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A soil science renaissance

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ABSTRACT

The renaissance was an intellectually-rich period following a period of stasis in the medieval period. Something analogous appears to be currently taking place in soil science where novel approaches to thought are combined with a revival of ideas from the past. Renewed interest in agriculture (food, feed, fuel) and numerous publications have brought soils back onto the global research agenda. The need for up-to-date and fine resolution soil information and the revival of soil research has been highlighted and prioritised in several recent studies by the UN and other international organizations. Soil erosion, nutrient depletion and pollution are key issues that have been brought up in many recent reports – in most cases in relation to environmental degradation, climate change and world-food production. There is also an increased interest in soils in the popular press and media, and soils have entered the policy arena in many countries and several continents. We guestimate that about €3.2 billion is annually spent on soil research in Europe, North America, and some of the main countries in Asia and Oceania. For the global soil science community, there are challenges ahead to address the questions raised in these reports. There is a whole set of new techniques and methodologies in the wings waiting to take centre stage. There is a direct need to educate a new generation of soil scientists and to increase the influx of soil science students in many universities. The soil science community should benefit from the current upsurge in soil science, but the community has to deliver the goods and information that is wanted and much needed.

1. Introduction

Soil science has always had strong ties with agriculture and soil science knowledge has made large contributions to the increase in agricultural production. A better understanding of soils has been essential for research questions on climate change, environmental regulation and ecosystem services. Reduced funding that started in many countries in the mid-1980s affected soil science and this followed widespread governmental budget cuts, and a reduced interest in agriculture. It took time before soil science departments shifted focus towards the study of soils as part of environmental and ecosystem services (Tinker, 1985). For some that shift came too late and departments were re-labelled, merged or closed, which was facilitated by a decreasing number of students (Baveye et al., 2006; Hartemink et al., 2008).

The soil science community has been somewhat inward looking and has not always providing quantitative answers to old questions in a manner that could be directly used by users of the soil or by decision makers. Soil science has suffered from communication problems within its own discipline, with other disciplines (except perhaps agronomy) and with the general public — Prof. Dennis Greenland wrote the following in the early 1990s: "…soil scientists have also been frustrated as their advice has gone apparently unheeded. This may be because the advice is couched in terms more easily understood by other soil scientists than by politicians and economists who control the disposition of land. If soil science is to serve society fully it is essential that its arguments are presented in terms readily understood by all and with both scientific and economic rigor so that they are not easily refuted." (Greenland, 1991).

There have been many ideas and reactions to the changes in soil science that were largely governed by changes in society (Bouma and Hartemink, 2002). Some searched for a soil science identity (Wild, 1989; Hudson, 1992) and there have been appeals for a new type of soil scientist (Warkentin, 1999), and a new type of soil science that is more holistic (Bridges and Catizzone, 1996). Others opined that soil science should be part of a multidisciplinary network society (Bouma, 2001), and that the discipline should be geared towards one of soil care (Yaalon, 1996). There has also been a continual call for soil science to be conducted more closely with society (McCracken, 1987; Simonson, 1991). It is difficult to asses whether all of these genuine ideas have had impact. There is some pessimism, particularly in North America, on the future of soil science (Baveye et al., 2006; Hopmans, 2007).

This paper disputes that pessimism and shows that there is increasing attention for both soils and soil research. This is part of the

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global renewed interest in agriculture as we approach a population of 8 billion. Currently, there is widespread concern about the land needed for energy (biofuels), food (hunger alleviation, increased demand) and feed (increased animal production). Oil prices are high and so is the demand for biofuels. The cultivation of biofuel crops is competing with food crops in some parts of the world and is driving-up commodity prices (UNEP, 2007a). The environmental and soil impact of the shift towards growing crops for energy or increased food production is still to be assessed (Hartemink, 2008) but it is widely realised that global soil information is not accurate or digitally available, and, certainly not up to date. The paper discusses our expanding knowledge base and impact, the fluctuating influx of students, the views in recent reports of UN and international organisations, the soil science research funding, and the development of soil legislation. From there on the rebirth of soil science is discussed and what should be done to maintain the momentum.

2. The expanding knowledge base and impact

One way to asses the vigour of a scientific discipline is the number of publications over time which is an indication of the productivity and a proxy for the amount of soil research. The trend in impact of soil science journals is an indicator for the impact of the discipline. Both the trend in the number of papers and impact factors are affected by other aspects but they are used here to illustrate that more and more is being published, and that the impact increases over time.

The total number of soil science publications was counted using ISI Web of Knowledge (Thomson Reuters) (Fig. 1). The annual increase in soil science publications is about 545 per year and there is a linear upward trend. About 16% of all soil science publications are published in primary soil science journals (Minasny et al., 2007), which means that most soil science research is being published in non-soil science journal (e.g. environmental-, chemical- or physical journals). Relatively little soil science publications appear in the top journals *Nature* and *Science*; 0.5% of all publications in these two journals have soil in the title, key word or abstract.

The impact factor of the major soil science journals has steadily increased in the past thirty years as it has in several other disciplines (Fig. 2). The increase has been accelerated in the past 7 years or so suggesting some sort of hockey-stick effect possibly caused by increased electronic access and more use of soil science papers. Some journals increased faster and the annual increase for Geoderma is 7.4%, European Journal of Soil Science 5.0%, Soil Science Society of America Journal 4.2%, and Soil Biology & Biochemistry 5.2%. The impact factors of Soil Biology and Biochemistry is higher than that of more generic journals like European Journal of Soil Science and Geoderma — soil biology continues to be 'hot' in soil science. Overall, the relative increase in impact of the soil science journals is larger than the annual increase in the number of publications.

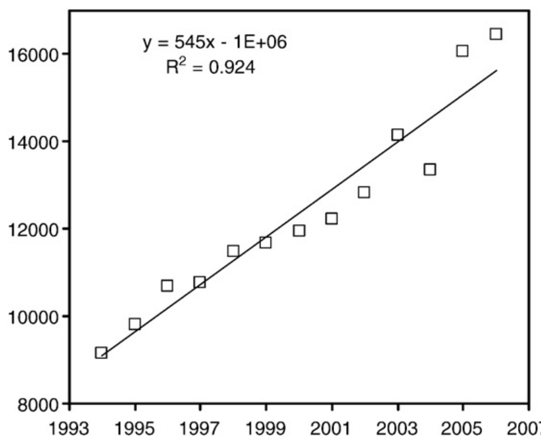

Fig. 1. Total number of soil publications (soil in Title, Keywords or Abstract) in the ISI Thomson Web of Science — 1993 and 2007.

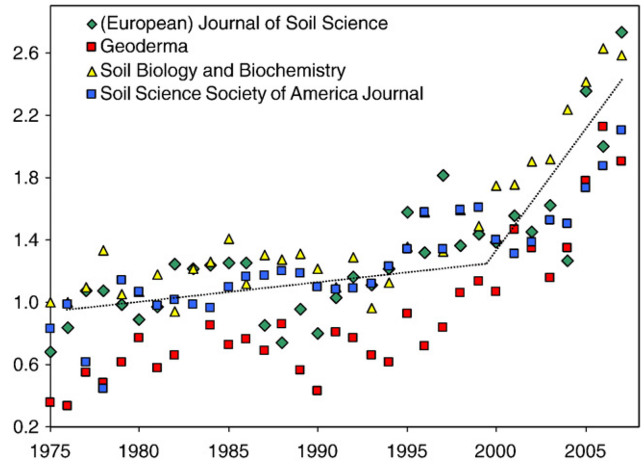

Fig. 2. Indexed impact factor of major soil science journals between 1993 and 2007 inclusive.

In addition to the increasing number of soil science publications five major soil reference works and encyclopaedias have been published in the past 8 years (Table 1). In total these works cover almost 7000 pages, with 1400 entries or subjects that have been written by over a thousand soil scientists. This is a soil science legacy that will be used for many years to come. It can be viewed as a sign of vigour of the discipline, but also as a conclusion of an era.

3. The fluctuating influx

Shifts in research foci, tertiary education and government support for the sciences have caused a reduction in the number of soil scientists and soil science departments. That happened in many parts of the world although not everywhere at the same magnitude. Recently, a dozen universities in the USA, Europe and Australia and New Zealand were surveyed and trends in student numbers was investigated (Hartemink et al., 2008). It confirmed a study from North America that soil science student numbers have considerably decreased (Baveye et al., 2006). In the Netherlands, the number of soil science students decreased and stabilised, whereas at Sydney University an increase was observed (Fig. 3) until very recently. There is a steady increase in female soil science students in many universities. Almost half of the MSc graduates in North America are now female compared to 30% in 1992. At Wageningen University in the Netherlands the number of female soil science students was less than 20% in the 1980s but is currently over 50%. Such trend has also been observed in the medical sciences and several other scientific disciplines that were traditionally dominated by men.

As many soil science departments have been merged, re-labelled or closed, the number of soil science courses has also been drastically reduced. In many universities it is not possible to graduate in soil science. The subject is often taught as part of degrees in biogeochemistry, biology, earth-system science, hydroecology etc. Although soil science is further specialising, the teaching is generalising to serve the need of students in natural resource studies. It may lead to a gap between graduate students' expertise and the work floor requirements.

4. Global studies

There have been many studies at the global level in which soils are mentioned, including the studies on global ecosystems — PAGE (Pilot Analysis on Global Ecosystems), the Millennium Ecosystems Assessment, but also in a range of conventions (e.g. United Nations Framework Convention on Climate Change, Convention to Combat Desertification)

Table 1
Major soil science reference works

Year	Title	Editor	Number of articles/entries	Number of authors	Number of pages	Pages/ article	Pages/ author
1979	The encyclopedia of soil science. Part 1 (1 volume)	R.W. Fairbridge, C.W. Finkl	136	112	620	4.6	5.5
2000	Handbook of Soil Science (1 volume)	M. Sumner	57	146	2110	37.0	14.5
2002	Encyclopedia of Soil Science, 1st edition (1 volume)	R. Lal	360	400	1476	4.1	3.7
2005	Encyclopedia of Soils in the Environment (4 volumes)	D. Hillel	267	374	2119	7.9	5.7
2006	Encyclopedia of Soil Science, 2nd edition (2 volumes)	R. Lal	463	595	1923	4.2	3.2
2008	Encyclopedia of Soil Science (1 volume)	W. Chesworth	620	127	845	1.4	4.9

and other global fora (e.g. Intergovernmental Panel on Climate Change). For a few years there has been an accelerated number of global studies in which soils and soil science are present - some had a climate change focus (Stern, 2007) and briefly mention the role of soils as sinks and sources of greenhouse gases, others project soils in a wider environmental agenda (Table 2). In the following sections some the main studies are summarised that highlight the importance of soils, soil information and soil science.

4.1. Millennium development goals

In September 2000, world leaders came together at the United Nations Headquarters in New York to adopt the United Nations Millennium Declaration, committing to a new global partnership to reduce extreme poverty. It set out a series of time-bound targets with a deadline of 2015: the Millennium Development Goals (MDGs). The MDGs were initiated by the previous UN Secretary General Kofi Annan and the undertaking is headed by Prof. Jeffrey Sachs. In total 8 goals have been defined and task forces have been formed.

Goal number 1 has two targets: eradicate extreme poverty, and hunger — the task force on hunger has published an extensive report with a range of recommendations on soil health (UN Millennium Project, 2005). Five major soil health interventions are discussed to increase the level of soil nutrients through the combination of organic and inorganic fertilisers: mineral and organic fertilisers, green manures, tree planting, returning crop residues, and better methods of soil and water conservation. This report makes a strong plea to replenish soil nutrients — particularly for the soils in Africa where the annual loss of nutrients exceed $4 billion (Sanchez, 2002). Africa is experiencing a decline in overall food production per capita and its farmers generate the lowest food output per hectare of any major region in the world (Sanchez and Swaminathan, 2005). In addition, the link between poverty, unhealthy people, unhealthy soils and poor soil management is reinforced in the MDG approach (Sanchez and Swaminathan, 2005; UN Millennium Project, 2005) — in the 1930s such thinking was also popular (Hall, 1936) and best worded by the soil conservationist H.H. Bennett as follows: "Poor soils make poor people and poor people make the soil worse" (Bennett, 1939). The MDGs have put agricultural production and soils on the global agenda — and will continue to do so for the years to come.

4.2. FAO external evaluation

The Food and Agriculture Organization (FAO) of the United Nations was founded in October 1945. From 1945 to 1970 FAO played an instrumental role in addressing global nutrition, food and agricultural issues and it was the main source of expertise in these three areas (FAO, 2007). By 1951, FAO had 100 projects in 35 countries employing over 200 experts; by 1959 there were over 1700 experts in the field (the number of soil scientists is not known). In 1961, FAO together with UNESCO agreed to prepare jointly a soil map of the world in association with the ISSS (now IUSS) (Dudal and Batisse, 1978). One of the objectives was to strengthen international contacts in the field of soil science. By the time all map sheets were published in 1981, FAO was past its zenith — many new and competing organisations were established (e.g. CGIAR, UNEP) funding strategies changed (for example, the World Bank became an executing agency hiring large numbers of experts), funding decreased with 31% between 1994 and 2005, there was a declining interest in agriculture and FAO produced disappointing and unimpressive results, and wasn't able to reverse the trends (FAO, 2007).

The contribution of FAO to soil science include the first-ever world soil map, the first world soil classification system, a large range of reports from land evaluation to irrigation guidelines of which many are seminal works, training soil scientists across the world and major contributions in the area of soil fertility and plant nutrition including the FAO/IAEA work on the use of nuclear techniques. In addition to the aforementioned reasons, soil research activities at FAO declined because of a shift

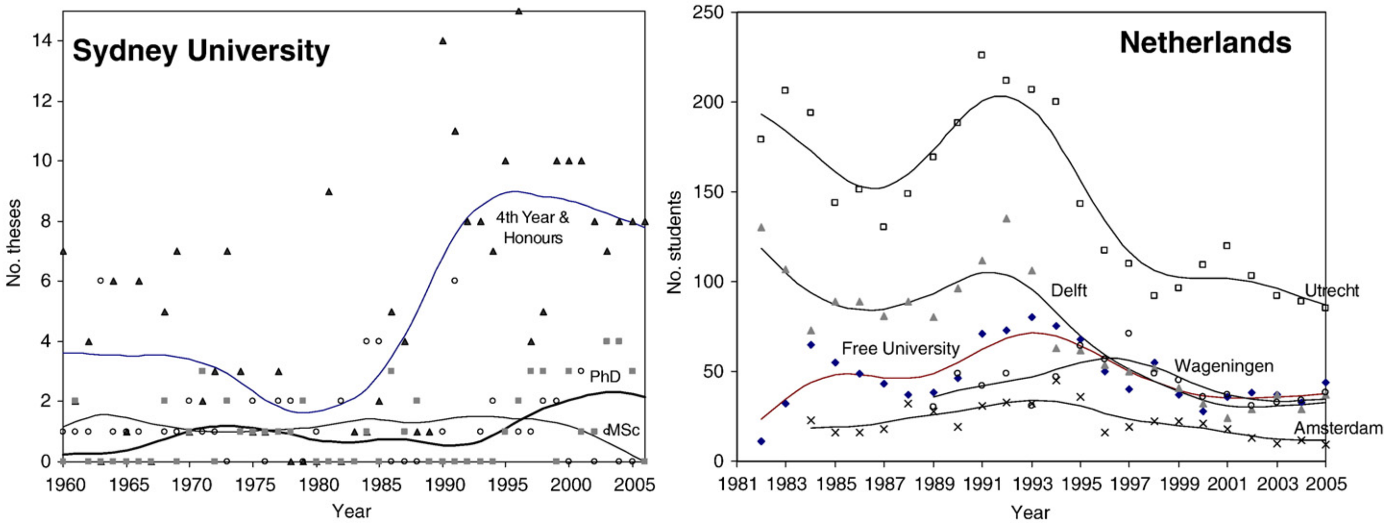

Fig. 3. Trends in the number of BSc, MSc and PhD theses in soil science at Sydney University between 1960 and 2005, and in the number of earth science (including soil science) students at five universities in the Netherlands between 1981 and 2005. Modified after Hartemink et al. (2008).

Table 2
Global studies from international organisations and some of their main conclusions on soils

Year	Title	Published by	Pages	Soil counts [1]	Assessment method	Main conclusions regarding soils
2005	Halving hunger: It can be done. Task force on hunger	UN, Earthscan	272	161	Literature review, expert team	Soil fertility replenishment in Sub-Saharan Africa is essential to overcome hunger, poverty and for political stability
2007	Climate change 2007:synthesis report	IPCC	52	14	Core writing team of about 35 scientists	Climate change will interact at all scales with other trends in global environmental and natural resource concerns, including water, soil and air pollution, health hazards, disaster risk, and deforestation. Their combined impacts may be compounded in future
2007	The challenge of renewal. Report of the independent external evaluation of FAO	FAO, Rome	403	36	Panel of six reviewers, interviews with over 100 senior FAO staff	Long history of soil activities and several key contributions; FAO has very few areas left in which it has technical leadership; land and soils the highest priority for resource allocation
2007	Global Environmental Outlook GEO4	UNEP, Nairobi	540	343	Hundreds of scientists and centres, three rounds of reviews and editing	Mostly, threats to soils are highlighted (including soil erosion, nutrient depletion, pollution etc). The need for soil spatial information needed at regional and local level is stressed
2007	World Development Report 2008 – Agriculture for Development	The World Bank, Washington DC	386	125	A core team of experts of about 20, with contributions of many more scientists and institutions	Agriculture can create good and bad environmental outcomes. It is by far the largest user of water, contributing to water scarcity. It is a major player in underground water depletion, agrochemical pollution, soil exhaustion, and global climate change. Soil fertility replenishment and erosion control is needed in many tropical countries
2007	Human Development Report 2007/2008 – Fighting climate change: Human solidarity in a divided world	UNDP, New York	384	24	Hundreds of contributors	Soil erosion, declining soil fertility, desertification, C soil storage, salinity and climate change receive attention in various parts of the report; no conclusions, just examples
2008	Trends In Sustainable Development. Agriculture, rural development, land, desertification and drought	UN – DESA, New York	42	5	Conclusions reached by the Commission on Sustainable development	Soil degradation and desertification are serious problems hindering agricultural development

[1]Counted how often the word "Soil" is used in the report.

from soils to land and climate research, and lack of vision by its leaders that resulted in minimised soil activities. The number of soil staff declined form about 20 in 1987 to less than 5 currently and the work on land and soils has seen one of the largest drops in the proportion of FAO's Regular Programme resources (27% since 1994–2005). The remaining staff work on a range of soil issues including SOTER, AEZ zoning with IIASA, land degradation and conservation agriculture. The rise and decline of soil research by FAO is perhaps exemplary for what happened in several countries, research centres, and university departments.

Following a major review and examination of the UN itself, the FAO had its first ever external evaluation in 2006 and 2007 (FAO, 2007). One of the conclusions of the report is that FAO is in crisis and has very few areas left in which it has technical leadership, which includes land and soils. Yet, an area of comparative priority is the provision of basic global natural resource data and statistics including land and soils. The review gives land and soils the highest priority for resource allocation (above, for example, water and irrigation or crop production and processing technologies). The report justifies it as follows: "There can be no doubt of the pressure put on land resources by increasing population, demand for increased supply of agricultural products, urbanization and climate change. National land management is a technical, economic and social issue and addressing it requires basic information. Global decision-making in areas such as climate change and agro-biodiversity will require up-to-date global information. New techniques of remote sensing, computer imaging and GIS potential continually require standards to be updated. (Recommendation 3.11)." The will is there to regain FAO's leading role — now the money and expertise.

4.3. UNDP human development report

The United Nations Development Programme (UNDP) was founded in 1965. UNDP is the United Nations' global development network and the largest multilateral source of development assistance in the world. The organization has country offices in 166 countries and UNDP works internationally to help countries achieve the Millennium Development Goals. Since 1990 UNDP publishes an annual Human Development Report to measure and analyze developmental progress. The reports contain systematic studies of issues central to human development include: Social progress, economics, efficiency in terms of resource use and availability, equity, participation and freedom, sustainability, and human security. Four main Human Development Indices have been developed of which the HDI — Human Development Index (a summary measure of human development) is the best known.

Between 1990 and 1999 these reports were between 120 and 170 pages but from 200 onwards the number of pages doubled. There was no mention of soil until the 2000 Human Development Report where it was briefly discussed in relation to pollution and toxicity (Fig. 4). In 2003, soils were present in several parts of the report in relation to nutrient depletion and soil degradation. In successive reports, issues like land rights (2004) and indigenous soil knowledge (2006) were brought up. The most recent report focused on climate change and soils as sink and sources of greenhouse gases are discussed (UNDP, 2007). Soil carbon

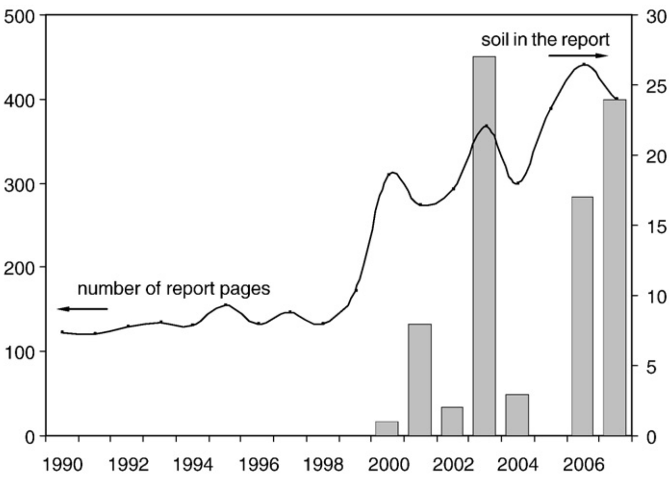

Fig. 4. Number of report pages in the UNDP Human Development Reports between 1990 and 2007, and the occurrence of "soil" in the text (i.e. since the year 2000 — prior to 2000 soil was not considered in these reports).

storage capacity is linked to carbon markets and sustainable development. Also soil erosion and soil fertility decline and the effect on food production are mentioned: "..the environmental degradation of soils is both a cause and an effect of poverty." There is no mention of the adequacy of soil information or how soil carbon markets ought to be measured and developed, but soils have now also entered the UNDP reports, and these are widely used by decision makers and in policy.

4.4. Global environmental outlook (GEO4)

The United Nations Environment Programme (UNEP) was founded in 1972 and coordinates the UN environmental activities. Since 1997, UNEP has produced Global Environment Outlook (GEO) reports that provide scientific assessments of the interactions between environment and society. GEO reports were published in 1997, 1999, and 2002 and 2007. The third assessment (GEO3) was from 2002, and for the soil information relied on GLASOD (Global Assessment of Human-induced Soil Degradation) from the early 1990s (Oldeman et al., 1991). The fourth assessment (GEO4) is the most comprehensive report.

The GEO4 assessment provides an overview of environmental issues, state and trends of the environment between 1987 and 2007, human dimensions of environmental change, an outlook for the future using four scenarios and the policy options available to sustain our common future 2 (UNEP, 2007a). A full chapter (33 pages) is devoted to Land and includes sections on water, forests, land degradation including chemical contamination and pollution, soil erosion, nutrient depletion, salinity, and disturbances in biological cycles. It is stated that depletion of nutrients by continued cropping with few or no inputs limits productivity over vast tropical and subtropical upland areas, and for severely nutrient-deficient soils, there is no remedy except external nutrient inputs. There is also a separately published 32-page Summary for Decision Makers (UNEP, 2007b), that states: Climate change may further exacerbate the loss of biodiversity and degradation of land, soil, forest, freshwater and oceans; Unsustainable land use and climate change are driving land degradation, including soil erosion and nutrient depletion. The eradication of extreme poverty and hunger, for example, is dependent on sustainable agriculture which, in turn, relies on soils, water and ecological processes." The summary report has two devastating soil erosion pictures. The use, management and threats to soils are included throughout the GEO4 report that also recognises the need for much better soil spatial information at regional and local scales.

5. Soil legislation

Soils have also entered the policy arena and in several countries and continents soil legislation is being developed. Legal and institutional frameworks provides law and policymakers with guidelines for identifying, developing, or strengthening a legal system concerned with the environment or a particular aspect of it (e.g. water, soils, biodiversity) (Hannam, 2004). In the past few years considerable progress has been made, e.g. on the development of soil research and indicators for regulating nutrient losses and soil pollution (Bouma, 2003; Schroder et al., 2004; Rombke et al., 2005) but also on the legal aspects of soil erosion and conservation (Yakovlev et al., 2006). In China, environmental and natural resources legislation was begun in the 1990s and currently also includes legal tools to tackle land degradation issues (Ke et al., 2008). The largest effort to effectively bring tools for soil legislation has been in the EU through its Soil Thematic Strategy, and more recently in the USA through the adoption of a Resolution in the US Senate.

5.1. EU soil thematic strategy

Environmental policies in Europe started in the 1970s and these policies are supported by many Europeans who realise that environmental problems go beyond national borders. Initially, the focus was on single pollutants and impacts but it became more integrated with seven thematic strategies proposed in 2005 and 2006 (European Commission, 2006). These strategies include air quality, marine environment, sustainable use of resources, waste prevention and cycling, pesticides, the urban environment, and soil quality. The thematic strategy on the protection of soil was started in 2002 and adopted by the European Commission in September 2006. The strategy is centered around a number of threats: erosion, organic matter decline, soil compaction, salinisation, landslides, soil contamination, and soil sealing. The strategy is aiming to give soil the same importance as air and water; it sets out a roadmap to address soil degradation by preserving and restoring soil and its functions. Total cost of soil degradation in the European countries has been estimated to be €38 billion per year (European Commission, 2006). The strategy will also facilitate the exchange of information and good practice between EU countries and encourage active public participation. It aims for good policies on soil and waste management to offset greenhouse gas emissions (Marmo, 2008) — but, the strategy has not been adopted by the European Parliament yet.

5.2. Soil Resolution in the US Senate

In June 2008, the US Congress adopted Senate Resolution on soil following the effort of Prof. Rattan Lal from Ohio State University. This resolution enforces the role of soils in our daily lives and emphasises the lack of legislation on soils in the USA (as opposed to for example climate change, water quality). The Senate (i) recognizes it as necessary to improve knowledge, exchange information, and develop and implement best practices for soil management, soil restoration, carbon sequestration, and long-term use of the Nation's soil resources; (ii) recognizes the important role of soil scientists and soils professionals, who are well-equipped with the information and experience needed to address the issues of today and those of tomorrow in managing the Nation's soil resources; (iii) commends soil scientists and soils professionals for their efforts to promote education, outreach, and awareness necessary for generating more public interest in and appreciation for soils; and (iv) acknowledges the promise of soil scientists and soils professionals to continue to enrich the lives of all Americans by improving stewardship of the soil, combating soil degradation, and ensuring the future protection and sustainable use of our air, soil, and water resources. In addition to the resolution, several States are encouraging systems to license soil scientists, which implies that jobs that require soil science expertise will have to be done by soil scientists.

6. Global funding for soil science

Countless studies have appeared on how soil science should be organised and what it should do (e.g. Wild, 1989; Gardner, 1991; Warkentin, 1994; Bouma, 2001). These papers appeared as a result of reduced funding for soil science and the search for soil science identity (Mermut and Eswaran, 1997; Kirkham and Clothier, 2007), and the firm believe that funding agencies should not dictate research topics from the top down (Hillel, 1993). To our knowledge no attempts have been made to quantify how much money is globally being used to study soils. Here is a first guestimate: According to the records of the International Union of Soil Sciences (IUSS), there are some 16,000 members of the national soil science societies in Europe, North America and parts of Asia and Oceania (mostly OECD countries). If we assume that it costs on average about €100,000 yr^{-1} to employ one soil scientist than the total costs are about €1.6 billion per year — that is the total funds spend on salaries, supporting staff, housing, offices, libraries, computers and all other indirect costs. We think about the same amount is needed for doing actual research, which brings the total annual funds of soil research to about €3.2 billion per year.

Although this a rough estimate and we have no real data, what do we get for it? There are annually about 16,000 "soil" publications in international journal (Fig. 1). So the average "cost" of a soil publication is about €200,000. Holmgren and Schnitzer (2004) counted the number of papers in international journals for all disciplines for Latin America, Canada and the USA, and compared it to total research funding. For Latin America and Canada, one publication cost about €330,000 whereas the costs in the USA were estimated to be about €700,000 per publication (Holmgren and Schnitzer, 2004). Many countries in Latin America have invested heavily in research and development although the percentage investment as part of GDP is still less than 40% as compared to Canada and less 20% compared to the USA. In any case, it seems that the average cost of a soil publication of about €200,000 is reasonable. Obviously, this excludes all books, non-refereed papers, patents, software and other contributions from soil scientists.

Secondly, how does €3.2 billion per year for global soil research compare to some other disciplines and research expenditures across the world? It is about half the total annual expenditure on science funding in the UK in 2007/2008 (Giles, 2004) which is about two-thirds of the annual research and development investment of private companies like Microsoft, DaimlerChrysler or Ford (Chipman, 2007). The US National Science Foundation estimates indicate that the government R&D budget for the USA was €260 billion in 2007 (Boroush, 2008) of which about 60% is spend on defence-related R&D (Brumfiel, 2006). In addition, a large sum of research money in the USA is granted through philanthropists (approx. €175 billion in 2003). The collective research budgets of South Korea, China and India are less than one-quarter that of the USA but their growth since the late 1990s has been rapid. The EU countries spend more than €55 billion per year on research (Brumfiel, 2006).

If we add the annual EU spending on R&D to that of the USA, Australia (€2.9 billion), Japan (€23 billion), South Korea (€5.4 billion), India (€2.5 billion), China (€10 billion), Russian federation (€2.6 billion), and Brazil (€0.9 billion) we see that annual research funds for soil research are less than 1% of the total annual global expenditure on R&D. There about 4 million researchers in the OECD, of which the 16,000 soil scientists are less than 0.5%. So if we assume that soil scientists are not underfunded and their number is proportional to the total funding on R&D than the €3.2 billion annually for soil research could be about right.

7. Discussion and conclusions

The first solid accounts on soil degradation were published some 20 to 30 years ago (FAO, 1971; Greenland, 1981; Dudal, 1982; Bruntland, 1987; Lal, 1988; Stoorvogel and Smaling, 1990; Oldeman et al., 1991) — these first accounts followed the pessimism of the Club of Rome report (Meadows et al., 1972) and a series of books and reports from the 1930s and 1940s (Bennett, 1939; Jacks and Whyte, 1939; Howard, 1940; Osborn, 1948). The analysis in this paper from global reports by UN and other organisations, showed that soil scientists have been very good at communicating the problem of soil degradation (e.g. soil erosion, nutrient depletion, soil pollution), and of all soil scientific activities, the research on soil degradation and the doom-and-gloom preaching has had the biggest impact. It continues do so in both the popular press (e.g. the September 2008 issue of the *National Geographic* and the “Dig It” exhibition in the Smithsonian Institute) as well as the scientific press (e.g. the “Soil and Trouble” issue of *Science* in June 2004). We think it needs stressing that soil degradation is just one facet of soil science.

Section 4 highlighted the need for soil research and soil science. Is it right to think from these reports that these indicate that soil science is currently experiencing a renaissance? The renaissance was a period that spanned roughly the 14th to the 17th century in which a revival of learning based on classical sources and an educational reform were major elements. It very much influenced intellectual life and included a revival of ideas from antiquity and novel approaches to thought. The sciences received much attention and some have seen this as a scientific revolution although the most important was not a specific discovery but rather a process for discovery: the scientific method (Brotton, 2006). The renaissance followed a dark medieval period and analogous to that soil science is now also departing from such period in which pessimism, overall decline, emphasis on soil degradation, and shortage of funding were dominant in many countries. The current upsurge in soil science could lead to a fruitful and highly productive new era and we expect an increase in research funding given the current upsurge. But the discipline should continue to be innovative and more quantitative. Innovation occurs at many levels and in many institutions and the link with real-world issues (climate change, hunger alleviation, environmental degradation etc.) is essential as is the development of fundamental research (Bouma, 2001). Much emphasis has been on practical applications (McKenzie, 2006) but there is a real need to challenge some of the old paradigms and come up with truly novel approaches (McBratney, 2006) — just like in the renaissance. Adoption and spread of new methodologies and techniques (e.g. pedometrics, DNA fingerprinting in soil ecology, digital soil mapping) is relatively low and requires a new type of soil scientists equipped with different tools and views. We see that other disciplines have taken on part of the soil science task like, for example, geologists (Lawley and Smith, 2008; Smith et al., 2008). Another example is the real-estate industry of the USA where companies hire foresters, biologists, and agricultural engineers to evaluate land for real estate development.

Now soils are in the picture, action is needed and is already being taken on some fronts e.g. AGRA (Alliance of Africa's Green Revolution) and a range of new soil projects across the globe (e.g. various new soil projects in the EU Framework 7 Programme, like iSoil, DigiSoil, and e-SOTER) and GlobalSoilMap.net. These projects will combine the demand for new data with new ideas on how such data should be collected. There are many novel techniques and methods available for the soil scientists and there is a range of software and hardware that needs exploring and further development, like for example digital soil mapping whereby use is made of traditionally collected soil data and environmental co-variables collected by on-the ground, airborne or space borne sensors that generate soil information with predictions that are statistically optimal (Minasny et al., 2008). Such techniques are exceptionally promising when combined with the demand for accurate and up-to-date soil information (McBratney et al., 2006). It is not only used in Europe, North America or Australia and these techniques are also being applied and developed in Sub-Saharan Africa (Shepherd and Walsh, 2002; Shepherd and Walsh, 2007; Awiti et al., 2008) although the soil research capacity in many parts of Africa is thin and shrinking (Bekunda, 2006; Gachene, 2006).

In conclusion, we think that a soil science renaissance is upon us — there is a massive demand and need for soil information and at the same time a technological revolution to address the questions raised by other scientific disciplines, policy and society at large. The global soil science community should act promptly and deliver, whilst at the same time the community should continue to be innovative and develop new thinking about soils and how they are studied and properly managed.

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