Soil science related to the human body after death

Literature review produced for The Corpse Project

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Contents

1. The mineral and nutrient composition of a human cadaver

The human body contains 26 elements (Tortora and Grabowski, 2000), of which four account for approximately 96% of the total body mass. These elements are: oxygen (65%), carbon (18.5%), hydrogen (9.5%) and nitrogen (3.2%). Combined, the nine elements calcium, phosphorus, potassium, sulphur, sodium, chlorine, magnesium, iodine and iron make up an additional 3.9% of the total body mass. The remaining 0.1% of the body mass comprises of 13 elements: aluminium, boron, chromium, cobalt, copper, fluorine, manganese, molybdenum, selenium, silicon, tin, vanadium and zinc.

The cadaver can provide 17 out of the 18 elements required for plant growth (Hillel, 2008). Nickel, an essential micro nutrient that helps prevent the toxic build-up of urea (Hänsch and Mendel, 2009), is not present in a cadaver.

Table 1. Mineral composition of the corpse

	Element	**Composition (%)**	**Combined Composition (%)**
Main elements	Oxygen (O)	65	96
	Carbon (C)	18.5	
	Hydrogen (H)	9.5	
	Nitrogen (N)	3.2	
Medium presence	Calcium (Ca)	1.5	3.9
	Phosphorus (P)	1.0	
	Potassium(K)	0.4	
	Sulphur (S)	0.3	
	Sodium (Na)	0.2	
	Chlorine (Cl)	0.2	
	Magnesium (Mg)	0.1	
	Iodine (I)	0.1	
	Iron (Fe)	0.1	
Rare	Aluminium (Al) Boron (B) Chromium (Cr) Cobalt (Co) Copper (Cu) Fluorine (F) Manganese Molybdenum Selenium (Se) Silicon (Si) Tin (Sn) Vanadium (V) Zinc (Zn)	Variable	0.1

2. The mineral and nutrient value of cremated remains and its use (animal or human) as a soil enricher.

Cremation is a common practice observed in the UK. In 2013, over 75% (approximately 375,000) of those who died were cremated. (The Natural Death Centre, 2016). Cremated human remains (or cremains) comprise of cremated (Figure 1) and pulverised bone (Buschmann and Tsokos, 2014) that can weigh up to 3 kg per body (Strand, 2008; Bass and Jantz, 2004). During cremation, organic fractions are burnt off and foreign objects (metals e.g. implants, coffin staples) removed, leaving a high concentration of calcium phosphate; a highly stable form of phosphorus (Strand et al., 2008) (Table 2).

Figure 1 Cremated remains before they are crushed. Source: Schultz et al. (2015).

Cremated remains of deceased pets are claimed to have a high pH (11.5) and high sodium content, with up to 2000 times the tolerable limit of plants (Let your love grow, 2016). This makes cremated remains toxic to plants. Only anecdotal evidence was found to suggest that this would also be the case for cremated human remains. Unless taken by wind, cremated remains can persist in the environment for a long period of time and can create an unsightly mass (personal communication with A. Abbot, Crownhill Crematorium, 2016). Consequently, the tradition of scattering cremated remains in the open environment is becoming increasingly restricted. Football clubs, Royal parks (including Richmond, Kensington and Greenwich) and private estates (e.g. Jane Austen's house) all refuse permission. Football clubs have even gone to the extent of creating memorial gardens for ash scattering to prevent scattering on the pitch. The Scottish Mountaineering

Council is also against the scattering of cremated remains, as the regular addition to mountain tops is changing the local ecology (Cramb, 2006). As the cremate weathers over time, it's likely that the calcium will become more available, and as such likely to increase soil pH. This has allegedly transformed the vegetation-poor environment from an acidic soil with low fertility to a more alkaline and fertile soil with increased vegetation (Mountaineering Council of Scotland, 2016). The negative environmental effect of cremated remains is aggravated when accompanied by tributes of plastic wreaths and flowers as well as the recently emptied cardboard/wooden/metal urns.

Table 2. Chemical composition of human cremated remains. Data source: http://www.scattering-ashes.co.uk/general/cremation-ashes-chemicalcompostion/.

Element	**Composition (%)**
Phosphate	47
Calcium	25
Sulfate	11
Potassium	3.69
Sodium	1.12
Chloride	1.0
Silica	0.9
Aluminium Oxide	0.72
Magnesium	0.418
Iron Oxide	0.118
Zinc	0.0342
Titanium Oxide	0.0260
Barium	0.0066
Antimony	0.0035
Chromium	0.0018
Copper	0.0017
Manganese	0.0013
Lead	0.0008
Tin	0.0005
Vanadium	0.0002
Beryllium	<0.0001
Mercury	<0.00001

Cremated remains alone do not typically provide soil enrichment. The phosphorus contained in human and animal cremate is insoluble and not readily available to plants (Strand et al., 2008). This differs from that of typical animal bone meal due to the means of processing. Animal bone meal is first cooked in water, which increases plant available nutrients (Deydier et al., 2005). Commercial research is being undertaken to unlock the phosphorus contained within human cremated remains (Strand et al., 2008; Let your love grow, 2016). The addition of acid is one means of achieving this, increasing the plant available phosphorus from 1 mg/kg to between 3 to 10 mg/kg (Strand et al., 2008). The process is similar to extracting phosphorus from its natural form: rock phosphate (Strand et al., 2008). Mixing cremated remains with a compost (of unknown origin) has demonstrated better results, achieving up to 6000 mg/kg available phosphorus (Strand et al., 2008). 'Let your love grow', a US company, markets such a product that claims to turn cremated remains (predominately originated from deceased pets, but with alleged applicability to humans) into a soil additive allowing a permanent living memorial in the form of a plant. Such composts claim to achieve complete decomposition within 24 to 36 months (personal communication, Bob Jenkins, 2015).

Cremated remains have also shown potential in soil remediation, locking up zinc, nickel and lead on contaminated land (Hodson et al., 2001, Kearney et al., 2000 and Deydier et al., 2003). This concept has been tested using incinerated animal meat and bone meal and so has applicability to human cremated remains. However, the volume required to achieve this as compared with the availability of human cremated remains is unknown. There would also be cultural implications affecting the uptake of this practice.

The effect of cremated remains on soil requires further investigation, as currently only anecdotal evidence exists. This evidence suggests that the effect of cremated remains depends upon the environment in which it is applied and subsequent interaction effects. This has shown two different effects of cremated remains. Typically, they do not appear to provide a soil fertilisation effect when applied in isolation, and due to the high salinity can be toxic. However, in impoverished environments cremated remains have been observed to change the soil to the extent that plant growth is improved. In order to better understand the effect of cremated remains on soils and improve the evidence base, scientific studies need to be undertaken.

3. Shallow burial of human remains; its effect on soil health and fertility, the longevity of any soil benefit and soil conditions required for this.

UK law (Local Authorities Cemetery Order Schedule 2, paragraph 2) requires that any part of a coffin is at least 0.91 m (3 feet) below ground level. This can be reduced to 0.61 m (2 feet) where soil conditions are suitable and the coffin is made of perishable materials. This has meant that studies of human shallow burial have been limited to either criminal investigations or forensic facilities that rely on body donation such as the Anthropology Research Facility at the University of Tennessee, Knoxville. Where human cadavers are not available for study, animal analogues are used instead. The preferred analogue is the pig as, like human bodies, it is largely hairless, and has a similar skin structure, body mass, fat-to-muscle ratio and physiology (Schotsmans et al., 2012).

A decomposing cadaver is considered to be a high quality nutrient resource; it has a low carbon to nitrogen ratio (good for decomposition) and a high water content (Carter et al., 2007). It has a high nutritional content, and has a greater localised soil nutrient benefit than the addition of plant matter or manure (Carter et al., 2007). This localised nutrient pool, which laterally extends as far as the cadaver and its associated maggot mass, is known as the ‘cadaver decomposition island’ (CDI) (Carter et al., 2007). This positively impacts soil quality by enhancing the soil's ability to sustain flora and fauna (both above and below ground). Burial at shallower depths can increase the rate of decomposition as it is a less anaerobic environment, more organic, and may be accessible to insects and scavengers (Figure 2) thus potentially making the nutrients more rapidly available and at a depth where they can be utilised by plants and organisms. However studies of surface vegetation and above-grave soil nutrients suggest that the CDI effect may only be present below the buried cadaver (France et al., 1992; Van Belle et al., 2009; Caccianiga et al., 2012). However, pig burial at 40 cm depth have been found to have no significant soil effect (Caccianiga et al., 2012). This suggests that whilst the soil becomes more fertile from the cadaver, nutrients are lost through leaching.

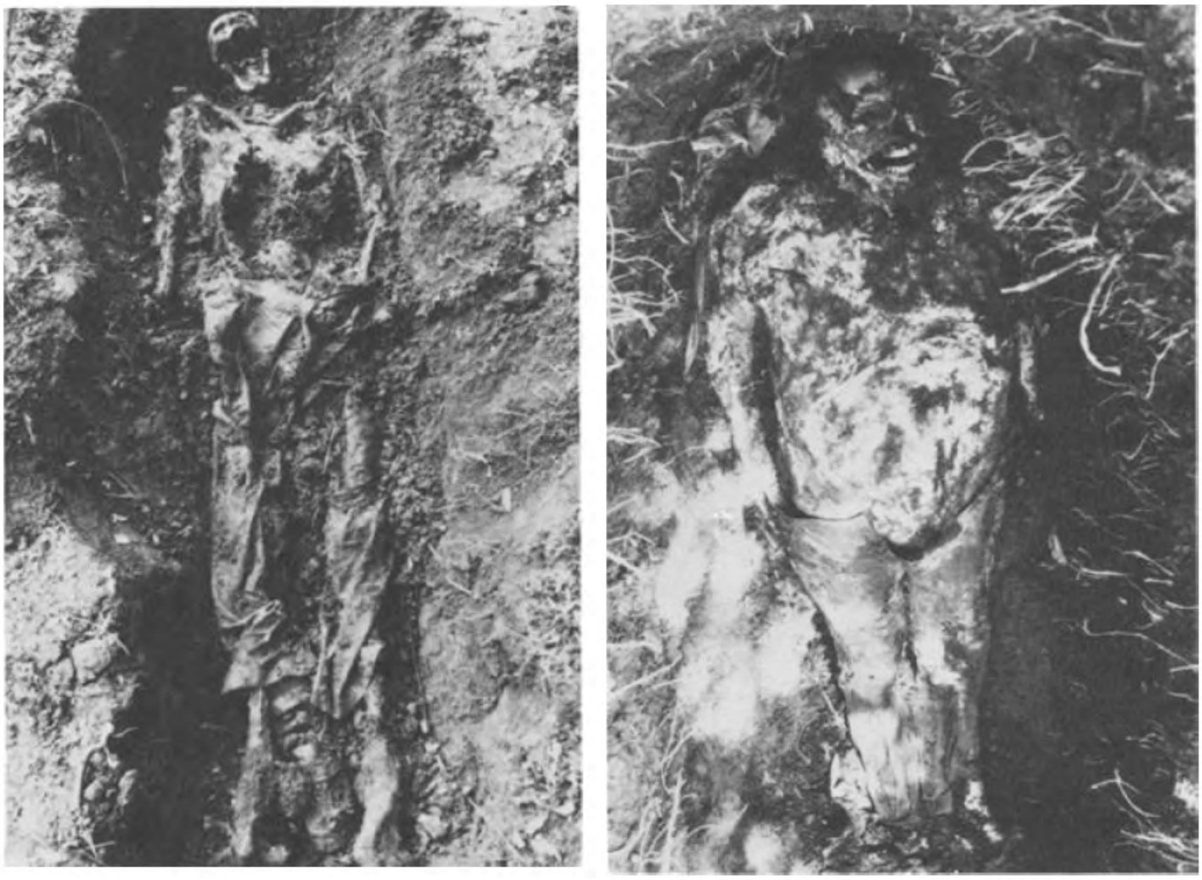

Figure 2. Differences in decomposition with burial depth. The left picture shows an exhumed corpse buried at 0.3 m for 6 months. The right photograph shows an exhumed corpse buried at 1.2 m for 1 year. Source: Rodriquez and Bass (1985).

The longevity of the CDI effect beneath a decomposing cadaver has been much studied in forensic science, especially within the realm of forensic entomology (the study of insect activity in criminal investigations), for the purpose of estimating minimum time since death (TSD) or post-mortem interval (PMI). Some studies have found that the nutrient enrichment associated with the CDI can persist for many years under different climates and soil types. In a temperate forest, nutrient enrichment of calcium, nitrate, potassium and phosphate beneath the surface decomposition of a bison carcass was observed for up to 7 years post-mortem (Melis et al., 2007). A similar effect has also been observed with pig cadavers buried in woodland beneath 10 cm of soil (Hopkins et al., 2000). Increased nutrient values of three times the amount of carbon and 1.4 times the amount of nitrogen of non-grave soil was observed beneath the cadavers 430 days post-burial, albeit in a soil with low microbial activity.

Although the sequence of decomposition of a cadaver is well known, the rate of decomposition varies. There are a number of factors that affect this rate of decomposition. Within soil, several conditions are known to affect the rate of decomposition of buried cadavers. These are; soil temperature, soil moisture and gas diffusivity. Temperature is generally dictated by burial depth whereby soil temperature decreases with depth (Rodriguez and Bass, 1985). Where soil temperature is increased the decomposition rate is quicker. This effect is greater in shallow burial. Gas diffusivity is important to ensure aerobic conditions within which microorganisms can decompose cadavers more efficiently. Coarse (sandy) textured soils have greater gas diffusivity and can facilitate decomposition (Carter et al., 2007). Fine textured soils such as clays have low gas diffusivity and can limit decomposition (Carter et al., 2007). This limited decomposition can result in adipocere formation, a soapy substance created by the bacterial hydrolysis of body fat (Schoenen and Schoenen, 2013). This can potentially persist for decades and has resulted in the need for mass exhumations in Germany in order to speed up decomposition for cemetery reuse (Fiedler et al., 2012). Moisture content needs to be sufficiently low to prevent anaerobic conditions, but also to a degree that can facilitate the movement of microorganisms, nutrients and waste through the soil (Carter et al., 2010). This bio-available moisture is attributed to the suction of water held between particles, with a low suction (such as -0.01 and -0.05 megapascals (MPa)) resulting in more efficient decomposition than a higher suction (-0.3 MPa) (i.e. drier soil). One good example of the impact of anaerobic conditions resulting from high moisture contents is peat bogs, where bodies preserved for thousands of years are often discovered (McGrath, 2013).

A large amount of research exists concerning the soil conditions required for effective decomposition, resulting in the release of nutrients into the soil. However, the current evidence base on the impact of this nutrient addition to soil health and fertility at different depths is limited and inconclusive. Further work is required.

4. How the aerobic decomposition process below ground can be supported or accelerated.

Decomposition below ground is a longer process than above ground. This is a result of the differences associated with soil temperature, oxygen and moisture in the two different environments. It is also a result of limited access to the cadaver by decomposers such as insects and carnivores. A typical burial in optimum soil conditions can decompose a cadaver to a skeleton in 10 to 15 years (Atkinson and Tavner, 2008), although this is known to vary. Bones can then persist for thousands of years (personal communication with Nick Marquez-Grant, 2016).

Insect access is an important part of the decomposition process. Insects ensure the removal of soft tissue and increase the temperature of the cadaver to encourage further microbial decomposition. Burial at 0.3 m depth reduces (but does not prevent) insect or scavenger access to human cadavers (Rodriguez and Bass, 1985). However, this relatively shallow burial increases decomposition as compared to deeper burials at 0.6 and 1.2 m, where insects or scavengers are not present. Exposing the cadaver pre-burial to insects is one way of accelerating the decomposition process. This has been found to enhance the decomposition of rabbits by 30% when left for 5 hours on the soil surface and subsequently buried at 35 cm depth (Bachmann and Simmons, 2010).

The nature of body preparation can support the aerobic decomposition process. Embalming by its very nature seeks to preserve a cadaver in a life-like state. In the UK, 50% of buried bodies are embalmed (Young et al., 2002). The fluid typically consist of 2% formaldehyde solution in water and a red dye, but is increasingly being replaced by a strong saline solution (Young et al., 2002). Embalming has been found to affect the natural sequence of decay (Mann et al., 1990). This was observed with a human cadaver whereby the first area to be removed by maggots was not the face, as is typical, but was instead the lower legs; the face remained intact for up to six months (Mann et al., 1990). However, in that study, the exact concentration of embalming solution was not recorded, and so it is unknown whether this reflects current embalming practices. In the case of natural burials (burials not undertaken in municipal cemeteries), incoming corpses are required to not be embalmed.

Textiles can also affect the rate of decomposition. 100% natural textiles decompose rapidly, but seem to have no effect on the below ground rate of decomposition of the body (Forbes et al., 2005). However, synthetic fabrics, such as polyester, have been found to slow down the rate of decomposition by retaining water, creating an anaerobic layer around the body (Forbes et al., 2005). This has been observed to lead to adipocere formation (Forbes et al., 2005).

Biodegradable coffins made from 100% natural products, including cardboard or woven natural products such as willow and bamboo, are increasingly available and support below ground aerobic decomposition (Figure 3). These will degrade quicker than treated coffins, allowing earlier insect access and quicker decomposition of the cadaver. Non-biodegradable coffins or tombs can both help and hinder decomposition. In anaerobic soils, a coffin can facilitate decomposition as it has a more aerobic environment. In Norway cadavers have been typically wrapped in cling-film for hygiene purposes resulting in no decomposition taking place (Jervell, 2013). These cadavers are now being treated retrospectively, with the addition of lime through surface bore holes to accelerate decomposition rates (Jervell, 2013). An additional benefit to coffin burial could include the carbon content of the coffin fuelling the decomposition process. However, no specific study has been identified that investigates this effect.

Figure 3 Examples of biodegradable coffin options; willow and cardboard. Source: http://www.thegreenfuneralcompany.co.uk/p/coffins

The decomposition process can be accelerated with the addition of carbon-rich bulking agents that address the low carbon: nitrogen ratio and sustain microorganisms during decomposition. This is recommended when composting farm animal cadavers (pigs, poultry, sheep, goats, cattle) and with careful management (turning the compost pile to maintain an optimal composting temperature) can result in decomposition to a brittle skeleton in 180 days (Morse, 2001). This has led to the pioneer of similar processes for human cadaver decomposition in the Urban Death Project (Spade, 2015). Although still in the concept phase, it is believed that the addition of wood chip to a buried human cadaver will result in rapid compost formation (Einhorn, 2015). Let Your Love Grow (2016) is also investigating human decomposition acceleration through the addition of compost. This company is testing the addition of wood chip and an aggressive bacteria to achieve full body decomposition in between 24 and 36 months. In Switzerland, a company exists that accelerates the decomposition of cadavers with adipocere because they are preventing cemeteries reusing graves. In order to do this they wrap the body in biodegradable plastic, re-bury the cadaver in a new location and add a carbon rich material such as wood chip on top of humus and gravel (Aeschlimann, 2006).

The Infinity Burial Project (Coeio, 2016) is developing a decomposition accelerator product that utilises the toxic-cleaning and decomposer properties of edible mushrooms such as shiitake and oyster mushrooms (Figure 4). This is designed to be used in place of a coffin and consists of a cotton suit with a crocheted mesh in which fungal spores will be contained (George, 2011). When buried, the 'mushroom suits' are claimed not only to aid decomposition but also remediate the 200+ toxins that have accumulated in the body (Coeio, 2016). However, no scientific evidence was identified to support these claims.

Figure 4 A prototype mushroom burial suit with representative mushroom mycelium.
Source: https://www.newscientist.com/blogs/culturelab/2011/07/designing-a-mushroom-death-suit.html

Many controllable factors affecting the rate of cadaver decomposition have been identified in scientific literature. Outside of scientific literature, many innovative means that claim to rapidly accelerate decomposition have also been identified. However, scientific investigations are required before any considerations can be made of the product effectiveness.

5. Conclusion

This review suggests that little research has been undertaken on the effect of cremated remains on soil. Therefore their current effect on soil quality and/or functions is unknown. Before further research takes place it is important to investigate the similarities and/or differences between human cremated remains and that of other animals. This will help to inform future research as to the relative applicability of using cremated animal remains as a substitute for cremated human remains.

Findings of this review suggest that published scientific research has focused on the effects of soil on cadaver decomposition rather than the effects of the decomposing cadaver on soil properties. Where the research does extend to investigating the effect of the cadaver on soil, this has been limited to forensic science applications; identifying burial sites and establishing the time since death or time post mortem. This review demonstrates that cadaver decomposition does affect soil properties. However, the extent of this interaction and whether it delivers any benefits to soil and their functions has not been identified in the scientific literature. This leaves the question open as to the effect of different post-mortem body practices on soil properties. Further scientific investigation is required to understand the effect of both decomposing bodies and cremated remains on soil properties, their functions and ultimately the ecosystem goods and services that are delivered by soil.

This literature review has identified several knowledge gaps in which future research could be focused. These are:

- The effect of cremated remains on soil health and fertility.
- The effect of different depths of cadaver burial on soil health and fertility.
- The effectiveness of products marketed to accelerate cadaver decomposition.

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