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History of soils in relation to animal and human health

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Introduction

What are the factors that influence animal and human health? Most people could rapidly list a number of items, most likely things like good nutrition, proper medical care, exercise, clean safe water, and so forth. Most people probably would not include soil on their list, but studies have shown that the properties of soils are actually very important to both animal and human health. This is true for many reasons, for example, soils supply many of the nutrients found in our food, serve as filters to clean the water we drink, and are a major source of medications. Soils can also expose animals and humans to pathogens or toxic levels of various elements and chemical compounds. This can happen through ingestion, inhalation, or penetration of the skin (Steffan et al., 2017).

While the scientific study of the relationships between soils and animal and human health is pretty new, the idea that such relationships exist goes back to at least 1400 before common era (BCE) (Brevik and Sauer, 2015). This paper will explore some of the highlights of this history and how our understanding of soil/animal-human health relationships has changed over time. It will conclude by drawing on this understanding of history to offer some perspectives on where such studies need to go as we look to the future.

Early history through the 1800s – Hints of understanding

Early humans were not conducting scientific studies to investigate links between soils and animal/human health, but there are definite indications that they had a fundamental understanding that such links existed. For example, in 1400 BCE Moses gave instructions to the scouts that he sent into Canaan that made it clear he understood that fertile soils were essential to the well-being of the people he was leading (Numbers 12:18-20). Likewise, when Hippocrates created a list of things that should be considered in a proper medical evaluation in 400 BCE he included the nature of the ground (Hippocrates, 2010). This fundamental understanding that there were links between soils and health continued into the 17th through 19th centuries. For example, in the mid-1600s in Great Britain, Izaak Walton pointed out that the quality of sheep wool, muscle meat, and tastiness of trout were all related to soil fertility (Albrecht, 1958), in the early 1700s de Crèvecoeur offered the opinion that the health and vitality of men, like plants, depended on the soils from which they were fed (de Crèvecoeur, 1904), in 1761 Mortimer suggested that chalky land substrates spoiled oxen feed more than any other soil (Horvath and Reid, 1984) and in North America during the 1800s it was noted that there was a link between agriculture and an enduring society (Stoll, 2002). One of the landmarks of bacteriology and medical history is the 1870 discovery by Robert Koch that the cause of the deadly animal and human disease anthrax was the soil-borne pathogen *bacillus anthracis*. In 1880 Luis Pasteur demonstrated that earthworms transfer these spore-forming pathogens from animal graveyards to the surface of grazing soils. The soil-borne disease anthrax shaped events worldwide from the Old World through to the New World, its spread influenced by human activity and movement. With the development of biotechnology anthrax was carried onto the “Future World” as a bioweapon (Jones, 2010).

Early to mid-1900s – The idea of soil as an influence on animal and human health gains traction

The idea that there were links between soils and animal/human health really took off in the 20th century, including the first scientific experiments designed to investigate these relationships. One of the early studies was McCarrison's (1921), where it was concluded that soils influenced human health through their influence on the vitamin content of foods grown in them. Similar to Koch and Pasteur, McCarrison (1921) also speculated that soil bacteria could be pathogens, speculation that was later confirmed. Another early milestone in Europe was the publication of *Medical Testament* (Kerr et al., 1939), a document developed by a panel of medical professionals in the United Kingdom. Kerr et al. (1939) concluded that illness was on the rise in the UK due to poor dietary nutrition, and that farming practices that depleted the soil of essential nutrients were responsible for the situation.

In the USA, the 1938 USDA Yearbook of Agriculture recognized the importance of soil as the origin of minerals in food crops in chapters written by Browne, Kellogg, and McMurtrey and Robinson (USDA, 1938); the influence of soils on both animal and human health were recognized in these chapters. This was followed up in 1940 by the establishment of the USDA Plant, Soil and Nutrition Research Unit (PSNRU) at Cornell University, with the charge to improve the nutritional quality and health promoting properties of food crops as a way to promote human health. In addition to the PSNRU, 1940 was a major year in the soils-health relationship because antibiotics were isolated from soil organisms for the first time in the laboratory overseen by Selman Waksman at Rutgers University, an achievement that earned Waksman the Nobel Prize in Physiology or Medicine in 1952 (Brevik and Sauer, 2015). Throughout the 1940s and 1950s William Albrecht at the University of Missouri conducted research into soil-human health relationships, with particular interest in links between soil fertility and dental health (e.g., Albrecht, 1945; 1951). His book titled "Soil fertility and animal health" (Albrecht, 1958) touched on the interdisciplinary nature of soil and health, bringing together climate change, soil degradation, the balance of nutritional elements, organic matter and connecting soil with animal health and agricultural economics.

Major individuals in the organic agriculture movement also weighed in on the soils and health issue starting in the 1940s. Howard (1940; 1947) addressed links between soil fertility and human health, as did Balfour (1943) and Rodale (1945). These books provided hypotheses, that is, the idea that better soil conditions should produce better food products and therefore better health, more so than tested theories, but they provided strong evidence of the interest that was developing regarding how soils could impact health. Balfour's (1943) work is noteworthy in that soils and human health is the focus of the book, rather than being a side-note such as in Howard's (1940; 1947) work.

In 1959 André Voisin published a book that took what was probably the broadest view of the links between soils, plant, animal, and human health published to that point. Voisin discussed the ways that a range of health problems, including birth defects, cancer, diabetes, goiter, and mental illness might be linked to nutrient deficiencies and/or imbalances in soils (Voisin, 1959). A major conclusion of this work was that soil science needed to be a major contributor to preventative medicine, but that the medical profession had essentially ignored soils.

The latter part of the 20th century – Increasing interest in soils and animal/human health

The number of studies addressing soil and health issues increased in the later part of the 20th century, with a wide range of topics being discussed. Major topics covered included heavy metals, organic chemicals, and radioactive elements in soils. Discoveries by the broader medical community that a given element or chemical, such as heavy metals or organic compounds, could cause health problems have tended to prompt soil scientists to conduct research into the presence of these elements or chemicals in the soil system. Likewise, the isolation of antibiotics from soil organisms led to increased interest in links between soil organisms and health, and disasters such as the 1986 Chernobyl incident in the Ukraine stimulated significant interest in related soils and health research (Brevik and Sauer, 2015). Increased veterinary, medical and microbial ecology knowledge led to the recognition of soil origins for various infectious agents and have increased interest in how soil chemical properties influenced animal health in a non-nutritional way (Horvath and Reid, 1984). Horvath and Reid (1984) associated particular soil conditions with growth patterns and the degree of virulence of bacterial, fungal and viral animal-pathogens and recommended that a series of systematic investigations of the roles of geochemistry in diseases of domestic and wild animals would be rewarding.

By the end of the 20th century there was considerable interest and a growing body of literature addressing the relationships between soils and health. However, there were also still major gaps in our knowledge. Abrahams (2002) wrote a comprehensive review on the implication of soils to human health, illustrating the focus of the century on discipline-specific investigations and stressing the need for multidisciplinary collaborations. Kibble and Saunders (2001) noted that our understanding of how increased heavy metal contents in soil translated into risks and health problems was poorly understood. As the 20th century came to a close, Oliver (1997) declared ". . . there is a dearth of quantitative information on the relations between elements in the soil and human health;. . . there is much speculation and anecdotal evidence."

Early 21st century – Multidisciplinary efforts increase

With the massive amounts of multidisciplinary research data generated over the later parts of the 20th century and early 21st century and the increased awareness of the importance of soil to human health, a relatively large number of review and discussion papers started appearing in soil, environmental and medical journals connecting biological, chemical and physical properties of soil with animal and human health. The level of complexity of the reviews increased with the enhanced accessibility of online resources and ease of finding information and they became multidisciplinary. Understanding of the soil-plant-animal/human health cycle gained complexity with an increasing number of aspects discussed (Sanchez and Swaminathan, 2005; Brevik, 2009; Pepper, 2013; Brevik and Sauer, 2015; Oliver and Gregory, 2015; Wall et al., 2015; Steffan et al., 2017). Le Mer and Shewmaker (2001) discussed soil's role in greenhouse gas emission, Mayland and Shewmaker (2001) linked animal health problems to silicon and other mineral imbalances, and a range of publications dealt with soil-borne human and animal pathogens, their mode of transfer, e.g. through ingestion (Callahan, 2003; Hooda et al., 2004; Abrahams, 2012), their ecology (Berg et al., 2005; Kidd et al., 2007; Baumgardner, 2012; Hruska and Kaevska, 2012; Sears and Genuis, 2012) and evolutionary aspects (Muir and Tan, 2006), increasing awareness of the connections between soils and health. It is now recognized that while soil is a source of animal and human pathogens, disconnecting humans from soil leads to asthma, allergies and negatively impacts immune system response (von Hertzen and Haahtela, 2006). There is also evidence that exposure to healthy soils can improve human health (Heckman, 2013; Hanyu et al., 2014).

The start of the century saw a shift from the need for tedious gene cloning to access genetic and functional diversity of uncultured microorganisms (Rondon et al., 2000) to high throughput sequencing methods, such as illumina and pyrosequencing, leading to fast advances in studying humans, animals, plants and soil microbiomes (Hattori and Taylor, 2009; Dave et al., 2012; Nguyen et al., 2015; Bulgarelli et al., 2015). The relationships between soil microbiota, ecosystem health and animal and human health became clearer and opinions evolved. While the organic movement at the start of the 20th century was calling for the use of manure to improve soil fertility, alarm bells started sounding with the linking of animal feces and waste to zoonotic soil-borne diseases (Sobsey et al., 2006; Beeler and May, 2011; Blaiotta et al., 2016) and the recognition that control mechanisms are needed (Manyi-Loh et al., 2016).

The roles of domestic animals (cats) in disease transmission from soils to humans were also elucidated (Goldstein and Abrahamian, 2015). The effects of antibiotics leaching into soils from animal production was recognized and its influence on the microbial community and antibiotic resistance, leading in return to human pathogens becoming resistant to antibiotics, was studied (Kim and Aga, 2007; Forsberg et al., 2012; Woolhouse et al., 2015). Researchers enhanced their understanding of the feedback reactions between human activities such as use of agrochemicals, spread of manure, use of antibiotics, their effects on soil health and in return effects on human health (Finley et al., 2013, Kachnic et al., 2013; Marin-Morales et al., 2013). Despite this, Burgess (2013) observed that we still know little about the interactions organic chemicals undergo in the soil system, both with other chemicals and with the soil microbial community, and what that means in regards to health concerns. The preservation of microbial diversity in soil ecosystems has been acknowledged as a key to sustainable productivity (Bath, 2013) and soil health, and in turn exerts considerable influence on human health. Conversely, the influence of human activities on soil health was clearly illustrated in Pepper's review of the "The Soil Health-Human Health Nexus" (Pepper, 2013).

In the last decade, we once more saw the nature of the reviews on soil microbiology and health evolving; not only dealing with community structures but extending to the connections between various microbiomes and how they evolve together (Sing and Sing, 2010; Berg et al., 2014; Hacquard et al., 2015), the effect of geographical regions on human microbiota affected by soil (Hospodsky et al., 2014), and how humans change and control microbiomes, including soil-borne gut pathogens (Adam et al., 2016; McNally and Brown, 2015; Graber et al., 2014). We have used and learned from the microbiome, answering questions such as: how can we use the soil microbes to solve aboveground problems, including increasing crop yield and food security (Lakshmanan et al., 2014), mechanisms soil microbes employ in human diseases (Gupte et al., 2015) and giving a human health perspective to global change and its effects on nutrient cycling by soil microbes (Ochoa-Hueso, 2017).

Concluding statements – Future needs

The idea that soils influence health is not a new one, but as Oliver (1997) noted there was need for well-designed, scientific studies to address the relationships between soils and health as the 21st century dawned. One of the challenges that has made this difficult is the extremely complex nature of soil and health studies, which is beyond the scope of any single discipline to address. Expertise is required from a wide range of fields, including but not limited to agronomy, animal science, biology, chemistry, crop science, economics, medicine, pharmacology, sociology, and soil science. In many cases these fields have not traditionally worked together, and even in situations where fields have, it has been different specialty areas (i.e., human health biologists have not traditionally worked with soil scientists but ecologists have). Therefore, even knowing that collaboration would be beneficial, there can be communication barriers as different scientists struggle to function together at a professional level. There is a strong need for interdisciplinary and transdisciplinary teams that can bridge these gaps and advance our understanding.

Another challenge is the need to find a platform that effectively communicates the importance of issues such as soils and health to the general public (Bouma et al., 2012). For many people soils are not something they spend much time thinking about, and when they do, soils often have a negative rather than positive connotation (Brevik et al., 2017). The soil health (not to be confused with soils, animal, and human health) concept has resonated with many in the general public, leading the USDA-NRCS to make soil health a centerpiece of their current work. The soil security concept, which is intended to link into other successful concepts such as energy and water security, is another possibility, as is some sort of terroir-type connection (Brevik et al., 2017). Regardless of what ultimately proves successful, finding a way to link soils to the health benefits they provide will be an important part of advancing research in this area. This is because public advocacy has been shown to significantly increase funding for research into directed medical areas, while medical areas that receive less advocacy also receive correspondingly reduced recognition through funding (Best, 2012). This indicates that public advocacy could be an essential component of generating research funding for soil and animal/human health issues.

References

Abrahams, PW, 2002. Soils: their implications to human health. The science of the total environment 291, 1-32.

Abrahams, PW, 2012. Involuntary soil ingestion and geophagia: A source and sink of mineral nutrients and potentially harmful elements to consumers of earth materials. Applied geochemistry 27, 954-968.

Adam, E, Groenenboom, AE, Kurm, V, Rajewska, M, Schmidt, R, Tyc, O, Weidner, S, Berg, G, de Boer, W, Salles, JF, 2016. Controlling the microbiome: microhabitat adjustments for successful biocontrol strategies in soil and human gut. Frontiers in Microbiology 7, 1079. doi: 10.3389/fmicb.2016.01079

Albrecht, A, 1958. Soil fertility and animal health, Webster City, Iowa, Fred Hahne Printing Company.

Balfour, EB, 1943. The living soil, London, UK, Faber and Faber Ltd.

Baht, AK, 2013. Preserving microbial diversity of soil ecosystem: A key to sustainable productivity. International Journal of Current Microbiology and Applied Sciences 2(8), 85-101.

Baumgardner, DJ, 2012. Soil-related bacterial and fungal infections. The Journal of the American Board of Family Medicine 25(5), 734-744.

Beeler, E, May, M, 2011. The link between animal feces and zoonotic disease. Rx for Prevention LA County Department of Public Health June-July 2011. (Accessed on 14/08/2017) URL: http://publichealth.lacounty.gov/vet/docs/Educ/AnimalFecesandDisease.pdf

Berg, G, Eberl, L, Hartmann, A, 2005. The rhizosphere as a reservoir for opportunistic human pathogenic bacteria. Environmental microbiology 7(11), 1673-1685.

Berg, G, Erlacher, A, Smalla, K, Krause, R, 2014. Vegetable microbiomes: is there a connection among opportunistic infections, human health and our 'gut feeling'? Microbial biotechnology 7(6), 487-495.

Best, RK, 2012. Disease politics and medical research funding: three ways advocacy shapes policy. American Sociological Review 77(5), 780-803.

Blaiotta, G, Di Cerbo, A, Murru, N, Coppola, R, Aponte, M, 2016. Persistence of bacterial indicators and zoonotic pathogens in contaminated cattle wastes. BMC microbiology, 6:87. DOI 10.1186/s12866-016-0705-8

Bouma, J, Broll, G, Crane, TA, Dewitte, O, Gardi, C, Schulte, RPO, Towers, W, 2012. Soil information in support of policy making and awareness raising. Current Opinions in Environmental Sustainability 4, 552–558.

Brevik, EC, 2009. Soil, food security, and human health, in: W Verheye (Ed.), Soils, Plant Growth and Crop Production. Encyclopedia of Life Support Systems (EOLSS), Developed under the Auspices of the UNESCO, EOLSS Publishers, Oxford, UK. http://www.eolss.net.

Brevik, EC, Steffan, JJ, Burgess, LC, Cerdà, A, 2017. Links between soil security and the influence of soil on human health, in: D Field, C Morgan, and A McBratney (Eds.), Global Soil Security. Progress in Soil Science Series, Springer, Rotterdam. p. 261-274.

Brevik, EC, Sauer, TJ, 2015. The past, present, and future of soils and human health studies. SOIL 1, 35-46. doi:10.5194/soil-1-35-2015.

Bulgarelli, D, Garrido-Oter, R, Münch, PC, Weiman, A, Dröge, J, Pan, Y, McHardy, AC, Schulze-Lefert, P, 2015. Structure and function of the bacterial root microbiota in wild and domesticated barley. Cell Host & Microbe 17, 392-403.

Burgess, LC, 2013. Organic pollutants in soil, in: EC Brevik and LC Burgess (Eds.), Soils and human health, CRC Press, Boca Raton, FL, USA. pp. 83–106.

Callahan, GN, 2003. Eating dirt. Emerging Infectious Diseases 9, 1016-1021.

Dave, M, Higgins, PD, Middha, S, Rioux, KP, 2012. The human gut microbiome: current knowledge, challenges, and future directions. Translational Research 160 (4), 246-257.

de Crevecoeur, J, 1904. Letters from an American farmer (reprinted from the original edition), Fox and Duffield, New York, NY, USA.

Finley, RL, Collignon, P, Larsson, DGJ, McEwen, SA, Li, XZ, Gaze, WH, Reid-Smith, R, Timinouni, M, Graham, DW, Topp, E, 2013. The scourge of antibiotic resistance: the important role of the environment. Clinical Infectious Diseases 57(5), 704-710.

Forsberg, KJ, Reyes, A, Wang, B, Selleck, EM, Sommer, MOA, Dantas, G, 2012. The shared antibiotic resistome of soil bacteria and human pathogens. Science 337, 1107-1111.

Goldstein, EJ, Abrahamian, FM, 2015. Diseases transmitted by cats. Microbiology Spectrum 3(5), IOL5-0013-2015. DOI:10.1128/microbiolspec.IOL5-0013-2015

Graber, ER, Frenkel, O, Jaiswal, AK, Elad, Y, 2014. How may biochar influence severity of diseases caused by soilborne pathogens? Carbon Management 5(2), 169-183.

Gupte, S, Kaur, T, Kaur, M, 2015. Virulence factors of environmental microbes in human disease. Journal of Tropical Diseases 3, 161. doi: 10.4172/2329-891X.1000161

Hacquard, S, Garrido-Oter, R, Gonza´ lez, A, Spaepen, S, Ackermann, G, Lebeis, S, McHardy, AC, Dangl, JL, Knight, R, Ley, R, Schulze-Lefert, P, 2015. Microbiota and host nutrition across plant and animal kingdoms. Cell Host & Microbe 17, 603-616.

Hanyu, K, Tamura, K, Mori, H, 2014. Changes in heart rate variability and effects on POMS by whether or not soil observation was performed. Open Journal of Soil Science 4, 36-41.

Hattori, M, Taylor, TD, 2009. The human intestinal microbiome: A new frontier of human biology. DNA Research 16, 1-12.

Heckman, JR, 2013. Human contact with plants and soils for health and well-being, in: EC Brevik and LC Burgess (Eds.), Soils and human health, CRC Press, Boca Raton, FL, USA. pp. 227–240.

Hippocrates, 2010. On airs, waters and places (reprint), Kessinger Publishing, LLC, Whitefish, MT, USA.

Hospodsky, D, Pickering, AJ, Julian, TR, Miller, D, Gorthala, S, Boehm, AB, Peccia, J, 2014. Hand bacterial communities vary across two different human populations. Microbiology 160, 1144-1152.

Hooda, PS, Henry, CJK, Seyoum, TA, Armstrong, LDM, Fowler, MB, 2004. The potential impact of soil ingestion on human mineral nutrition. Science of the Total Environment 333, 75-87.

Horvath, DJ, Reid, RL, 1984. Indirect effects of soil and water on animal health. Science of the Total Environment 34, 143-156.

Howard, A, 1940. An agricultural testament, Oxford University Press, London, UK.

Howard, A, 1947. The soil and health: A study of organic agriculture, Devin-Adair Company, New York, NY, USA.

Hruska, K, Kaevska, M, 2012. Mycobacteria in water, soil, plants and air: a review. Veterinarni Medicina 57, 623–679.

Jones, SD, 2010. Death in small package: A short history of anthrax, The Johns Hopkins University Press, Baltimore, USA.

Kachnič, J, Sasáková, N, Papajová, I, Laktičová, KV, Hromada, R, Harkabus, J, Ondrašovičová, S, Papaj, J, 2013. The risk to human health related to disposal of animal wastes to soil – microbiological and parasitical aspects. Helminthologia 50(3), 147-154.

Kerr, J, Boswell, NA, Bennett, JB, Allan, FG, Jaffe, H, Binns, G, Kerr, JH, Blacklay, OH, Loney, RE, Bower, HE, Lynd, WS, Brice, HD, Murphy, J, Chadwick, JW, Murphy, JB, Chisholm, JD, Parkes, M, Davidson, RB, Platt, JN, Dickson, WW, Pollard, LT, Dwyer, M, Robertson, JR, English, H, Russell, WJA, Fellows, FM, Thomas, WEC, Fulton, JB, Wraith, F, Gerrard, RF, Picton, LJ, 1939. Medical testament – County Palatine of Chester local medical and panel committee, available at: http://journeytoforever.org/farm_library/medtest/medtest.html. Accessed 24 July 2017.

Kibble, AJ, Saunders, PJ, 2001. Contaminated land and the link to health, in: RE Hester and RH Harrison (Eds.), Assessment and Reclamation of Contaminated Land. Issues in Environmental Science and Technology, Royal Society of Chemistry, Cambridge, UK. pp. 65–84.

Kidd, SE, Chow, Y, Mak, S, Bach, PJ, Chen, H, Hingston, AO, Kronstad, JW, Bartlett, KH, 2007. Characterization of environmental sources of the human and animal pathogen *Cryptococcus gattii* in British Columbia, Canada, and the Pacific Northwest of the United States. Applied and Environmental Microbiology 73, 1433-1443.

Kim, S, Aga, DS, 2011. Potential ecological and human health impacts of antibiotics and antibiotic-resistant bacteria from wastewater treatment plants. Journal of Toxicology and Environmental Health Part B 10, 559-573. DOI: 10.1080/15287390600975137

Lakshmanan, V, Selvaraj, G, Bais, HP, 2014. Functional soil microbiome: belowground solutions to an aboveground problem. Plant Physiology 166, 689-700.

Le Mer, J, Roger, P, 2001. Production, oxidation, emission and consumption of methane by soils: A review. European Journal of Soil Biology 37, 25-50.

Mayland, HF, Shewmaker, GE, 2001. Animal health problems caused by silicon and other mineral imbalances. Journal of Range Management 54(4), 441-446.

Marin-Morales, MA, Ventura-Camargo, BC, Hoshina, MM, 2013. Toxicity of herbicides: Impact on aquatic and soil biota and human health, in: AJ Price and JA Kelton (Eds.), Herbicides – Current research and case studies in use. InTech, Rijeka, Croatia. DOI: 10.5772/55851

McCarrison, R, 1921. Studies in deficiency disease, Hazell, Watson and Viney Ltd., London, UK.

McNally, L, Brown, SP, 2015. Building the microbiome in health and disease: niche construction and social conflict in bacteria. Philosophical Transactions of the Royal Society B 370: 20140298. http://dx.doi.org/10.1098/rstb.2014.0298

Manyi-Loh, CE, Mamphweli, SN, Meyer, EL, Makaka, G, Simon, M, Okoh, AI, 2016. An overview of the control of bacterial pathogens in cattle manure. International Journal of Environmental Research and Public Health 13, 843. doi:10.3390/ijerph13090843

Muir, R, Tan, MV, 2006. Evolution of pathogens in soil, in: HS Scifert and VJ DiRita (Eds.), Evolution of microbial pathogens. ASM Press, Washington, D.C. pp. 131-146.

Nguyen, LDN, Viscogliosi, E, Delhaes, L, 2015. The lung mycobiome: an emerging field of the human respiratory microbiome. Frontiers in Microbiology 6, 89. doi: 10.3389/fmicb.2015.00089

Ochoa-Hueso, R, 2017. Global change and the soil microbiome: A human-health perspective. Frontiers in Ecology and Evolution 5, 71. doi: 10.3389/fevo.2017.00071

Oliver, MA, 1997. Soil and human health: a review. European Journal of Soil Science 48, 573-592.

Oliver, MA, Gregory, PJ, 2015. Soil, food security and human health: a review. European Journal of Soil Science 66(2), 257–276.

Pepper, IL, 2013. The soil health-human health nexus. Critical Reviews in Environmental Science and Technology 43(24), 2617-2652. DOI: 10.1080/10643389.2012.694330

Rodale, JI, 1945. Pay dirt: Farming and gardening with composts, Devin-Adair Company, New York, NY, USA.

Rondon MR, August PR, Bettermann AD, Brady, SF, Grossman, TH, Liles, MR, Loiacono, KA, Lynch, BA, MacNeil, IA, Minor, C, Tiong, CL, 2000. Cloning the soil metagenome: a strategy for accessing the genetic and functional diversity of uncultured microorganisms. Applied and Environmental Microbiology 66, 2541–7.

Sanchez, PA, Swaminathan, MS, 2005. Hunger in Africa: The link between unhealthy people and unhealthy soils. The Lancet 365, 442-444.

Sears, ME, Genuis, SJ, 2012. Environmental determinants of chronic disease and medical approaches: Recognition, avoidance, supportive therapy, and detoxification. Journal of Environmental and Public Health 2012, 1-15. doi:10.1155/2012/356798

Sing, D, Sing, C, 2010. Impact of direct soil exposures from airborne dust and geophagy on human health. International Journal of Environmental Research and Public Health 7, 1205-1223.

Sobsey, MD, Khatib, LA, Hill, VR, Alocilja, E, Pillai, S, 2006. Pathogens in animal wastes and the impacts of waste management practices on their survival, transport and fate, in: JM Rice, DF Caldwell, FJ Humenik (Eds.), Animal Agriculture and the Environment, National Center for Manure and Animal Waste Management White Papers, St. Joseph, MI. pp. 609-666.

Steffan, JJ, Brevik, EC, Burgess, LC, Cerdà, A, 2017. The effect of soil on human health: an overview. European Journal of Soil Science. doi:10.1111/ejss.12451.

Stoll, S, 2002. Larding the lean Earth: Soil and society in nineteenth century America, Hill and Wang, New York, NY, USA.

USDA, 1938. Soils and men: Yearbook of agriculture 1938. United States Government Printing Office, Washington, DC, USA.

Von Hertzen, L, Haahtela, T, 2006. Disconnection of man and the soil: Reason for the asthma and atopy epidemic? Journal of Allergy and Clinical Immunology 117(2), 334-344.

Wall, DH, Nielsen, UN, Six, J, 2015. Soil biodiversity and human health. Nature 528, 69-76.

Woolhouse, M, Ward, M, van Bunnik, B, Farrar, J, 2015. Antimicrobial resistance in humans, livestock and the wider environment. Philosophical Transactions of the Royal Society B 370, 20140083. http://dx.doi.org/10.1098/rstb.2014.0083