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What does the future hold for soil science?

¿Qué futuro le espera a la ciencia del suelo?
Que futuro está reservado à ciência do solo?

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ABSTRACT

In the last decade many authors have talked about a crisis in soil science, manifested by the disappearance of the term "soil" in many research organizations, cuts in funding and a loss of "visibility" of pedological studies. Nonetheless, the crisis is considered to have started in the 1980s, during the so-called "environmental wave" described by Bouma and Hartemink (2002). The causes of the crisis may include competition from other specialists for soil-related studies, superspecialization and a decline in field studies. Proposed solutions to the crisis include a return to the holistic study of soil systems, collaborative research with specialists from other fields and the consideration of studies within wider contexts such as those defined by the "critical zone" proposed by Lin (2005). Finally, the need for soil studies to appear in the media is emphasized, along with the fact that if this is not carried out it will be possible that in some countries soil research teams and structures may even disappear.

RESUMEN

En la última década muchos autores hablaron de una crisis en la ciencia del suelo, puesta de manifiesto por la desaparición del término "suelo" de muchos centros de investigación, recortes en los presupuestos y perdida de "visibilidad" de los estudios edafológicos. La crisis se considera que comenzó en la década de los ochenta, durante la denominada "onda ambiental" descrita por Bouma y Hartemink (2002). Las causas de la crisis podrían estar en la competencia de otros especialistas por los estudios del suelo, la superespecialización y el declive de los estudios de campo. Las soluciones que se proponen incluyen una vuelta a los estudios holísticos del sistema edáfico, investigación colaborativa con otros especialistas y la consideración de los estudios del suelo en contextos más amplios como los de la "zona crítica" definida por Lin (2005). Finalmente, se resalta la necesidad de realizar un esfuerzo para que estos estudios lleguen a los medios de comunicación de masas, así como el hecho de que si estas reformas no se llevan a cabo, en algunos países los equipos de investigación en suelos podrían llegar a desaparecer.

RESUMO

Na última década muitos autores falaram de uma crise na ciência do solo manifestada no desaparecimento do termo "solo" en muitos centros de investigaçao, cortes nos orçamentos e perda de "visibilidade" dos estudos pedológicos. Considera-se que a crise começou na década dos oitenta, durante a denominada "onda ambiental" descrita por Bouma e Hartemink (2002). As causas da crise poderiam residir na competição de outros especialistas em estudos do solo, na superespecializaçao e no declinio dos estudos de campo. As soluçoes propostas incluem um regresso aos estudos holísticos dos sistemas do solo em contextos máis amplos como os da "zona crítica" definida por Lin (2005). Finalmente, salienta-se a necessidade de realizar um esforço para que estes estudos cheguem aos meios de comunicaçao de masas, bem como o facto de que se estas reformas não forem levadas a cabo, nalguns países as equipas de investigaçao em estudos do solo poderem vir a desaparecer.

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1. Phases in the history and concepts of soil science

Never has a crisis in pedology been talked about as much as it is at present. In the last decade many authors have considered that the changes brought about by this crisis are having a negative effect on the future of soil science and have presented a series of objective indicators that support this pessimistic view of the future of edaphological studies.

The alarming decrease in the number of students and qualified researchers involved in this field in different countries is the most frequently cited indication of such a crisis (Baveye 2006; Hartemink et al. 2008). The disappearance of the term "soil" from many subjects and departments, together with the merging of soil science with other more general or more fashionable subjects, has contributed to the pessimism with which the academic future of pedology is viewed. On the other hand, reduced funding available for studying soils and a general loss of visibility and of strategic interest in the activities of soil scientists are also often cited (although on a less reliable basis). With his "pedobarometric index", Hartemink et al. (2008) dates the decline in the impact of soil science on society from the end of the 1980s until the present, although recognising a substantial degree of recovery in recent years.

KEY WORDS
Soil crisis, history, philosophy, future trends

PALABRAS CLAVE
Crisis del suelo, historia, filosofía, tendencias futuras

PALAVRAS-CHAVE
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From the point of view of the history of soil science, Bouma and Hartemink (2002) consider the existence of three periods or "waves" in the years following the Second World War. The *production wave* (1945-1970) corresponds to a period in which most research was aimed at agricultural production. Basic research played an important role within the wide margin of freedom available to choose the study objectives. This was also a period of specialization of pedology into its different branches (chemistry, physics, microbiology, genesis etc.).

This was followed by the *environmental wave* (1970 – end of 1980s) during which environmental concerns began to appear, encouraged by the UN Conference on the Human Environment, held in Stockholm (1972), and by the celebration of Earth Day in the US (1970). Evidence that extreme agricultural productivity has strong repercussions on the environment brought a halt to the supply of resources dedicated exclusively to this end. On the other hand, research policies in which the objectives were controlled by the state or community began to be implemented through periodically announced programmes. All of these changes had repercussions on the study of soils, starting with the gradual replacement of agrarian research topics by environmental research topics. However, the environmental aspect of soil science was not fully reflected in the literature until the 1980s (Hartemink 2006); the intervening decade (1970-1980), suggested by Bouma as the beginning of this wave, can be considered as a transitional period when environmental concerns began to be expressed in society (Díaz-Fierros 2000) but had not yet made an evident impression on soil science.

The *information wave* (end of 1980s - present day), coinciding with the hegemony of liberal capitalism in society, and the worldwide eruption of information and communication technologies, also brought about changes in research policies. The increasing demand for economic evaluation of these policies meant that the research not only had to be instigated via specific programmes but that it also had to be justified on the basis of its profitability or commercial value. The relationships between science and society also changed, and the linear model of transfer of knowledge from basic to strategic and applied research was replaced by a more flexible structure of networks involving different protagonists (scientists, managers, politicians, businesses, members of the public, etc.). Although soil science was affected by all of these changes, the multifunctionality of soil became particularly evident as its functions were no longer seen as being restricted merely to environmental and productive applications.

2. Background and causes of current crisis in soil science

The current crisis in soil science probably began during Bouma's *environmental wave*. During this period, agriculture, which attempted to maximize profits by the intensive application of fertilizers and the use of different kinds of technology, began to be looked on suspiciously because of the clear repercussions on the environment. At the same time, the success of genetic selection and the emerging importance of the increasingly globalized market and its promotional techniques produced a slow but inexorable shift in resources towards these productive factors. As a result, the study of soils and of other classical aspects of agrarian production was becoming less important in the sector.

This could have led to the replacement of such resources by others that should have appeared in conjunction with the new environmental studies. However, this was obviously delayed as soil was the last component to be considered in the new environmentally-oriented research. First to be considered was air (the first protective measures were implemented in the EU in the 1960s), followed, in the 1970s, by water, precisely in relation to the problem of contamination caused by agricultural activities (use of pesticides and fertilizers). Pedologists could have played an important role at this point, but in fact it was hydrologists, chemists and geologists who initially gave the question most thought. Contaminated soils did not clearly become an item on the scientific agenda until the end of the 1980s.

During the *environmental wave*, something also occurred that would become of particular importance - the interest that specialists from fields other than pedology began to take in soils. This is clearly demonstrated in the literature, as from the 1980s onwards there was a substantial increase in the number of studies that included the word "soil" in the title, although without a corresponding increase in the number of soil scientists as authors (Díaz-Fierros 2011). The interest shown by specialists in more general disciplines (such as chemistry, physics, engineering, geology, etc.), who usually publish articles in journals of higher impact than pedologists, is especially significant as this contributed to increasing the awareness of soil within these areas. On the other hand, the fact that researchers who were not trained in soil science undertook studies involving soil may have given rise to some perverse effects, including the trivialization of soil as a natural element with specific functions and processes. Soil became simply another material to be studied and analysed.

Another difficulty, in this case specific to specialists in soil science, was the degree of fragmentation reached in these studies. As a natural progression from the consolidation of the different specialities in the preceding period, the different fields into which pedology is subdivided were increasingly strengthened. However, the interrelationship between the different specialists in soil science was weakened and conceptual barriers were created in each field, each with its own jargon and keys to learning, making cross-fertilization of practices and ideas increasingly difficult. Moreover, interest in soil genesis and its cartographic applications was lost and, as a result, the holistic integrative approach (which compensates for reductionist tendencies) was also progressively weakened.

Finally, the relegation of field studies by the upsurge of laboratory studies, and particularly office-based studies (Hartemink 2001), also contributed to loss of the understanding of soil as a natural object – a viewpoint that was enormously fruitful at the outset of pedology as a science and one that had always been deemed necessary for teaching the subject. The didactic and epistemological aspects of nature were largely substituted by the mathematical formulation of models and convenient experimentation in closed controlled laboratory systems. The speciality of cartography, the success of which relies on a good number of days being spent in the field, was even gradually usurped by the use of remote sensors to supply information (that was received in the office). What was once a powerful and indispensable tool for the spatial representation of soils was converted into the central argument of such studies, and the true representation of soil for proper field evaluation was consigned to history.

These considerations, which appear to reflect a great deal of pessimism in relation to the future of soil science, contrast with other views. For

example, the leading research journal *Science* published a special issue dedicated to soils (11.06.2004) and declared that "interest in soil is booming". Moreover, in justifying a workshop held in 2005 on "Frontiers in Soil Science Research", the US National Research Council pointed out that "soils provide a support for both natural and human systems".However, it is above all Hartemink who places the greatest emphasis on the renewed role that soil is playing at present. "Soil are back to the global agenda" (Hartemink 2008) and "A soil science renaissance" (Hartemink and McBratney 2008) are some of this author's articles, in which he aims to demonstrate how international organisms such as FAO, UNEP and UN, via their different programmes of action, are again according soil great importance. Moreover, the fact that five handbooks and encyclopaedias of soil science were published between 2000 and 2008 may also be a symptom of the emergent interest in soil. Finally, taking into account other considerations related to the capacity of soil to interact with the hydrosphere and the atmosphere (defined as the "critical zone"), Lin (2005) predicted that "soil science can enter its golden age via vigorous integration of its expertise with other bio and geosciences".

3. Future in soil science: key factors in the crisis and possible solutions

The apparent contradiction between these two visions of soil science may be resolved by considering that the optimistic approach considers "soil" as an object, whereas the negative approach involves the classical form of understanding soil science, which is basically the predominant approach used in universities and research centres. Although soil will be claimed as an object of study by an ever-wider group of specialists (giving rise to the aforementioned boom), as a group, soil scientists will find it increasingly difficult to be recognised as important by society. This diagnosis, which appears to be correct judging from the data available, represents a formidable challenge for the future of soil science. The final reflections outlined in this paper are made in an attempt to analyse the key factors in this crisis and to discuss some possible solutions.

The first observation is fundamental: leaving the study of soil scientists to non specialists will lead, more or less in the long term, to the disappearance of the concept of soil as a natural entity that evolves and displays its own processes and functions in nature. Soil will probably be considered as a material of interest for its complexity and functions, but little more. It is therefore important to consider the core fundamentals of pedological knowledge in order to define what soil is and to ensure that all researchers dedicated to the study of soil, whether soil scientists or not, accept and use this definition as a basic conceptual framework. The definition should be fairly simple so that it can be disseminated successfully, and it will possibly be largely based on the concepts of soil proposed by Jenny and Simonson, and of the importance and properties of their levels of organization. Mention of the seven basic soil functions will provide the necessary practical balance that should also be highlighted (Bouma 2008). In summary, a return to the "research traditions" associated with soil science would be timely. Churchman (2010) analyzed these traditions, which Laudan (1986) proposed as an improvement on the "programmes" of Lakatos or the "paradigms" of Khum. Churchman's approach considers that studies that use methods or concepts from other disciplines, such as chemistry, physics and biology, should be excluded from the definition, as although applied to soil, they really belong to these other fields. Churchman concludes that the three unique aspects of soil science are horizons, aggregates and colloids. We would add that rather than considering soil horizons, it might be better to consider soil profiles or even the three-dimensional expression defined by Hugget (1975). We have no objections regarding aggregates; however, the colloidal state can only be interpreted in this respect if it is considered as the initial state of the aggregation processes, according to proposals such as that made by Tysdall and Oades (1982).

In an open society, free competition is inevitable and soil scientists must therefore compete with other specialists for soil-related studies. In this situation, it is essential to clarify the specific role of soil and of the study methods, and therefore the reductionist approaches used in many of the specialities or subspecialties of pedology merely restrict the field, making competition with other specialists more difficult. Nevertheless, in some disciplines, such as chemistry and physics, certain techniques and theories were always much more established and consolidated than in soil science. Therefore, it is not superspecialization, but rather a holistic and integrated view of soil that confers a competitive advantage. Holistic, because the soil system possesses particular characteristics that make it unique in nature, and integrated, because its functions cannot be separated from its relationships with air, water, rock material and life.

An interdisciplinary approach can also be considered. First and foremost, training in soil science must be interdisciplinary. Soil in all its complexity cannot be understood without some basic knowledge of geology, biology, physics, chemistry and mathematics. The specialities into which soil science is divided may represent fields of knowledge that should be investigated further by the application of certain techniques and specific concepts, but they should never represent hermetic spaces delimited by insurmountable barriers, as is often the case. Soil genesis, an integrative discipline most usually concerned with soil types, should constitute a cohesive force for the different specialities. However, this should not be done in the discreet, closed and cryptic manner in which soil systematics has often been approached, but in an open manner modulated by the space and time continuum of soils. The field approach would be the most appropriate for expressing what pedological measurements have already made clear: that the different properties of soil extend continuously across space and that the limits that we impose are conceptual constructs used to organize information, but are rarely tangible realities. In summary, the interdisciplinary approach should be applied systematically with specialists from the different fields with which soil science interacts. In the collective work entitled *The Future of Soil Science*, edited by Hartemink (2006), many of the 55 soil scientists who collaborated in the book considered that soil science "cannot work in isolation, needs to be part of multidisciplinary or interdisciplinary teams, and should reach out other disciplines."

The interesting "Critical Zone" concept proposed by the US National Research Council (2001) emphasizes the central role of the pedosphere in relation to the atmosphere, lithosphere, hydrosphere and biosphere; within this framework, the interfaces via which the soil comes into contact with other media can be clearly defined. How exchange of matter and energy occurs and, finally, how these generate the different biogeochemical cycles can also be considered. It is within these limits that the richest exchange of knowledge and the birth of new ideas should arise readily and spontaneously, which is why they should be encouraged. The term "interdisciplinary approach" is a continually cited objective of science, which in practice is difficult to achieve. It is extremely difficult to decipher the codes of a discipline, which have been developed during years of experience, and to transfer them to other disciplines and thus establish a fluent, constructive dialogue. Nonetheless, it is a worthwhile goal, as the search for a common language in order to expand the frontiers of knowledge has perhaps become the most pressing task for specialists (science cannot be anything other than specialized) at the beginning of this millennium.

Moreover, we must remember that pedology is an applied science, which has traditionally addressed the numerous demands of society. Therefore, its future success will largely depend on the timeliness and appropriateness of the response to these needs. In 2010, the Soil Science Society of America attempted to identify the main challenges facing soil science. Four problematical areas were identified: Human and Ecosystem Health, Waste Treatment and Water Quality, Food and Energy Security, and Climate Change. The fundamental lines of study were defined for all of these areas in the short, mid and long term, and the priority knowledge gaps towards which studies should be directed were identified (SSSA 2010).

Finally, the society in which we live is increasingly dependent on communication, and many people are only aware of topics that appear in the mass media. For soil science to achieve this level of "visibility", scientists must recognize that although a research paper represents the first link in the chain of scientific communication, it is not the only or nowadays the most important link in this chain. Articles published in the most widely read journals (Science, Nature, etc.) are used to create press releases, which are fed to new agencies and thus reach the mass media (newspapers, TV, popular magazines, etc.) (Díaz-Fierros 2005). The scientific stories that reach the public and centers of political and economic decisions are usually constructed from the most easily understood and popular articles, which are not usually research papers. Soil scientists must urgently make efforts to appear in the media if they wish to receive appropriate recognition of their research work.

In his book on research policies in South America, Sagasti (2011) pointed out that these are comparable to the Myth of Sisyphus: research networks are built up over many years with great effort (rolling the boulder up the hill), and can then be totally ruined by the application of misplaced policies, and must be constructed anew. In the same way, the Argentinian physicist Jorge Sábato stated that "It takes 15 years to construct a world level research institute, but only two years to destroy it."

In many countries, strong soil research teams have been built up with a great deal of investment in terms of talent and structures. The current economic crisis that has been superimposed on the larger-reaching crisis that has affected pedology since the *environmental wave* may lead to the total disappearance of these research groups. This is a reality that cannot be ignored. It must also be recognized that a country cannot develop most of its strategic sectors without adequate knowledge of its soils and their functions. This is a dramatic and pessimistic message to finish on. However, as soil scientists we must take this message on board and use all of the means available to transmit the crude reality to society and propose the necessary solutions.

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