ACCUMULATION OF POTENTIALLY TOXIC ELEMENTS IN AGRICULTURAL SOILS

IAIN Green,[*] TILAK Ginige,[**] Merve DEMIR[†] and Patrick VAN CALSTER[‡]

Abstract

Soil health is threatened by many processes associated with intensive agriculture. This study highlights the inadequacies of the current direct and indirect legal instruments to protect soils from one of these threats: the accumulation of potentially toxic elements (PTES). Organic fertilisers are key sources of PTEs and the findings of this study suggest that their current poorly controlled use could damage soil fertility within a time scale measured in decades. This serves as an example of the ineffectiveness of the current legislation to protect soils. If we are to preserve the fragile balance between the human need to exploit our natural capital and maintain the delicate soil ecosystems, it is crucial to adopt a synergetic approach through the application of ecosystem services to halt the deterioration of our Earth.

Keywords: Soil health, potentially toxic elements, metals, ecosystem services, fertiliser, agro-ecosystems

1. INTRODUCTION

Over recent decades, it has become evident that certain anthropogenic influences have drastically changed the composition and organisation of our soil,[1] reducing its ability to function.[2] In addition, this has had a further impact by generating a downward spiral in both organic matter and biodiversity. This has caused an increase in contamination, compaction, salinisation, floods and landslides, which has, therefore, reduced the ability of soil to support life systems.[3] With the world population predicted

[*] Senior Academic in Biological Sciences, Department of Life & Environmental Sciences, Bournemouth University, Convener in Environment & Threats Strategic Research Group.

[**] Senior Academic in Environmental Law and Management, Department of Life & Environmental Sciences, Bournemouth University, Convener in Environment & Threats Strategic Research Group.

[†] PhD Candidate in Environmental Law, Department of Life & Environmental Sciences, Bournemouth University, Researcher in Environment & Threats Strategic Research Group.

[‡] Senior Academic in Criminology, Department of Social Sciences & Social Work, Bournemouth University, Convener in Environment & Threats Strategic Research Group.

[1] *European Commission*, The Implementation of the Soil Thematic Strategy and Ongoing Activities, COM(2012) 46.

[2] *S.M. Rodrigues et al.*, A Review of Regulatory Decisions for Environmental Protection: Part I Challenges in the implementation of national soil policies, Environ. Int. 2009 (35), p. 202.

[3] Id. at p. 1.

to reach 9.7 billion people by 2050,[4] the pressure on soil is going to increase considerably and hence soil conservation is vital to achieving sustainability.

Although in 1996 the Royal Commission for Environmental Pollution (RCEP)[5] acknowledged the need to protect and conserve the sustainability of soil, since then very little has been done to effectively prevent its degradation.[6] Indeed, soil health has failed to capture both society's attention and politicians' interests,[7] which has led some academics to compare its situation to that of "the Cinderella of environmental media",[8] highlighting the lack of attention towards it and its weak legal protection.[9] Moreover, at a global level, the promotion of soil health has repeatedly been overlooked by governments in comparison with other environmental concerns.[10] This seems odd, as the need to maintain healthy soil was known as far back as 1500 BC, with the Vedas Sanskrit Scripture stating, "Upon this handful of soil our survival depends. Husband it and it will grow our food, our fuel and our shelter and surround us with beauty. Abuse it and the soil will collapse and die, taking humanity with it." This acknowledges the underlining the symbiotic relationship between nature and man, where if one suffers, the other suffers as well. Consequently, humanity should act on the need to re-address the value of nature and more specifically soil. There are, as one may suspect, a few hurdles preventing this from happening.

The 19th century development into the industrialised, self-centred, market-based economic model instigated the neglect of the symbiotic relationship between man and nature that ancient wisdom emphasised.[11] This economic model prioritises the need to exploit nature for short-term gains and immediate prosperity,[12] with policy and legislation as its co-conspirator. This had led to an agricultural economy where the introduction of chemicals into the soil is a necessity to guarantee the viability of food production levels.[13] This model may explain why soils have not received the attention they truly deserve in environmental policy and law. This omission intensifies the effects of the global challenge posed by soil degradation, which is one of the most serious threats to ecosystem

---

[4] *UN, Department of Economic and Social Affairs*, Population Division. World Population Prospects: Highlights, ST/ESA/SER.A/423 (2019), p. 5.
[5] *S. Owens*, Knowledge, Policy, and Expertise: The UK Royal Commission on Environmental Pollution 1970–2011, Oxford University Press, 2015, p. 336.
[6] *Royal Commission on Environmental Pollution*, Sustainable Use of Soil – Nineteenth Report, 1996.
[7] *S. Bell*, A Slow Train Coming? Soil Protection Law and Policy in the UK, JEEPL 2006 (3), p. 227.
[8] Id.
[9] Id.
[10] *M.G. Kibblewhite et al.*, Soil Health in Agricultural Systems, Philos. Trans. R. Soc. Lond. B Biol. Sci. 2008 (363), p. 685.
[11] *C.L. Spash*, Bulldozing Biodiversity: The Economics of Offsets and Trading-in Nature, Biol. Conserv. 2015 (192), p. 541.
[12] *N.C. Brady & R.R. Weil*, The Nature and Properties of Soils, 11th ed., Prentice-Hall, 1996.
[13] *E. Plaas et al.*, Towards Valuation of Biodiversity in Agricultural Soils – A Case for Earthworms, Ecol. Econ. 2019 (159), p. 291.

functionality[14] and ultimately sustainability.[15] As Jannes Stolte and colleagues have suggested, extensive degradation leads to a decline in the capability of soil to provide vital functions and ecosystem services (ES).[16] ES are the benefits humans obtain from ecosystems for their survival and well-being such as food production,[17] making the prevention of soil degradation a priority. Food production is considered one of the most important ES provided by agro-ecosystems and 72 per cent of the UK land area is given over to farming.[18] In many parts of the world, maximising food production is still the overriding motivation due to a lack of food security,[19] which seems to be increasingly overlooked. Implementations of ES into economic systems will hopefully lead to the promotion of a more sustainable future. However, developing effective policy measures and effective legal instruments in regards to sustainable ES is proving to be incredibly difficult.[20]

The challenge faced by both scientists and policy makers, therefore, is to find methods to effectively protect soil functionality,[21] whilst at the same time guaranteeing existing economic benefits. This chapter aims to contribute to the debate by critically discussing the weaknesses of both UK and EU soil pollution regulation.

The first part of the chapter will focus on the scientific exploration of soil biodiversity and the threats it faces. The scientific perspective will enable us to better understand the irregularities in current environmental policies and legislation. We will then develop the argument that ES must be taken into consideration in addressing the problems faced by policy makers and legislators.

---

[14] *G.V. Dobrovol'skii & E.D. Nikitin*, Ecological Functions of Soils, Izd. Mosk. Gos. Univ., 1986 [in Russian].
[15] *L.R. Oldeman,* Soil Degradation: A Threat to Food Security, 1998, http://www.isric.org/sites/default/files/isric_report_1998_01.pdf; *K. Adhikari & A.E. Hartemink,* Linking Soils to Ecosystem Services – A Global Review, Geoderma 2016 (262), p. 101.
[16] *J. Stolte et al.*, Soil Threats in Europe: Status, Methods, Drivers and Effects on Ecosystem Services, European Commission Joint Research Centre Technical Reports, European Union, 2016.
[17] *Millennium Ecosystem Assessment*, Ecosystems and Human Well-being: Synthesis, Island Press, 2005.
[18] *United Kingdom National Ecological Assessment (UKNEA)*, Understanding Nature's Value to Society – Synthesis of the Key Findings, 2011; "Enclosure (sometimes inclosure) was the legal process in England of consolidating (enclosing) small landholdings into larger farms. … In England and Wales the term is also used for the process that ended the ancient system of arable farming in open fields": Managing and Owning the Landscape, https://www.parliament.uk/about/living-heritage/transformingsociety/towncountry/landscape/overview/enclosingland/.
[19] *D.S. Powlson et al*., Soil Management in Relation to Sustainable Agriculture and Ecosystem Services, Food Policy 2011 (36), p. 572.
[20] *C.L. Lant et al.,* The Tragedy of Ecosystem Services, Bioscience 2008 (58), p. 969.
[21] *Dobrovol'skii*, *supra*, note 14.

2. SOIL BIODIVERSITY AND THE THREATS TO IT

As soil biodiversity is crucial to soil health,[22] there is a fundamental need to understand biodiversity.[23] In this section, we will first address the manifestation of soil diversity, after which we will look at the threats it has to face.

2.1. SOIL BIODIVERSITY

Soil consists of a range of minerals, such as silica, in differing proportions, a variety of organic matter, chiefly of plant origin, atmospheric gases, water and billions of organisms.[24] Living within the soils are plant roots, viruses, bacteria, fungi, algae, protozoa, mites, nematodes and oligochaete worms.[25] It is estimated that one quarter of all the species on the planet live within the soil.[26] Species abundance, however, varies from soil to soil, depending on organic matter content, pH, soil texture and water content.[27]

Anne Turbe and colleagues[28] have suggested the following classification as a means to better understand how, soil biodiversity. First, there are chemical engineers. These are micro-organisms, such as bacteria, fungi and protozoa.[29] Micro-organisms are major agents by which carbon and energy move though soil food webs, and are responsible for the decomposition of plant organic matter and concomitant recycling of nutrients, which is a fundamentally important process for plant growth. Secondly, biological regulators such as nematodes, pot worms, springtails and mites that feed on plants. Unfortunately, very little is currently known about how these invertebrates contribute to the emergence of soil biodiversity.[30] Soil structure is enhanced by the different organisms within the soil that are considered ecosystem engineers, which impact on the environment physically, chemically and microbiologically.[31] Larger ecosystem engineers, such as oligochaete worms, ants, termites and small mammals, create or modify habitats for smaller soil organisms by building resistant soil aggregates and pores.[32] Earthworms, in particular, are hugely beneficial to the environment and structure of the soil as they produce casts at the soil surface that affect its roughness and the

Commented [RB1]: There seem to be some words missing here – could you please have a look and amend as necessary?

---

[22] *Environment Agency*, The State of Soil in England and Wales, 2004, http://www.adlib.ac.uk/resources/000/030/045/stateofsoils_775492.pdf.
[23] *S. Jeffery et al.*, European Atlas of Soil Biodiversity, Office of the European Union, 2010.
[24] *J. Clapperton*, Managing the Soil as a Habitat, Proceedings of the 2006 Indiana CCA Conference, 2006, https://www.agry.purdue.edu/cca/2006/pdf/clapperton.pdf.
[25] *M. Blouin et al.*, A review of earthworm impact on soil function and ecosystem services, Soil Sci. 2013 (64), p. 161.
[26] *Jeffery*, *supra*, note 23.
[27] *R. Bardgett*, The Biology of Soil: A Community and Ecosystem Approach, Oxford University Press, 2005.
[28] *A. Turbe et al.*, Soil Biodiversity: Functions, Threats and Tools for Policy Makers, Bio Intelligence Service, IRD and NIOO. Report for European Commission (DG Environment), 2010, http://ec.europa.eu/environment/archives/soil/pdf/biodiversity_report.pdf.
[29] Id.
[30] Id.
[31] *Jeffery*, *supra*, note 23.
[32] *Turbe*, *supra*, note 28 at p. 4.

distribution of macrospores.[33] Stephane Boyer and Stephen Wratten[34] have argued that these soil processes are likely to accelerate soil restoration. Indeed, this classification provides a good framework for better management initiatives in preserving soil biodiversity as it highlights critical groups of organisms to be protected. However, there is still insufficient knowledge on the role soil microbes play in the establishment of soil health.[35]

2.2. POTENTIALLY TOXIC ELEMENTS THREATING SOIL BIODIVERSITY

As Simon Jeffery and colleagues argue, there is increased concern with regard to the potential decline of soil biodiversity.[36] Especially within England, there is a high level of potential threats to soil biodiversity, mainly due to inappropriate management practices.[37] These threats are damaging agricultural soils by reducing their functioning capacity through compaction, which in turn lessens water infiltration, eventually increasing soil erosion and surface run off.[38] Soil erosion affects soil biodiversity both directly and indirectly: directly though the removal of soil biota and its habitat, and indirectly through changes in the vegetation, which is linked to biodiversity.[39] Other key impacts caused by inappropriate management, especially in agricultural contexts, are organic matter loss and contaminant accumulation. Soil is a major store of organic matter[40] and its loss reduces soil fertility, which is a key indicator of soil health.[41] A reduction in soil organic matter also results in a decrease in soil organism abundance and diversity.[42] Soil contaminants, such as heavy metals and hydrocarbons, affect soil biota by reducing soil abundance and thus soil biodiversity.[43] Heavy metals, or more appropriately described as potentially toxic elements (PTEs), include zinc (Zn), copper (Cu), nickel (Ni), lead (Pb), cadmium (Cd), chromium (Cr) and mercury (Hg). Some PTEs, such as Zn, Cu, Ni and Cr, are important nutrients, which are required for proper metabolic function, whilst other PTEs, such Cd, Hg and Pb, have no known function. All PTEs, however, can be toxic to soil health

---

[33] *L. Thyug & L.N. Kakati*, Earthworm – The Soil Architect, IOSR-JESTFT 2018 (12), p. 77.
[34] *S. Boyer & S.D. Wratten*, The Potential of Earthworms to Restore Ecosystem Services After Opencast Mining – A Review, Basic Appl Ecol. 2010 (11), p. 196.
[35] *Environment Agency*, *supra*, note 22 at p. 4.
[36] *Jeffery*, *supra*, note 23 at p. 4.
[37] *C. Gardi et al.*, An estimate of potential threats levels to soil biodiversity in EU, Global Change Biol. 2013 (19), p. 1538.
[38] *Department for Environment, Food & Rural Affairs (DEFRA)*, Safeguarding Our Soils – A Strategy for England, 2009, https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69261/pb13297-soil-strategy-090910.pdf.
[39] *Jeffery*, *supra*, note 23 at p. 4.
[40] *B. Bolin et al.*, The Global Perspective, in R.T. Watson, I.R. Nobel & B. Bolin (eds.), IPCC Special Report on Land Use, Land-Use Change And Forestry, Cambridge University Press, 2001.
[41] *Kibblewhite*, *supra*, note 10 at p. 2.
[42] *Jeffery*, *supra*, note 23 at p. 4.
[43] Id.

if the detoxification systems at the organism or cellular level are overwhelmed by the concentration of PTEs the organism is exposed to.[44] These PTEs enter the agro-ecosystem through a variety of sources, such as animal manures, sewage sludge, pesticides, fertilisers and depositions from air and water.[45] Contamination occurs when PTEs are introduced to the environment in amounts that increase the natural levels in the soil. Over time, this may impose serious health problems for soil organisms, plants and thus the people and livestock that feed on the plants.[46] These elevated concentrations of PTEs can be sustained for very long periods.[47] The half-life of a PTE varies among the different elements; Cd, Ni and Zn remain in soils for a relatively shorter time in comparison to Pb and Cr.[48] However, for all PTEs, half-lives are measured in hundreds of years. Furthermore, PTEs are difficult to remove completely as soil has a natural ability to retain metals.[49] Due to their toxicological impact on ecosystems, agriculture and human health,[50] the reduction of heavy metals in soils has been made a strategic aim by the UK.[51] Before we explore the control of PTEs, we would like to delve further into the way PTEs endanger soil health.

2.3. SOILS AND POTENTIALLY TOXIC ELEMENTS

Soil fertility depends on ecosystem processes within the soil, especially those driving the provision of nutrients into crop-available forms. These processes are largely driven by the action of soil micro-organisms. The three main microbially mediated processes delivering nutrients to plants are: decomposition of organic matter and concomitant release of plant-available nutrients;[52] fixation of

---

[44] *M. Braungart et al.*, Cradle-to-cradle design creating healthy emissions – a strategy for eco-effective product and system design, J. Clean Prod. 2006 (15), pp. 1337–1348.

[45] *F.A. Nicholson et al.*, Quantifying heavy metal inputs to agricultural soils in England and Wales, Water Env. J. 2006 (20), p. 87.

[46] *V. Grubinger & D. Ross*, Interpreting the results of soil tests for heavy metals, 2011, https://www.uvm.edu/vtvegandberry/factsheets/interpreting_heavy_metals_soil_tests.pdf.

[47] *P.C. Brookes*, The use of microbial parameters in monitoring soil pollution by heavy metals, Biol. Fert. Soils 1995 (19), p. 269.

[48] *B.J. Skinner et al.*, Dynamic Earth – An introduction to Physical Geology, John Wiley and Sons, 2004; *S. Dudka & D.C. Adriano*, Environmental impacts of metal ore mining and processing: a review, J. Envi. Qual. 1997 (26), p. 590.

[49] *R. Sanghi & K.S. Sasi*, Pesticides and heavy metals in agricultural soil of Kanpur, India, Bull. Env. Contam. Toxicol. 2001 (67), p. 446.

[50] *L. Popescu & A. Stanca*, Monitoring of heavy metals soil contents in the area of thermal power plants in Romania, Proc. World Acad. Sci. Eng. Technol. 2008 (46), p. 382.

[51] *DEFRA*, The First Soil Action Plan for England: 2004–2006, 2004, https://webarchive.nationalarchives.gov.uk/20081023175603/http://www.defra.gov.uk/environment/land/soil/pdf/soilactionplan.pdf; *European Commission*, Communication from the Commission to the Council, the European Parliament, the Economic and Social Committee and the Committee of the Regions – Towards a Thematic Strategy for Soil Protection, COM(2002) 179.

[52] *D.B. Alexander*, Bacteria and Archaea, in D.M. Sylvia et al. (eds.), Principles and Applications of Soil Microbiology, 2nd ed., 2005, pp. 101–140.

atmospheric nitrogen (N);[53] and acquisition of nutrients from the soil for plants by fungal symbionts.[54] The decomposition of organic matter is driven by free-living micro-organisms in the soil and specifically in agricultural soils bacteria are mainly responsible for this process. The fixation of N and direct acquisition of nutrients are both largely driven by symbiotic relationships between plants and micro-organisms. Fixation of atmospheric N is achieved by bacteria of the *Rhizobium* and *Frankia* genera, which form nodules in the roots of plants belonging to members of several families and most notably the *Fabacea* (e.g. field peas, broad beans, etc.). The fixed N provided to the plant reduces the need for fertiliser inputs and leakage of the fixed N into the soil surrounding the roots can supply N to subsequent crops not involved in the symbiosis. Over 80 per cent of terrestrial plant genera form symbiotic relationships with soil-dwelling mycorrhizal fungi to acquire part of their nutrients, especially phosphorus.[55] Mycorrhizal fungi breakdown organic matter, releasing nutrients and passing them on there their plant hosts and receive carbon (C) sources from the plant in return.[56] This relationship is less important in intensive agriculture because the nutrient demands of modern crop cultivars are met through the use of inorganic fertilisers. However, the mycorrhizal relationship may be of greater importance in less intensive agriculture, where it potentially plays an important role in nutrient acquisition, particularly in the future as sources of phosphorus for fertiliser production become limited.

Commented [RB2]: As phosphorus is only referred to twice in the chapter (the other time being earlier in this paragraph), I have suggested using the full term here rather than the chemical symbol to keep things simple for the reader.

In the UK, the concentration limits for PTEs applied by the EU laws were reviewed to ensure soil fertility was protected.[57] It was agreed that the limits set for the concentration of Zn in soil were insufficient to protect some aspects of the fertility pertaining to soil micro-organisms, especially *Rhizobium* spp. and possibly mycorrhizal fungi. The recommendation of the review was to lower the limits of Zn from 300 mg kg^{-1} to 200 mg kg^{-1} for soils with a pH<7.0.[58] Further, a series of field experiments demonstrated that where soil Zn concentrations have been elevated by sewage sludge additions, the mean probable number (a statistical estimate of the number of micro-organisms in a substance) of *Rhizobium* in the soil was significantly decreased and in some instances, no *Rhizobium* were detectable.[59] Significant decreases in the soil microbial biomass carbon have also been shown at or close to the limit concentrations for both Cu and Zn, indicating that wider change in the soil

[53] *P.H. Graham*, Biological dinitrogen Fixation: Symbiotic, in D.M. Sylvia et al. (eds.), Principles and Applications of Soil Microbiology, 2nd ed., 2005, pp. 405–432.
[54] *S.E. Smith & D.J. Read*, Mycorrhizal symbiosis, 3rd ed., Academic Press, 2008.
[55] Id. at pp. 145 et seq.
[56] Id.
[57] *MAFF/DoE*, Review of the Rules for Sludge Application to Agricultural Land: Soil Fertility Aspects of Potentially Toxic Elements: Report of the Independent Scientific Committee, MAFF/DoE, 1993.
[58] Id.
[59] *UK Water Industry Research (UKWIR)*, Effects of sewage sludge applications to agricultural soils on soil microbial activity and the implications for agricultural productivity and long-term soil fertility: Phase III, October 2007, Report Ref: SP0130; CSA 6222.

microbial community can also occur.[60] This work has also shown that Cu and Zn affect the soil microbiology at lower concentrations than the more notoriously toxic element Cd.[61] These findings clearly demonstrate both the potential for Cu and Zn to detrimentally affect soil health through their impact on soil micro-organisms and that the current limits on Cu and Zn concentration in sewage sludge amended soil represent a value beyond which Cu and Zn accumulation should not be allowed to pass.

Let us now address the way PTEs are controlled by both UK and the EU regulation.

3. CONTROLS ON POTENTIALLY TOXIC ELEMENTS

Up to now, we have been discussing the threats to soil, focusing on PTEs, specifically Cu and Zn. To truly appreciate the gravity of the situation, we will now turn our focus on the use of organic by-products such a sewage sludge and animal manures/slurries as fertilisers,[62] which are applied to the UK's agricultural landscape.[63]

3.1. ORGANIC BY-PRODUCTS

Sewage sludge is formed during the process of initial settlement treatment of wastewater. The solids falling out of the water column are collected and transferred to an anaerobic digester for treatment. Once treated, sludge is a significant source of plant nutrients and organic matter,[64] rendering it a valuable fertiliser and soil conditioner and thus creating a product suitable for beneficial use in agriculture.[65] The bulk of PTEs in the wastewater are associated with the solid phase[66] and hence sewage sludge is enriched with PTEs. The agricultural use of sewage sludge is controlled by the Sewage Sludge Directive,[67] which sets out how it should be used in agriculture; incorporating protection to soil; focusing on the known threats of PTE contamination;[68] covering record keeping, soil and sludge testing requirements, and maximum contaminants concentration in sludge and soil; with requirements for treatment and timing of application.

---

[60] *D.A. Abaye et al*., Changes in the microbial community of an arable soil caused by long-term metal contamination, Euro J. of Soil Sci. 2005 (56), p. 93.
[61] Id.; UKWIR, *supra*, note 59.
[62] *L.H. Moss et al.*, Evaluating Risks and Benefits of Soil Amendments Used in Agriculture, Water Environment Research Foundation, 2002.
[63] Id.
[64] *B.J. Alloway*, Heavy Metals in Soils, 2nd ed., Springer, 1995.
[65] *DEFRA*, Fertiliser Manual (RB209), http://www.defra.gov.uk/publications/files/rb209-fertiliser-manual-110412.pdf.
[66] *S.P. McGrath et al*., Land application of sewage sludge: scientific perspectives of heavy metal loading limits in Europe and the United States, Environ. Rev. 1994 (2), p. 108.
[67] Council Directive 86/278/EEC of 12 June 1986 on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture, OJ 1986 L 181/6 (Sewage Sludge Directive).
[68] *A. Charlton et al*., Long-term impact of sewage sludge application on soil microbial biomass: An evaluation using meta-analysis, Environ. Pollut. 2016 (219), p. 1021.

However, as Cieślik and colleagues have suggested, there are concerns that large amounts of harmful chemical compounds that may occur in processing of sewage sludge lie outside the control of current established legal regulations.[69] Furthermore, EU regulations allow Member States to put limits on organic contaminants in reaction to public concerns rather than scientific research[70] where the latter would ideally be the starting point for environmental policy.[71][72][73] The UK government implemented the Sewage Sludge Directive untouched,[74] in the midst of ongoing legal research and debates which saw proposed amendments translated into guidance.[75] It was felt that agricultural land was the best disposal route and that the legal controls in place were sufficient to manage the hazards[76] from a risk assessment perspective.[77] Sludge quality is ensured by controlling inputs and treatment.[78][79] Organic wastes are in the main seen as an energy resource resulting in marketisation, which causes legal uncertainty for combined waste streams and potentially creating loopholes.[80]

To secure quality, sludge analysis is required to be performed every six months, and more frequently where composition varies significantly. However, a lack of clear definition makes enforcement of the procedure highly problematic.[81] Similarly, soil testing is required every 20 years; however, it commonly occurs every three to five years to inform nutrient management planning.[82] There is an

Commented [RB3]: Intersentia house style generally aims to avoid consecutive footnotes, as here. Since each footnote only contains one citation, would it be possible to combine them into a single footnote?

If this amendment is made, footnote cross-references would need to be updated in the rest of the chapter.

Commented [RB4]: Have I understood this correctly? I have suggested specifying which Directive this is referring to as it was otherwise a little unclear in the context.

Commented [RB5]: As above, would it be possible to combine these into one footnote?

---

[69] *B.M. Cieślik et al.,* Review of sewage sludge management: standards, regulations and analytical methods, J. Clean Prod. 2015 (90), p. 1.

[70] *K. Jones & J. Stevens*, Organic Contaminants in Sewage Sludge Applied to Agricultural Land: A Critical Evaluation of the Proposed Limit Values for Organics in the EU Working Document on Sludge and Development of a Tiered Screening Process to Identify Priority Pollutants in Sewage Sludge, UK Water Industry Research, 2002, https://www.ukwir.org/reports/02-SL-04-2/66964/Organic-Contaminants-in-Sewage-Sludge-Applied-to-Agricultural-Land

[71] *G. Mininni et al.*, EU policy on sewage sludge utilization and perspectives on new approaches of sludge management, Environ. Sci. Pollut. Res. 2015 (22), p. 7361.

[72] The Sludge (Use in Agriculture) Regulations 1989, SI 1989/1263.

[73] *A. Christodoulou & K. Stamatelatou*, Overview of legislation on sewage sludge management in developed countries worldwide, Water Sci. Technol. 2016 (73), p. 453.

[74] The Sludge (Use in Agriculture) Regulations, *supra*, note 72.

[75] *B. Crathorne et al.,* Implementation of HACCP controls under the new Sludge (Use in Agriculture) Regulations, in Proceedings of CIWEM/Aqua Enviro 7th European Bio Solids and Organic Residuals Conference, 18–20 November 2002.

[76] *DEFRA*, Review of Research on Recycling of Sewage Sludge to Agricultural Land, 2006 <http://sciencesearch.defra.gov.uk/Document.aspx?Document=WT03051_4104_FRP.doc

[77] *R.D. Davis*, The impact of EU and UK environmental pressures on the future of sludge treatment and disposal, Water Environ. J. 1996 (10), p. 65.

[78] *H. Kirchmann et al.,* From agricultural use of sewage sludge to nutrient extraction: A soil science outlook, Ambio 2017 (46), p. 143.

[79] *I. Thornton et al.,* Pollutants in urban waste water and sewage sludge – Final report prepared for European Commission Directorate-General Environment, European Commission, 2001, http://ec.europa.eu/environment/archives/waste/sludge/pdf/sludge_pollutants_2.pdf

[80] *OFWAT*, The Fifth Sludge Working Group Meeting, 2016 https://www.ofwat.gov.uk/wp-content/uploads/2016/08/sludge-working-group-consolidated-slides-20160720.pdf

[81] *P.H.T. Beckett*, The Statistical Distribution of Sewage and Sludge Analyses, Environ. Pollut. (Series B), 1980 (1), p. 27.

[82] *DEFRA*, Sewage Sludge on Farmland: Code of Practice for England, Wales and Northern Ireland, 2017, https://www.gov.uk/government/publications/sewage-sludge-on-farmland-code-of-practice/sewage-sludge-on-farmland-code-of-practice#sludge-treatment.

ongoing debate as to whether this is sufficient, as soil parameters including heavy metal concentration do not vary between applications.[83] However, 10 years of repeated application have brought to the surface several adverse effects.[84] Although guidance regarding sampling depth and limits was updated, it was not translated into law. Research indicates that concentrations of metals are misleading as they may be affected by underlying geology, and the bioavailability (and therefore toxicity) of metals is not necessarily reflected by the total concentration. Moreover, metal toxicity can increase with time after sludge application as the protective effect of organic matter diminishes (the "sludge time bomb"); therefore care is required in determining safe thresholds.[85] Metals in sewage sludge can also increase environmental damage from pesticides so other factors should be considered.[86] This clearly calls for regular monitoring in support of current government policy,[87] which in turn will improve scientific understanding of long-term effects, as well as the emerging pollutants and farmers' understanding of their soil.

As discussed above, when used as fertiliser, manures can also damage soil, if not managed responsibly. However, direct legislation is lacking. Metals such as Zn, Cu and arsenic (As) are added to animal feed as antimicrobial and bulking agents, especially in intensive pig and poultry systems. Application of manure from these sources negatively affects soil health,[88] being implicated in antibiotic resistance[89] and increased pesticide toxicity.[90] This is in the face of Soil Association

Commented [RB6]: Could you please check and confirm that the page reference at the end of this footnote is correct (as it seems on the higher side)?

[83] *A. Cundill et al.,* Review of the application of organic materials to land, Natural Scotland and SEPA, 2012, https://www.sepa.org.uk/media/163500/review_application_-organic_materials_to_land_2011_12.pdf.
[84] *B.J. Chambers et al*., Effects of sewage sludge applications to agricultural soils on soil microbial activity and the implications for agricultural productivity and long-term soil fertility: Phase III – SP0130; CSA 6222 DEFRA, 2007, https://randd.defra.gov.uk/Document.aspx?Document=SP0130_6505_FRP.pdf
[85] *M.B. McBride*, Toxic metal accumulation from agricultural use of sludge: are USEPA regulations protective?, J. Environ. Qual. 1995 (24), p. 5/
[86] *R.P. Singh & M. Agrawal*, Potential benefits and risks of land application of sewage sludge, Waste Manage. 2008 (28), p. 347.
[87] *B. Petri et al.,* A review on emerging contaminants in wastewaters and the environment: current knowledge, understudied areas and recommendations for future monitoring, Water Res. 2015 (72), p. 3.
[88] *W. Tian et al.,* Short-term changes in total heavy metal concentration and bacterial community composition after replicated and heavy application of pig manure-based compost in an organic vegetable production system, Biol. Fert. Soils 2015 (51), p. 593.
[89] *Y. Kang et al*., High diversity and abundance of cultivable tetracycline-resistant bacteria in soil following pig manure application, Scientific Reports 2018 (8), p. 1489; *S. Peng et al.,* Prevalence of antibiotic resistance genes in soils after continually applied with different manure for 30 years, J. Hazard. Mat. 2017 (340), p. 16; *M. Wang et al.,* Fate of antimicrobial resistance genes in response to application of poultry and swine manure in simulated manure-soil microcosms and manure-pond microcosms, Environ. Sci. Pollut. Res. 2017 (24), p. 20949.
[90] *Y.X. Chen et al*., Behavior of Cu and Zn under combined pollution of 2, 4-dichlorophenol in the planted soil, Plant and Soil 2004 (261), p. 127; *B. Sharma et al.,* Synergistic effects of heavy metals and pesticides in living systems, Front. Chem. 2017 (5), p. 70.

standards[91] prohibiting usage of these elements and the progressive tightening of limits.[92] However, these elements can still be prescribed separately to treat infections,[93] thus polluting the soil.

Levels of heavy metals and other pollutants are regulated through the concentration in food,[94] although this is not necessarily reflected in soil or manure concentration. Additionally, there are voluntary soil concentrations of Zn and Cu to provide warnings when using manure, whilst mandatory limits remain only a recommendation for all organic fertilisers.[95] Moreover, determining responsibility for contamination is ambiguous except in the case of on-site manure application. The code of practice states that it is the sludge producer's responsibility, according to the "polluter pays" principle, in line with the Waste Framework Directive,[96] but it is not explicit. Furthermore, complications could arise where multiple producers supply a farm. In this scenario, the farmer is responsible for ensuring sludge comes from a reputable source and must keep his accounts up to date concerning, for example, imports and exports of sludge and the usage of all fertilisers. Furthermore the possibility still exist for the landowner to be prosecuted as the liability rests with the owner if they "knowingly permitted" contamination.[97] Finally, these procedures do not eliminate the problem of identifying the sources of pollution and it could lead to a lack of trust in environmental protection legislation and may cause financial problems to businesses as the true source goes unnoticed.

[91] *Soil Association*, Soil Association organic standards farming and growing, 2016, https://www.soilassociation.org/what-we-do/organic-standards/our-standards/.

[92] Commission Implementing Regulation (EU) No. 2016/1095 of 6 July 2016 concerning the authorisation of Zinc acetate dihydrate, Zinc chloride anhydrous, Zinc oxide, Zinc sulphate heptahydrate, Zinc sulphate monohydrate, Zinc chelate of amino acids hydrate, Zinc chelate of protein hydrolysates, Zinc chelate of glycine hydrate (solid) and Zinc chelate of glycine hydrate (liquid) as feed additives for all animal species and amending Regulations (EC) No. 1334/2003, (EC) No. 479/2006, (EU) No. 335/2010 and Implementing Regulations (EU) No. 991/2012 and (EU) No. 636/2013, OJ 2016 L 182/7; Commission Regulation (EC) No. 1334/2003 of 25 July 2003 amending the conditions for authorisation of a number of additives in feeding stuffs belonging to the group of trace elements, OJ 2003 L 187; *G. Aquilina et al.*, Revision of the currently authorised maximum copper content in complete feed EFSA Panel on Additives and Products or Substances used in Animal Feed (FEEDAP), EFSA Journal 2016 (14), p. 4563.

[93] *F.A. Nicholson & B.J. Chambers*, Sources and impacts of past, current and future contamination of soil Appendix 1: Heavy Metals. Final Report to DEFRA, 2007, http://randd.defra.gov.uk/Document.aspx?Document=SP0547_7265_FRA.pdf.

[94] Commission Regulation (EC) No. 1334/2003 of 25 July 2003 amending the conditions for authorisation of a number of additives in feeding stuffs belonging to the group of trace elements, OJ 2003 L 187; Commission Regulation (EC) No. 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs, OJ 2006 L 364; Commission Regulation (EC) No. 629/2008 of 2 July 2008 amending Regulation (EC) No. 1881/2006 setting maximum levels for certain contaminants in foodstuffs, OJ 2008 L 173.

[95] *Cundill et al.*, *supra*, note 83.

[96] Commission Directive 2008/98/EC of the European Parliament and of the Council of 19 November 2008 on Waste and Repealing Certain Directives, OJ 2008 L 312/3.

[97] The Environmental Permitting (England and Wales) Regulations 2016, SI 2016/1154, ss. 12 and 38.

3.2. LEGISLATION AND ORGANIC FERTILISERS

Large amounts of animal faecal wastes are applied to agricultural land in the UK,[98] both to dispose of this by-product of animal husbandry and to derive fertiliser value from the essential micro- and macro-elements they contain.[99] It is well known that farmers have supplemented soils with animal manures/slurries for more than 2,000 years in order to increase crop yields, provide plant nutrients, and to enrich soils.[100] However, it can also elevate levels of PTEs, including Cu and Zn, which in the long term may lead to undesirably high levels in the soil[101] and detrimental health effects, as discussed above. Nicholson et al.[102] estimated that 2,000t of Zn is spread onto agricultural land from animal manures each year, while in the total agricultural area of England and Wales, livestock manures are responsible for around 40 per cent of the total input of Zn. It is therefore not surprising that, with current large-scale livestock production and increasing globalisation, there is a growing need to protect soil health, especially with regard to the food chain. Although there are measures that set limits for levels of heavy metals found in animal feed, they are regulated in a very indirect way. Directive 2002/32/EC of the European Parliament and of the Council of 7 May 2002[103] on undesirable substances in animal feed provides for the maximum allowable concentration in feeding stuff of elements such as As, Cd, Pb and Hg. Other legislation that indirectly protects the soil from contamination due to animal manure is the Commission Regulation (EC) No. 1881/2006 of 19 December 2006,[104] setting the maximum levels for certain contaminants in foodstuffs. Nicholson and Chambers found that reducing levels of Zn and Cu in livestock feeds would substantially reduce manure Zn and Cu concentration and decrease inputs to agricultural land and loadings to individual feeds.[105] The EU Animal By-products Regulation[106] applies a light touch to the use of manure and digestive tract content, and seeks to control its use only where necessary. The transposition of the EU law in the UK through the Animal By-products Regulations 2013[107] makes provision for the administration and enforcement of the Regulation in England but it is silent on levels of soil

Commented [RB7]: I have suggested this to avoid repetition of 'increasing' in the same sentence.

Commented [RB8]: Just to clarify, does this refer to Regulation 1881/2006, above?

---

[98] *F.A. Nicholson et al.*, A study on farm manure applications to agricultural land and an assessment of the risks of pathogen transfer into the food chain, A Report to the Ministry of Agricultural Fisheries and Food, 2000.
[99] *A.A. Araji et al.*, Efficient use of animal manure on cropland – economic analysis, Bioresour. Technol. 2001 (79), p. 179.
[100] *Moss*, *supra*, note 62 at p. 8.
[101] *DEFRA*, *supra*, note 65 at p. 8.
[102] *Nicholson*, *supra*, note 45 at p. 6.
[103] Commission Directive 2002/32/EC of the European Parliament and of the Council of 7 May 2002 on undesirable substances in animal feed, OJ 2002 L 140/10.
[104] Commission Regulation (EC) No. 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs, OJ 2006 L 364/5.
[105] *Nicholson*, *supra*, note 93 at p. 11.
[106] Commission Regulation (EC) No. 1069/2009 of the European Parliament and of the Council of 21 October 2009 laying down health rules as regards animal by-products and derived products not intended for human consumption and repealing Regulation (EC) No. 1774/2002, OJ 2009 L 300/1.
[107] The Animal By-Products (Enforcement) (England) Regulations 2013, SI 2013/2952.

improvers. It suggests significant gaps in the EU and UK legislation in regards to animal manures and inorganic fertilisers.

3.3. INORGANIC FERTILISERS

There has been an increase in the use of inorganic fertilisers, which are essentially synthetic chemicals that help to supply the plants with the nutrients required, promoting plant growth when applied to agricultural soils. Currently Regulation (EC) No. 2003/2003 of the European Parliament and of the Council of 13 October 2003 related to fertilisers does not provide for heavy metal limits associated with inorganic fertilisers, even though they have known to have serious impacts.[108] It follows from the above that the UK has no specific limits on heavy metals in animal manures and inorganic fertilisers, and that the country's agro-ecosystem is inadequately protected.

The EU Commission Regulation setting maximum levels for certain contaminants in foodstuffs (No. 1881/2006)[109] represents an "end of pipe" regulation by setting a limit on the concentration of selected metal PTEs (Cd, Hg, Pb and Sn) in foodstuffs. This may have the consequence of protecting the food produced by rendering a crop unsalable if PTE levels have reached concentrations exceeding statutory limits. However, end of pipe control is of dubious efficacy in protecting soil fertility due to the disconnect between produce and soil concentrations, i.e. safe food can potentially be produced from polluted soil. Other aspects of soil health are dealt with sporadically through 24 European Union laws that in some way address elements of soil "contamination" in the relation to air, water, waste, chemicals, impact assessment and environmental liability.[110] For example, the Water Framework Directive (2000/60/EC)[111] seeks to achieve good ecological status of water resources/bodies, thus indirectly mitigating soil health through reduced erosion, runoff, phosphate and nitrate levels. While the Common Agricultural Policy seeks to reduce erosion and maintain organic matter and structure, it only provides guidelines to avoid contamination, which are typically in line with existing legislation. Other sources of Cu and Zn within agro-ecosystems can be applied through the addition of composted "wastes", which are controlled through a voluntary code of conduct that details heavy metal concentrations. Separated biodegradable wastes "compost" is controlled in England and Wales by BSI PAS 100,[112] which sets target concentrations and upper limits for metals, including Cu and

[108] Commission Regulation (EC) No. 2003/2003 of the European Parliament and of the Council of 13 October 2003 Relating to Fertilisers, OJ 2003 L 304/1.
[109] Commission Regulation (EC) No. 1881/2006 of 19 December 2006 setting maximum levels for certain contaminants in foodstuffs, OJ 2006 L 364/5.
[110] *Rodríguez*, *supra*, note 2 at p. 1.
[111] Commission Directive 2000/60/EC of the European Parliament and of the Council of 23 October 2000 establishing a framework for Community action in the field of water policy, OJ 2000 L 327/1.
[112] WRAP, The Waste and Resources Action Programme, BSI PAS 100 FAQs, 2016, http://www.wrap.org.uk/collections-and-reprocessing/organic-waste/composting/guidance/BSI-PAS-100-FAQs

Zn, that can be applied without permit. Although this standard is targeted at the horticultural industry, there is opportunity for small holders to use such fertiliser material. Another source for concern has to do with the Environmental Permitting Regulations 2016[113] and its amendments, which permits the application of waste where it can be shown that there is an agricultural benefit or ecological improvement. There is a possibility that this waste could contain high levels of PTEs.

3.4. THE POTENTIAL FOR ORGANIC FERTILISERS TO HARM SOILS

The lack of legal controls on the addition of PTEs to soil in forms other than sewage sludge clearly leaves soil health vulnerable. Amongst the chemicals categorised as PTEs, Cu and Zn are the least controlled and have the greatest potential to affect soil health and fertility due to their potential to cause toxicity to important soil microbes at relatively low concentrations. Whilst organic by-products such as manures have a sufficient nutrient content to act as fertilisers and can replace lost organic carbon from the soil, they can also contain significant levels of Cu and Zn.[114]

The authors therefore estimated the time required for the application of these materials to raise the concentration of Cu and Zn in an average agricultural to the levels enshrined in the Sewage Sludge Directive. Calculations were based on the mean metal concentrations for rural soils in the UK[115] and the mean bulk density (1.24 g cm^{-3}) for arable soils in England and Wales.[116] Metal concentrations in organic by-products used to derive the estimates were those reported by Nicholson et al. (2006)[117] and the assumption was made that the organic fertiliser was evenly distributed throughout a plough layer 25 cm deep. Applications of organic fertilisers are limited to 180 kg N ha^{-1} yr^{-1} in nitrate vulnerable zones and 250 kg N ha^{-1} yr^{-1} outside these zones. Consequently, estimates were made at both N application rates using the values for N content quoted by MAFF[118] to determine the amount of each organic fertiliser that represented the appropriate N application. A dry matter content of 6 per cent and a specific gravity of 1.038 was assumed for dairy slurry, whilst the respective values for pig slurry were 4 per cent and 1.026.

[TYPESETTER: Please insert TABLE 1 here]

Commented [RB9]: As requested by Intersentia, I have changed all personal pronouns referring to the author to the third person throughout the chapter.

I have also suggested beginning a new paragraph here, as the paragraph was otherwise very long.

---

[113] The Environmental Permitting (England and Wales) Regulations 2016, SI 2016/1154.
[114] *Nicholson*, *supra*, note 45 at p. 6.
[115] *Environment Agency*, UK soil and herbage pollutant survey – UKSHS Report No. 1, 2007.
[116] *Environment Agency*, The development and use of soil quality indicators for assessing the role of soil in environmental interactions – Science Report SC030265, 2006.
[117] *Nicholson*, *supra*, note 45 at p. 6.
[118] *MAFF*, Fertiliser recommendations for agricultural crops and horticultural crops (RB209), 7th ed., The Stationary Office, 2000.

The result of these calculations demonstrated that sewage sludge application could most rapidly increase soil concentrations of both Cu and Zn to limit values and therefore the level at which soil microbial process important to fertility may be affected. However, pig manure may increase soil Cu concentrations slightly quicker than sewage sludge (Table 1). The time taken for dairy and pig slurries to raise soil Cu concentrations to the limit value can also come close to sewage sludge if the most contaminated slurries are applied at a high rate. Where organic fertilisers have a mean concentration of Zn, pig manure is again the only fertiliser that is close to sewage sludge in ability to increase soil concentrations (Table 2). However, dairy, layer and broiler manure can also increase soil Zn concentrations at rate that could lead to limit values being reached within a time scale short enough to suggest that their application could impact soil quality. When organic fertilisers with high concentrations of Zn are considered, pig slurry and manure could potentially raise the Zn concentration in an "average" soil to the limit value within a human lifetime. Moreover, dairy slurry, dairy manure, layer manure and broiler manure could potentially raise soil concentrations to the limit value within 200 years.

[TYPESETTER: Please insert TABLE 2 here]

The scenarios used in these calculations are not unrealistic. For example, maximal applications of dairy manure/slurry are applied to soil to drive maize production to feed to cows and the need to dispose of manures/slurries frequently requires their application at the maximum permission N loading rate. Moreover, whilst organ manures are frequently applied annually, sewage sludge amendments are typically made every third year. Consequently, the use of organic fertilisers can elevate soil Cu and Zn concentrations with similar, and in some case higher, rates than sewage sludge. However, the extent of the problem of PTE enrichment in European soils is not well researched and there is a very real risk that soil health could to be damaged within a human lifetime.

Commented [RB10]: Should this read 'organic manures'?

It is clear that the application of manures/slurries can elevate soil PTE concentrations in the plough layer to levels that could affect the functionality of the microbial soil community, which in turn will have a negative impact soil health and fertility. Thus, current agricultural practices are not compatible with sustainable food production and lowered crop production may occur in a time scale as short as decades. To date, legal controls on the accumulation of PTEs, particularly from the use of organic by-products, are insufficient to prevent this and urgent action is required to address this.

It is surprising, therefore to realise that currently there are no specific legislative controls on the accumulation of PTEs applied to agricultural soils via animal manure and inorganic fertilisers. Sewage sludge indicator pathogen concentrations are regulated, but no such regulations exist for manures. Furthermore, Regulation (EC) No. 2003/2003 of the European Parliament and of the Council of 13 October 2003 relating to fertilisers[119] does not provide for heavy metal limits.

At this point, we may perhaps introduce a synergetic approach[120] to the topic addressed, as it could bring some clarity and flexibility that may help with integrating the variety of legal instruments, ensuring the return of valuable nutrients and organic matter to the polluted soil and thus undoing the current unbalanced relationship between economics and soil health.[121]

4. ECOSYSTEM SERVICES

So far, we have argued that for decades, science, policy and legal initiatives installed to protect soil from degradation are, at least in part, inadequate. We would like to suggest that novel ways need to be explored in order to address the problems at hand.

One way is the application of ES within soil policy and legislation to provide management practices that avoid damage to the soils and therefore promote sustainable agricultural systems. If ES were to become an imperative, it would be a substantial addition to current soil protection policy and legislation. It may be beneficial in supporting the continuous flow of ES, which would secure the availability of natural capital (NC), i.e. the world's stocks of natural assets, which includes air, water, and all living entities.[122] A decrease in NC would create a situation in which substitutes such as manufactured or human capital would be used.[123] A common example of this situation is seen when farmers add fertilisers to the soil to offset the decrease in fertility.[124] However, situations where substitution is possible are highly unlikely in cases where for example there is loss of important species that hold cultural importance and where there are economical impracticalities due to the loss of services like erosion control.[125] The original public good is free; therefore, difficulties arise when the use of substitutes become too costly, or when available substitutes for that particular service are absent.[126] In addition, it is important to note that many ES do not have feasible substitutes.[127]

[119] Commission Regulation (EC) No. 2003/2003 of the European Parliament and of the Council of 13 October 2003 Relating to Fertilisers, OJ 2003 L 304/1.
[120] *A.C. Singer et al.,* Review of antimicrobial resistance in the environment and its relevance to environmental regulators, Front. Microbiol. 2016 (7), p. 1728.
[121] *J. Hall*, Ecological and economical balance for sludge management options, in European Commission Joint Research Centre, Workshop on Problems Around Sludge, 2000.
[122] *World Forum on Natural Capital*, What is Natural Capital?, https://naturalcapitalforum.com/about/.
[123] *R. Costanza*, The value of the world's ecosystem services and natural capital, Nature 1997 (387), p. 253.
[124] *Millennium Ecosystem Assessment (MEA)*, Ecosystems and Human Well-being: A Framework for Assessment, Island Press, 2003, p. 14.
[125] Id.
[126] *G.C. Daily*, Management Objectives for the Protection of Ecosystem Services, Environ. Sci. Pol. 2000 (3), p. 333.
[127] *Costanza*, *supra*, note 123.

As Daily has argued, when economic activities are limited, ES is under less pressure.[128] The more our economy develops, the more societal wants and needs create a situation that causes pressures to be brought to bear on vital ES.[129] When demand for a service reaches the limits of its capacity/availability or where its supply decreases to the minimum level for survival, the price of that service can become infinite.[130] This may potentially create difficulties for obtaining access to these vital services, thus threatening human well-being.[131]

Protecting soil ES and NC is important and challenging at the same time. These concepts have been undervalued by governments, businesses and society, which may be one explanation as to why they have been inadequately protected. Governments seem to invest in protection of certain ES if the benefits obtained from those services are apparent,[132] for example drinking water. However, this is not the case with less apparent ES, such as erosion control or nutrient cycling.

Even though there is a movement towards the integration of ES into soil policy,[133] fundamental issues need to be dealt with in order to achieve robust soil protection. To begin with, there is a lack of information regarding the concept of ES.[134] The science of ES is equally complex[135] and practical problems such as classification and calculation of ES and their valuation are yet to be addressed.[136] Furthermore, it is argued that, without legal status, these services will continue to diminish.[137] Integrating ES into the current environmental policy and law cannot be addressed through minor alterations of legal instruments.[138] Thus, a radical shift in this approach is required.[139] One such approach has been suggested by Salzman and colleagues, who propose that this ES approach can be operationalised through a four-step process which involves the following aspects: education, science, law and economics.[140]

Applying Salzman and colleagues' approach to soil ES, firstly, it is argued that awareness and education are crucial for understanding the importance of ES for humans.[141] Humans do not

---

[128] *Daily*, *supra*, note 126.
[129] *Green Facts*, Biodiversity & Human Well-being https://www.greenfacts.org/en/biodiversity/index.htm#2.
[130] *M.A. Finvers*, Application of e^2DPSIR for analysis of soil protection issues and an assessment of British Columbia's soil protection legislation, MSc Thesis, Cranfield University; *Costanza*, *supra*, note 123.
[131] *Daily*, *supra*, note 126.
[132] *H. Tallis et al.*, An Ecosystem Services Framework to Support Both Practical Conservation and Economic Development, PNAS 2008 (105), p. 9457.
[133] *L. Greiner et al.*, Soil Function Assessment: Review of Methods for Quantifying the Contributions of Soils to Ecosystem Services, Land Use Pol. 2017 (69), p. 224.
[134] *D. Markell*, Symposium – Ecosystem Services, Stan. Envtl. L.J. 2001 (20), p. 309.
[135] *K.M.A. Chan et al.*, Conservation Planning for Ecosystem Services, PLoS Biology 2006 (4), p. 2138.
[136] *K. Grunewald & O. Bastian*, Ecosystem Services – Concept, Methods and Case Studies, Springer, 2015.
[137] *B. Pardy*, Book Review: The Law and Policy of Ecosystem Services, by J.B. Ruhl, Steven E. Kraft and Christopher L. Lant. OHLJ 2008 (46), p. 445.
[138] Id.
[139] Id.
[140] *J. Salzman et al.*, Protecting Ecosystem Services: Science, Economics and Law, SELJ 2001 (20), p. 309.
[141] Id.

appreciate the potential threats to ES,[142] owing to the fact that there is disconnect between them and the natural world. ES helps to make the soil functions visible, resulting in more human appreciation of their role.[143]

Following on, knowledge of the linkages between functions of ecosystems and the provision of ES should be strengthened through science.[144] There are numerous aspects missing within the existing soil ES classification frameworks, such as: the complexity and characteristics of soil functioning;[145] the link between soil NC, functions and ES;[146] the categorisation of different services; the potential beneficiaries of soil ES;[147] and a standardised definition for each soil ES.[148] To operationalise the aforementioned aspects, it is necessary to overcome the lack of consensus in the scientific literature regarding the classification of soil ES.[149] In addition, sustainable soil management[150] and governance based on ES can only be achieved through interdisciplinary approaches.[151] It is not possible to generate an effective environmental policy without validating it with scientific information.[152] Hence, soil scientists should engage with stakeholders from other disciplines, policy makers, communities and the public, and communicate more productively to improve the legal regime.[153]

The third step of this ES approach deals with the operationalisation of ES in order to promote the importance of soils in policy and law.[154] The integration of ES within institutional and regulatory frameworks is required in order to avoid ES remaining as an abstract idea.[155] It is opined that creating effective soil protection laws from an ES perspective requires ecological consciousness and the

---

[142] Id.

[143] *A. Grêt-Regamey et al.,* Soils and Their Contribution to Ecosystem Services, National Research Programme NRP 68, 2016.

[144] *Salzman*, *supra*, note 140.

[145] *E. Garrigues et al.,* Soil Quality in Life Cycle Assessment: Towards Development of an Indicator, Ecol. Indic. 2012 (18), p. 434.

[146] *E. Dominati et al.,* A Soil Change-Based Methodology for the Quantification and Valuation of Ecosystem Services From Agro-Ecosystems: A Case Study of Pastoral Agriculture in New Zealand, Ecol. Econ. 2014 (100), p. 119.

[147] *J. Örvar et al.,* Classification and valuation of soil ecosystem services, Agri. Sys. 2016 (145), p. 24.

[148] *Dominati*, *supra*, note 146.

[149] *G.C. Daily*, Nature's Services: Societal Dependence on Natural Ecosystems, Island Press, 1997; *P. Lavelle et al.*, Soil Invertebrates and Ecosystem Services, Eur. J. Soil Biol. 2006 (42), S3; *E. Barrios*, Soil Biota, Ecosystem Services and Land Productivity, Ecol. Econ. 2007 (64), p. 269; *S.M. Swinton et al.,* Ecosystem Services and Agriculture: Cultivating Agricultural Ecosystems for Diverse Benefits, Ecol. Econ. 2007 (64), p. 245; *W. Zhang et al.*, Ecosystem Services and Dis-services to Agriculture, Ecol. Econ. 2007 (64), p. 253; *H.S. Sandhu et al.,* The Future of Farming: The Value of Ecosystem Services in Conventional and Organic Arable Land – An Experimental Approach, Ecol. Econ. 2008 (64), p. 835; *E. Dominati et al.*, A Framework for Classifying and Quantifying the Natural Capital and Ecosystem Services of Soils, Ecol. Econ. 2010 (69), p. 1858; *Örvar*, *supra*, note 147.

[150] *Y.-G. Zhu & A.A. Meharg*, Protecting global soil resources for ecosystem services, Ecosys. Health Sustain. 2017 (1), p. 11.

[151] *R.B. Prado et al.,* Current Overview and Potential Applications of the Soil Ecosystem Services Approach in Brazil, Pesq. Agropec. Bras. 2016 (51), p. 1021.

[152] *MEA*, *supra*, note 124 at p. 17.

[153] *A.M. Wyatt*, The Dirt on International Environmental Law Regarding Soils: Is the Existing Regime Adequate?, DELPF 2008 (19), p. 165.

[154] *Grêt-Regamey*, *supra*, note 143 at p. 18.

[155] *Salzman*, *supra*, note 140 at p. 18.

concepts of natural rights of soil being embedded into the legal instruments.[156] Furthermore, these laws should be underpinned by monitoring and valuation of soil ES to promote effectiveness.[157]

The final step of ES integration requires the valuation of ES.[158] Appreciation of the actual monetary value of ES[159] enables appropriate consideration of the overall effects of changes in soil functionality.[160] A fundamental weakness of the existing frameworks is that soil is normally valued from the perspective of land or production[161] and rarely is the economic valuation of soil ES considered.[162] These schemes focus on the above-ground component of ES, rather than the less visible ones, for example nutrient cycling,[163] which are overlooked in decisions regarding land use and management as these are commonly non-marketable.[164] However, more rational decisions require marketable and non-marketable ES to be taken into consideration by decision-makers.

Overall, it is argued that the main aim of integrating the ES approach is to protect and restore services that function for the benefit all edaphic organisms and human existence. Implementing this into policy and legislation, and more importantly creating a paradigm shift, is crucial for the protection of soil and the ES it provides.

5. CONCLUSION

It is clear from the above discussion that the accumulation of Zn and Cu in agricultural soil has serious implications for soil biodiversity. The more serious issue is the fact that it highlights the inadequacies of the current direct and indirect legal instruments used to protect soils. Legal controls on PTEs within agro-ecosystems are minimal in Europe and the UK. Their control is largely through codes of practice, incentive schemes and infrequently legislation. This serves as an example of the ineffectiveness of the current legislation to protect soils. If we are to preserve the fragile balance between the human need to exploit our natural capital and maintaining the delicate soil ecosystems, it is crucial to adopt a synergetic approach through the application of ES to halt the deterioration of our Earth.

---

[156] *I. Hannam & B. Boer*, Legal and Institutional Frameworks for Sustainable Soils: A Preliminary Report, IUCN, 2002.
[157] *B.B. Ghaley et al.,* Quantification and valuation of ecosystem services in diverse production systems for informed decision-making, Environ. Sci. Pol. 2014 (39), p. 139.
[158] *Salzman*, *supra*, note 140 at p. 18.
[159] Id.
[160] *D.A. Robinson et al.,* Natural Capital, Ecosystem Services, and Soil Change: Why Soil Science Must Embrace an Ecosystems Approach, Vadose Zone J. 2012 (11), p. 5.
[161] Id.
[162] *Örvar*, *supra*, note 147 at p. 19.
[163] *Dominati*, *supra*, note 149 at p. 19.
[164] *Ghaley*, *supra*, note 157.