Earth-Science Reviews 127 (2013) 1–15

Contents lists available at ScienceDirect

Earth-Science Reviews

journal homepage: www.elsevier.com/locate/earscirev

The impact of warfare on the soil environment

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ARTICLE INFO

Article history:
Received 19 June 2012
Accepted 17 August 2013
Available online 9 September 2013

Keywords:
Anthropogenic disturbances
Bombturbation
Pollution
Contamination
Radionuclides
Pedogenesis

ABSTRACT

One of the most dramatic ways humans can affect soil properties is through the performance of military activities. Warfare-induced disturbances to soil are basically of three types – physical, chemical, and biological – and are aimed at causing direct problems to enemies or, more often, are indirect, undesired ramifications. Physical disturbances to soil include sealing due to building of defensive infrastructures, excavation of trenches or tunnels, compaction by traffic of machinery and troops, or cratering by bombs. Chemical disturbances consist of the input of pollutants such as oil, heavy metals, nitroaromatic explosives, organophosphorus nerve agents, dioxins from herbicides, or radioactive elements. Biological disturbances occur as unintentional consequences of the impact on the physical and chemical properties of soil or the deliberate introduction of microorganisms lethal to higher animals and humans such as botulin or anthrax. Soil represents a secure niche where such pathogens can perpetuate their virulence for decades.

Soil morphology, composition, and biology can be profoundly modified by warfare activities in either wartime or peacetime (e.g. at test-firing facilities), and complete recovery of some characteristics can require years or even centuries. A few soil functions can be definitively compromised, if appropriate reclaiming techniques are not carried out. Such techniques often are extremely expensive, as in the case of contamination by dioxins or radionuclides, and remediation can even impel the complete removal of the polluted soil and its substitution with soil material from elsewhere. Taking into account how much of the pedosphere is currently and was in the past involved in warfare, warfare is actually a major means by which humans play a recognized role as a soil forming factor, as well as the parent material, topography, time, climate, and organisms not endowed with the power of reason. The variegated impact of warfare on the soil environment is reviewed here.

Contents

1. Introduction

Humans affect pedogenesis mainly through agricultural activities and urbanization. But, warfare has been an increasing part of human influence on soils. The consequences of this activity on soil properties are significant in many cases, especially in the modern time when weapons have become ever more devastating. The common perception of the impact of war operations is the destruction of the above ground world: ruined cities, disrupted food chains, and the dramatic deterioration of the welfare of survivors (Fig. 1). However, sooner or later towns are rebuilt, forests regrow, food chains are restored, and human welfare is recovered. Yet, the possibility that the environmental and social wounds are repaired depends much on the impact of warfare on the soil quality.

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http://dx.doi.org/10.1016/j.earscirev.2013.08.009

Such an impact, usually negative, ranges from short-term drops in fertility to complete soil loss. Seldom is the legacy of war on soil exploited in original ways, such as in the case of the craters left by US B-52 bombers in Vietnam. Vietnamese people have creatively adapted them to nurseries for fish with systems of dikes and levees (Webster, 1996). There are a few positive effects of military activities on soil, such as the fertilization by nitrogen and phosphorus contained in nitroaromatic explosives or incendiary bombs, or the creation of no-mans lands where the natural succession is allowed. The no man's land between North and South Korea, known as the Demilitarized Zone (DMZ) is now an important reservoir of biodiversity, home to thousands of species on the Korean peninsula (Kim, 1997; Brady, 2012; Shin et al., 2012). A few other cases of positive impacts of war on forest ecosystems and biodiversity hotspots are listed in McNeely (2003) and Hanson et al. (2009). Also in peacetime, shooting ranges are restricted to civilians and it may imply the occurrence of a high biodiversity (Warren et al., 2007). Enlightening examples in this regard are the militarized zones included into the "Natura 2000" network, consisting of a number of sites designated by the Member States of the European Union, under the Habitats and Birds Directives, which because of their particular environmental value, need an appropriate management to maintain a favorable conservation status (Ostermann, 1998). Denmark has included in Natura 2000 45% of its military estate, The Netherlands 50%, and Belgium even 70% (Gazenbeek, 2005). However, much more often the effects of activities of warfare on the environment are negative, in some cases even devastating and lasting for long periods.

At the beginning of the third millennium numerous conflicts were still occurring worldwide (Fig. 2) and the present situation is not much different.

The number of studies dealing with the effects of warfare activities on soil is now enough to be reviewed, although it is unbalanced between individual topics. Our aim is to summarize this sparse knowledge. In the following discussion warfare-induced disturbances to soil are placed into three groups – the physical, the chemical, and the biological – although sometimes they occur contemporaneously.

2. Physical disturbances

Warfare has changed the morphology of soils over millennia, superimposing unnatural features. Physical disturbances of soil by military activities can be very circumscribed in space, but also extend on a regional scale. An example of long-range impact of warfare engineering is the 4000-year-old Great Wall of China, originally of rammed earth and later covered by stones and fired bricks. The 1800-year-old Hadrian's Wall is one of the main examples of the defensive apparatus of the Roman Empire; a continuous fence where Cambisols, Histosols, and Luvisols were packed within a 118 km long and 12 m high anthropogenic hill that cut northern England from coast to coast (Breeze and Dobson, 2000). The 63 km long stone and turf Antonine Wall across southern Scotland is a similar Roman defensive construction. Around AD 1000 Vikings carried out vast movements of soil material to build their ring castles, such as those of Fyrkat and Trelleborg in Denmark (Roesdahl, 1987). More recent examples of impressive earthworks in Northern Europe are the sixteenth–seventeenth-century fortifications at Friedrikstad in Norway, Bourtange in The Netherlands, and Kastellet again in Denmark. Considerable human disturbances to soil for defensive purposes was implied by the wide trench systems on the Western Front in World War I and the antitank ditches constructed in World War II (Rose, 2005). During WWII striking trench systems were also emplaced by civilians for the purpose of saving houses, monuments, or factories from destruction (Fig. 3).

Fig. 1. One of the most expressive dramatic ways humans can affect soil properties is through the performance of military activities. The effect of warfare on soil and the aboveground was effectively depicted in 1919 by Paul Nash in "The Menin Road" (Courtesy of *Imperial War Museum*, London). Warfare-induced disturbances to soil are basically physical, chemical, and biological. Physical disturbances to soil include sealing due to building of defensive infrastructures, excavation of trenches or tunnels, compaction by traffic of machinery and troops, or cratering by bombs. Chemical disturbances consist of the input of pollutants such as oil, heavy metals, nitroaromatic explosives, organophosphorus nerve agents, dioxins from herbicides, or radioactive elements. Biological disturbances occur as unintentional consequences of the impact on the physical and chemical properties of soil or can result from the deliberate introduction of microorganisms lethal to higher animals and humans such as botulin or anthrax.

In excavating for offensive operations or escape attempts some soil material is disturbed or even removed, and the hydrology of the area upset. The most impressive examples of excavation for defensive purposes are perhaps the underground cities constructed ca. 4000 BP by the Hittites in Cappadocia (Caldwell et al., 2004). Examples at Derinkuyu, Kaymakli, Ozkonak, Ozluce, and Tatlarin run hidden for several kilometers at depths from a few centimeters to over one hundred meters (Eastler, 2004). More recent examples of warfare tunneling are documented during the American Civil War at Vicksburg, MS (Eastler, 2004) and Petersburg, VA (Corrigan, 2006) or in the immediate pre-World War II period, in the case of the Maginot Line in France (Hupy, 2005). The net of tunnel in Vietnam testifies to the attempts to vanish easily after guerrilla attacks and avoid capture. In some places, tunnel systems were several stories deep and levels were separated by airtight doors and U-bends in tunnel floors filled with water to stop the spread of gases and impede the shock waves from explosions (Cawthorne, 2003). Such tunnel systems run for hundreds of miles and resulted in the removal or turbation of vast tons of lateritic soil.

The term "cratering" has been inherited from the planetary sciences and indicates the effect of a meteorite impact on a loose surface and essentially consists in the formation of a crater with an uplift border. Cratering in conflicts or troop exercises is caused by bombs and shells. Soil is removed to some extent by the explosion, leaving a pit (Fig. 4). The soil collaring the pit, although remaining in place, is turbated, compacted, and contaminated by metallic fragments and ash. Such a type of soil disturbance has been defined as "bombturbation" and includes the input of the soil removed from the pit to the close proximity (Hupy and Schaetzl, 2006). Like other types of soil turbation, as cryoturbation, vertization, bioturbation (Wilkinson et al., 2009), bombturbation mixes the soil horizons, partly canceling the effects of pedogenesis, but overall changes the landscape; hence resulting in a substantial transformation of the soil forming factor *topography*. Shortly, a thick vegetation invades the bottom of the pits, indicating localized higher soil moisture and, possibly, missing intensive efforts of cattle grazing (Hupy and Koehler, 2012). There, a different pathway of pedogenesis hence occurs, whose first outcome is the formation of thicker litter layers (O horizons) than elsewhere. The bombturbation-induced differentiation of vegetation contributes to different pathways of pedogenesis on contiguous micro lowlands and highlands within the bombed areas. Hupy (2005, 2006) studied long-term effects of bombturbation at the WWI battlefield of Verdun, France, where in 1916, during the opening artillery bombardments the Germans fired ca. 80,000 shells on a 1000 by 800 meter area of the Bois de Caures. At five sites, this author estimated an average cratering of over one-fifth of the total surface. In the onsite Calcisols, less than one century after