

Sinister soils and risky rhizospheres: The ecology of melioidosis and other soil-borne infections

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Abstract

The danger of soil borne human infection is not only seasonal. It has a patchy distribution over a huge geographic range, causing problems with accurate risk modelling. Infections resulting from environmental exposure are caused by organisms that can persist in the soil for a long time either as spores or by relying on an internal nutrient store. There is a remarkable lack of hard data on the occurrence of soil borne human diseases. Melioidosis is a soil-borne disease of surprises. In its most severe form, it presents as a systemic bloodstream infection with or without pneumonia. The microbial ecology of soil is complex and probably has a bearing on bacterial survival, growth and therefore the risk of subsequent human disease following soil contact. Given the ability of some disease-causing bacteria to persist for long periods in soil, it is clear that some soils must be regarded as a potential health hazard. It would be sensible to combine bacteriological risk and soil health index analysis in a hypothesis-driven surveillance programme.

Key Words

Risk modeling, seed borne, uncertainty, tropical environments

Introduction

"I will show you fear in a handful of dust."

TS Eliot, *The Waste Land*, 1922.

Not that long ago a driver bogged his 4x4 near Katherine in the Northern Territory, Australia. He managed to get going again after a bit of heavy digging, but within 48 hours he was dead; slain by a little-known bacterial infection that lies dormant in the soil of northern Australia. This is not the only story of sudden death from soil-borne infection in recent times. Every year the *Northern Territory News* carries reports of deaths and intensive care admissions due to soil disease. Public health authorities warn people of the risks yet, despite these warnings the deaths continue. The danger of soil borne infection is not only seasonal. It has a patchy distribution over a huge geographic range, causing problems with accurate risk modelling.

Dishing the Dirt

The above infection is known as melioidosis and is caused by the Gram negative bacterial species *Burkholderia pseudomallei*. It is not the only soil-borne infection. A short list includes anthrax (*Bacillus anthracis*), a variant of Legionnaires' Disease (*Legionella longbeachae*), gas gangrene (*Clostridium perfringens*), tetanus (*Clostridium tetani*) and Nocardiosis (*Nocardia* species) (Table 1). The details of atypical *Legionella* infection have yet to be worked out but *L. longbeachae* generally causes pneumonia after the use of garden products such as potting mix (1). The other conditions listed are caused by infections linked to farm animals. Interestingly, these infections are rarely if ever contracted by man-to-man transmission. They are all infections of environmental exposure and are all caused by infective agents that can persist in the soil for a long time either as spores or by relying on an internal nutrient store. These bacteria are tougher than the ones that cause more common infections.

Sweeping the Dirt Under the Table

There is a remarkable lack of hard data on the occurrence of soil borne human diseases. Where, when, how often and under what circumstances these infections occur is often a matter of conjecture because they are not normally communicable diseases. They do not cause outbreaks in the classic sense of the word and therefore do not attract the attention of public health authorities. That is, unless they have the potential for use as a biological weapon, as is the case with *B. pseudomallei*, the cause of melioidosis. This bacterial species has gained notoriety in the last decade because it is on the Centers for Disease Control wanted list as

a potential weapon agent (2), having attracted the attention of the Soviet Union during the Cold War. There is no good evidence that it has been used in this capacity, but more tellingly there have been several clusters of cases with fatalities. Two of these case-clusters occurred in northern Australia; one in the West Kimberley and one in the Northern Territory (3, 4). All Australian jurisdictions in the tropics now include melioidosis on their list of notifiable diseases. Unfortunately, the rest of Australia has yet to catch up. Melioidosis is not notifiable in New South Wales, Victoria, the Australian Capital Territory, South Australia and Tasmania where sporadic, travel-associated infection goes without further comment.

An Unusual Infection

Melioidosis is a disease of surprises. In its most severe form, it presents as a systemic bloodstream infection with or without pneumonia (5). Death occurs rapidly unless intravenous antibiotic treatment is commenced without delay, and may not be averted even when the right antibiotics are used from the start. This septicaemia can relapse after a few days or weeks of antibiotic therapy, necessitating a prolonged course of oral antibiotic treatment to eradicate residual, dormant infection. But melioidosis can also present after a long, disease-free interval of up to six decades following initial environmental exposure. In between septicaemia and asymptomatic, dormant infection lie localised, abscess-like foci which can erupt at any time into a full-blown bloodstream infection. Patients with melioidosis therefore die in spite of the correct antibiotics or they can survive, having been right to the brink of hopeless multi-organ system failure (6). Most of the severe cases occur in people with underlying medical conditions such as diabetes, renal failure and alcoholic liver disease, but not all fatalities occur in these vulnerable people.

Table 1. Selected human bacterial infections associated with soil exposure

Infection	Bacterial cause	Distribution	Exposure
Anthrax	<i>Bacillus anthracis</i>	with domestic livestock & wildlife worldwide	skin inoculation, inhalation
Botulism	<i>Clostridium botulinum</i>	With domestic livestock worldwide	ingestion
Gas gangrene	<i>Clostridium perfringens</i>	with livestock worldwide	dermal inoculation
Infective diarrhoea	<i>Salmonella</i> , <i>Shigella</i> , <i>Campylobacter</i> , <i>E.coli</i>	worldwide	ingestion of faecal-soil mix
Legionnaires' Disease	<i>Legionella longbeachae</i>	patchy, sporadic including W & S Australia	inhalation
Leptospirosis	<i>Leptospira icterohaemorrhagiae</i>	Widespread in tropics & temperate zones	Mucosal surface exposure to urine-soil mix
Melioidosis	<i>Burkholderia pseudomallei</i>	tropics esp. N Australia & SE Asia	inhalation, dermal inoculation
Nocardiosis	<i>Nocardia</i> species	Patchy, sporadic	Dermal inoculation, inhalation
Tularaemia	<i>Francisella tularensis</i>	N America, Scandinavia	Inhalation, skin inoculation
Tetanus	<i>Clostridium tetani</i>	with livestock & other animals worldwide	dermal inoculation into deep soft tissues

Geographic Distribution

The sporadic nature of melioidosis and its link with environmental exposure allows us to draw a map of the endemic area; broadly speaking in the tropical north of Australia where annual rainfall is greater than 800mm. This appears to be an infection of warm, wet summers, as confirmed by detailed analysis in Darwin. Beyond Australia, melioidosis is found in many parts of the tropics, particularly in Southeast Asia where rice

farmers are at high risk of infection. Environmental studies have shown that *Burkholderia pseudomallei* is sporadically distributed in our region and can be found in a variety of types of worked soil, including rice, rubber and banana plantations and close to urban centres (7,8) (Figure 1).

Seed and Soil

Understanding of the distribution of *B. pseudomallei* in the rhizosphere is far from complete. Where present, it is usually located between 5cm and 60cm depth and has a preference for waterlogged and clay soils (9). Recent prospective sampling on a mine site in WA suggested a predilection for transitional soil environments in an area of re-vegetation (10). Crushed rock on the excavation site, mine tailings and also pristine bush were either no- or low yield for *B. pseudomallei*. These results are consistent with finding other *Burkholderia* species in forest environments where soil has been altered by forest management (11). It is interesting that a rural location in southwestern Australia where cases of melioidosis occurred in goats and the human community yielded *B. pseudomallei* from environmental samples during the case cluster (12), but not after established restoration of native vegetation and avoidance of chemical fertilization with substances that can be used by *Burkholderia* species as growth substrates. The microbial ecology of soil is complex and probably has a bearing of bacterial survival, growth and therefore the risk of subsequent human disease following soil contact. We discovered that *B. pseudomallei* could survive inside free-living amoebae of a type that are commonly found in soil and surface water (13). More recently we showed that these bacteria can also survive in mycorrhizal fungi and can be transferred from generation to generation in this protected environment (14). These interactions between bacteria and more complex microorganisms have been used to improve the yield of *B. pseudomallei* from surveillance soil samples (15). The observation raises the question of whether fungal spores or amoebic cysts can act as a vehicle for airborne spread of these disease-causing bacteria.



Figure 1. Rice fields in Malaysia; a suitable worked soil habitat for proliferation of *B. pseudomallei*.

Healthy Soils?

Given the ability of some disease-causing bacteria to persist for long periods in soil, it is clear that some soils must be regarded as a potential health hazard. Effective laboratory methods for field studies are still in their infancy, but a molecular microbiology approach shows some promise (15). Backed up by GIS mapping of known high-risk locations, it may be possible to develop a predictive approach in future, but with the caveat that the areas of interest are large and the knowledge gaps are large. An alternative or possibly complementary approach is to attempt a definition of bacteriologically healthy soil, to include qualitative and quantitative bacteriological analysis. Very little work has been done on this in tropical Australia as yet because it has previously been given a low priority. Now that the increasing rainfall patterns in the northwest have been recognized and an expansion of agriculture in the Kimberley is planned, it is a good time to revisit the issue. Surely it would be sensible to combine bacteriological risk and soil health index analysis in a hypothesis-driven surveillance programme? A failure to act at this stage may lose an opportunity to both plan for sustainability of arable production and minimize human disease risk in the East Kimberley.

Wider Issues

These are not trivial issues. There may only be a handful of cases of melioidosis in the Kimberley each year, but that number reflects a small population base. It is still one of the highest incidence locations for the disease in the region. Multiply the population, increase a receptive soil environment by expanding productive agriculture and add steadily increasing annual rainfall and periodic cyclones, and you can see why the epidemiologists expect to see an increase in melioidosis cases. This is only one soil borne disease we believe to be impacted by climate change and other anthropogenic drivers (16). It is likely that these determinants of soil borne disease will also impact subtly on the epidemiology of the other infections considered here, though the precise outcomes are difficult to predict without better surveillance data. This is likely to be a subject of intense study in years to come.

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