, 4 - 30 ºC, 6 d | The phylotypes varied dramatically in their ability to survive in the different soil types and conditions | Topp et al., 2003 |
| *E.coli* O157:H7 | Sandy loam | 108 cfu/ml | Cattle slurry & ovine slaughterhouse waste introduced to vegetation, pH (5.8), 15 ºC, | Survived but did not proliferate on grassland vegetation for up to 6 weeks and in the underlying soil for 8 weeks. Capable of survival above the infectious dose for both humans and animals, for at least 2 months in soils irrespective of (contaminant) application method. | Avery et al., 2004a |
| *E. coli a* | NS | 7.70, 7.59, 7.48 log10 cfu/g in cattle, sheep & pig feces respectively | Fate of feces from cattle, sheep & pigs in soil examined, soil at 8 cm depth measured, 218 d, 0.4 – 15.6 ºC | Capable of survival on grassland for at least 5 – 6 months. | Avery et al., 2004b |
| *E.coli* O157:H7 | Vegetable field soil | 105 cfu/g (via inoculated water), 107 cfu/g (inoculated poultry & dairy manure) | Soil amended with poultry, dairy and alkaline stabilized dairy manure/irrigated with inoculated water, pH(5.7 – 8.3), moisture content- <1 – 12.2% | Survival recorded for atleast 154 d in all the amended soil samples, in poultry manure amended and dairy cattle manure amended soils, survival was up to 196 d. *E.coli* from inoculated animal manure can survive for > 7 months under Southern Fall-winter conditions | Islam et al., 2004a |
| *E. coli* (indigenous) | Loamy sand  Silt loam  Silty clay loam | 104.2 cfu/g | pH (6.8, 6.0, 6.3) for loamy sand, silt loam and silty clay loam respectively. ≥120 d. | Rapid decrease of *E.coli* in manure amended soils. Persistence of low levels for more than 100 d. Detected in all 3 enriched soil types 132 to 168 d after inoculation. | Ingham et al., 2004 |
| *E. coli* O157:H7 | Sandy  Loamy | 107 cfu/g | Compared conventional & organic soils, soil amended with high digestible grass silage plus maize silage or low digestible grass silage & straw. 15 ºC, pH (7.1 & 7.3) for sandy & loamy respectively | Survival varied between 2 and 56 d depending on soil type. Growth declined more rapidly in organically managed soils compared to conventional soils. Manure type made no difference except in conventionally managed loam soil, where decline rate was higher with high digestible grass silage plus maize silage amendment | Franz et al., 2005 |
| *E. coli* O26 | Loam  Clay loam | 106 cfu/g | 4 and 20 ºC, pH [8.19, 5.87 (for loam samples), 7.58 for clay loam], pH [8.9 ± 0.02, 6.5 ± 0.02(for loam soil samples), 8 ± 0.07 for clay loam samples] | Survival in loam soil for for 288 and 196 days at 4 and 20 ºC respectively. Survival in clay loam soil for atleast 365 days at both temperatures | Fremaux et al., 2007b |
| *E. coli* O157:H7 | Clay loam | 108 cfu/mL  (Of slurry) | pH (6.8), 15 ºC, moisture- 214 g kg-1, | Survived for over 5 W, better survival in soils that received ovine stomach content compared to cattle slurry. | Williams et al., 2007 |
| *E. coli* O157:H7 | Sand  Loam | 107 cfu/g | 60% WHC, 16 ºC, 60 d | Available Carbon sources greatly influenced survival. Pathogen may have selective advantage to survive at lower pH. Faster initial decline in sandy soils, but real differences in the final survival time between sandy and loam soils. Survival was correlated with manure type application. | Franz et al., 2008 |
| *E. coli* O157:H7 | Sandy | 107.8 cfu/g | Manure and slurry treatment | Significantly lengthier survival in slurry amended soil compared to manure amended soil | Semenov et al., 2009 |
| *E. coli* O157:H7 | Sand  Loam | 107 cfu/g | 60% WHC, 16 ºC, Weibull model used to predict survival | Soil community structure parameters like species diversity and evenness may be indicative for the reliability of predictive models describing the fate of pathogens in soil ecosystems. | Van Overbeek et al., 2010 |
| *E. coli* KS7-NR | Loamy sand | 103 cfu/g | 15, 37 ºC. pH (5.8), Water potential (-0.010, -0.033, -0.10, -1.5) | Soil temperature, moisture, nutrients and occurrence of antagonistic species influence survival in soils | Ishi et al., 2010 |
| *E. coli* O157: H7 | Silt loam  Clay loam  Sandy loam  (fallow) | 106 cfu/g | Manure amended, presence of roots, 80% rh | Survived for at least 92 d. Apparently, manure did not affect survival. Suggested clay increases activity and persistence of *E.coli* O157:H7 & other coliforms. | Gagliardi & Karns, 2002. |
| *E. coli* O157:H7 | Sandy loam  Silty clay | 108 cfu/ml | Amended with poultry manure, cattle manure slurry or human urine, 6 months, | Inactivation varied depending on the manure type used and its carbon content. The longest inactivation was observed in samples amended with poultry manure (up to 90 d), while the most rapid inactivation occurred in samples amended with urine. | Nyberg et al., 2010 |
| (non-pathogenic) *E. coli* K-12 strains LMM1010 and ATCC 25253 | Silty clay loam | 108 – 109 cells/ml of irrigation water | Comparison of three irrigation systems-(solid set overhead sprinklers, drip irrigation & surface applied furrow irrigation) 7 – 15 ºC, 8 - 16 ºC, 17 - 27 ºC | Most persistent survival in furrow irrigated soils | Fonseca et al., 2011 |
| *E. coli* O157 | Sandy | ~107 cfu/g | pH (5.3), 60% WHC, 16 ºC | Oxidative capacity of strains enhances survival in manure amended soils | Franz et al., 2011 |
| *E. coli* O157:H7 | ‘Fresh’ Loamy | 107 cfu/g  104 cfu/g | pH(6.4), Manure amended, 46% moisture content, | Survival for 4 and 12 weeks at low and high inoculum densities respectively under tropical conditions. | Ongeng et al., 2011 |
| *E. coli* O157:H7 | NS | 107 cfu/g | Soil amended with contaminated compost, two different seasons (fall & spring). -0.5 – 27.5 ºC (Fall) & 4.3 – 32. 5 ºC (Spring). Average humidity (82% & 62%) in fall & spring respectively. | Better survival in Fall indicating an important influence of environmental conditions. *E. coli* O157:H7 from contaminated compost and irrigation water may survive in soils for up to 9 W. | Oliveira et al., 2012 |
| *E. coli a* | Silty clay loam | NS | Amended with dairy slurry (raw & digested), 10.5 ºC, average precipitation- 690 mm, | Waste treatment and application method did not affect the rate of bacteria die-off | Saunders et al., 2012 |
| *E.coli* O157:H7 | Sandy loam  Clay loam | 108 cfu/g | Sterile & non-sterile soils compared. pH (6.07, 6.6), for coarse loamy & clayey soils respectively. 4 ºC for the first 6 days, 18 ºC thereafter, 64 d, | Concentrations increased in sterile soils and decreased in non-sterile soils. Concentrations generally stable at 4 ºC, | Moynihan et al., 2013 |
| *E. coli* O157:H7 | NS | 107 cfu/g | 25 ± 1 ºC, -33 kPa, pH (4.57 – 5.14; 6.51 – 7.39) | Rapid decline in acidic soils compared to neutral soils. pH and organic carbon influenced survival. | Zhang et al., 2013 |
| *E. coli* O157:H7 | Sandy loam  Silty clay | 109 cfu/ml | Amended with cattle slurry & human urine, Below 0 - 25 ºC, 180 d. | Rapid cell reduction when amended with both as opposed to when amended with only cattle slurry. | Nyberg et al., 2014 |
| *E. coli* O157:H7 | F- Forest (loam)  T- Tea plantation (clay loam)  B- Bamboo grove, (clay loam)  V- Vegetable garden (Silt loam) | 107 cfu/g | Effect of different land use types- was assessed- 25 ± 1 ºC, soil water content- -33 kPa, pH (3.97, 3.92, 4.40, 4.53 for F,T, B, V) respectively. | Rapid decline in test soils, survival dynamics varied, depending on land use of test soils, | Wang et al., 2014 |
| *E. coli* O157:H7 | Clay loam  Clay  Loam  Loam | 107 cfu/g | About 50% moisture, 30 ºC, pH ( 8.74 ± 0.04, 5.97 ± 0.03, 8.42 ± 0.04, 6.05 ± 0.01) for clay loam, clay, loam & loam soil samples respectively. Microbial biomass Carbon- 3454.8 ± 32.6, 9957.0 ± 280.3, 5744.4 ± 628.1, 7968.9 ± 576.4 for clay loam, clay, loam & loam soil samples respectively. | pH, microbial biomass carbon, dehydrogenase activity influenced survival in soils. | Naganandhini et al., 2015 |
| *E. coli* O157:H7 | Sandy loam  Clay loam  Silt loam | 104 cfu/ml    106 cfu/ml | Soils amended with poultry litter, dairy manure liquids & horse manure 17 – 36 ºC, 56 d, | Soil type did not affect survival. Poultry litter amended soils significantly supported survival compared to horse manure amended soils. | Sharma et al., 2016 |
| *E. coli* O157:H7 | Clay  Sandy | 107 cfu/g | Biofertilized with swine effluents, 120 d, pH (8.62 ± 0.40, 6.71 ± 0.02) for clay and sandy soil respectively. | Effective and rapid percolation to deep strata of both soils. | Fongaro et al., 2017 |
| *Listeria monocytogenes* | NS | 106 cfu/g | 20 ºC, 84 d | Growth declined with time | Locatelli et al., 2013 |
| *Listeria monocytogenes* | ‘Fertile’ clay | 108 cfu/g | 30 ºC, 295 d | Decreased but still detected throughout the incubation | Welshimer 1960 |
| *Listeria monocytogenes* | Sandy loam | 105 cfu/g | 15 ºC, 8 W | Intermittently detected during 6 W after inoculation. | Renterghem et al., 1991 |
| *Listeria monocytogenes* | Forest | 106 cfu/g | 8 ºC, 14d,  25 & 30ºC, | Sharp decrease and undetected by 8th d. | McLaughlin et al. 2011 |
| *Listeria monocytogenes* | Sandy arable  Clay loam grassland | 106 cfu/g | pH (6.9, 6.5), moisture 12%, 31% for sandy arable and clayloam grassland respectively.  Liquid (beef, cattle, dairy cattle, pig slurry & dirty water), solid (beef cattle, dairy cattle, pig & sheep FYM, broiler litter) manures were inoculated with pathogens and applied to soil. | Survived for 16, >32, 8, 32, 4, 8, 16, 8 & 8 d in sandy arable soil amended with beef FYM, dairy FYM, Pig FYM, Sheep FYM, Broiler FYM, beef slurry, dairy slurry, pig slurry & dirty water respectively. Persisted for 32, 16, >32, >32, >32, 32, 32, >32, 32 d in respective clay loam grassland soil treatments. | Nicholson et al., 2005 |
| *L. monocytogenes* | Sandy  Clay loam  Sandy loam | 102 cfu/g  106 cfu/g | 25 - 30 ºC, 32 d | Least survival in sandy soils. | Dowe et al., 1997 |
| *L. monocytogenes* | Loamy | 105 cfu/g | 25 ºC, 1 year, sterilized soil | Significant increase in 2 days and then decrease in population. | Piveteau et al., 2011 |
| *L. monocytogenes* | ‘surface’ | 8 ºC, 14 d, 25 & 30 ºC, 14 d | pH(5.2), 8 ,25, 30 ºC | Steady decline in survival at both 25 and 30 ºC with the strains reaching undetectable levels at between 8 and 10 d post inoculation. Greater survival potential at 8 ºC. | McLaughlin et al. 2011 |
| *Campylobacter* a | Gley  Sandy loam | NS | Amended with (simulated) farm dairy effluent, simulated rainfall events, pH (5.1, 5.8) for gley & sandy loam respectively, 28d, | Rapid decline in cell numbers with no difference identified for soil type. Increase in retention at both rainfall rates. | Donnison & Ross, 2009 |
| *Campylobacter jejuni* | Clay loam silt | 105 cfu/g  106 cfu/g  107 cfu/g | Two distinct strains, 21 d, 27 ºC | Both strains survived for atleast 28 d. | Jäderlund et al., 2011 |

Key: WHC- Water Holding Capacity; FC- Field Capacity; temp-temperature; h- hours; d- days; W-weeks, DRT: Decimal reduction time, NA- Not applicable, NS- Not specified, a- studies did not provide test strains/serotype used, e- resistant to streptomycin (100 µg/ml) and nalidixic acid (50 µg/ml)