História da Ciência e Ensino
Construindo interfaces

http://dx.doi.org/10.23925/2178-2911.2019v20espp738-746

Soil Science: from Babylon to the Present

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Abstract

Soil is a material with unique features and behavior at the interface between the biologic, hydrologic, lithologic, and atmospheric spheres of our planet that plays a vital role in human welfare. The history of soil has been in step with the history of the use of soils to grow plants, a history of agriculture from earlier civilizations to our days. Until the 19th century, no experimentation and testing of theories were conducted and there was no real science. Soil science was born about 150 years ago with the works of English, German, Danish and, above all, Russian scientists. In mid-20th century, under pressure of human activities upon the environment, soil science out grew its base knowledge applied to agriculture and agronomy to play an ever-increased role of land and environmental issues. It was born the concept of soil security and soil was understood in its role of delivering ecosystem services and used to quantify the soil resource aggregating contributions of soil scientists, economists, social scientists and policy makers for decision-making process about soil.

Keywords: *Soil Evolution, History, Science*

Resumo

O solo é um material com características e comportamento únicos na interface das esferas biológica, hidrológica, litológica e atmosférica do nosso planeta e tem um papel vital no bem-estar humano. A história do solo tem seguido a par do uso do solo para crescer plantas, a história da agricultura desde as antigas civilizações até aos nossos dias. Até ao século 19, não houve experimentação e validação de teorias e não existiu verdadeira ciência. A ciência do solo nasceu há cerca de 150 anos com o trabalho realizado por cientistas Ingleses, Alemães, Dinamarqueses e, sobretudo, Russos. A meados do século 20, sob pressão das actividades humanas sobre o ambiente, a ciência do solo ultrapassou a sua base de conhecimento aplicada à agricultura e agronomia para abraçar temas sobre a terra e o ambiente. Nasceu o conceito de segurança do solo e este tratado no seu papel de proporcionar serviços ambientais e usado para quantificar os recursos edáficos agregando contribuições de pedologistas, economistas, sociólogos e políticos no processo de tomadas de decisões sobre o solo.

Palavras-Chave: *Evolução de Solo, História, Ciência*

Introduction

Friedrich Albert Fallon (1794–1877), considered a founding father of soil science in Germany, wrote in 1892 "there is nothing in the whole nature which is more important or deserves much attention as the soil. Truly it is the soil which nourishes and provides for the whole nature, the whole of creation depends on the soil, which is the ultimate foundation of our existence"[1] . Soil has also been defined as a natural body consisting of layers composed of weathered mineral materials[2], organic material, air and water

[1] Sparks, D.L. *Soil Physical Chemistry, Second Edition*. Edited by John DSulzycki. 2nd ed. London: Taylor & Francis,1998.
[2] FAO, [Food and Agricultural Organization]. "Fao Soils Portal." FAO. Last modified 2018. Accessed Nov 2018, 2018. http://www.fao.org/soils-portal/about/all-definitions/en/.

that plays a vital role in human welfare assuring agricultural productivity and environmental stability. Soil science provides the fundamental understanding of the physical, chemical, and biological properties and processes occurring in this complex ecosystem.

Soil is at the interface between the biologic, hydrologic, lithologic, and atmospheric spheres of our planet. It serves in many roles such as the support to our construction projects, it is intrinsically related to the global climate, it provides raw materials, and products from which medicines have been developed, and many more.

This is a timeline that has the objective of illustrate the increased complexity of a scientific area from its humble origins as an empirical observation with the single purpose of growing plants to an actual multidisciplinary field concerned with many aspects of Human culture, development and sustainability.

From Antiquity to Renaissance

The history of soil for millennia has largely been a history of agriculture, a history of the use of soils to grow plants. The earliest evidence of "soil science" comes from Mesopotamia, about 11000 years ago, where people recognized differences in fertility between soils. Babylonians developed a complex civilization based on irrigation but their used of sloped land for growing crops and animals destroyed their soil by erosion and consequent siltation that, eventually, demised their rule.

The Ancient Egyptian civilization was dependent on irrigation and the fertility of the agricultural soils naturally maintained by regular flooding of the Nile River which deposited rich silt. The Egyptians knew how to prepare soil to receive seed and the importance of fertilized soils brought about by the flooding.

Libation, or the pouring of wine or blood on the ground, was an important element of religious practice in ancient Greek religion, indicating reverence for soil[3] . Ancient Greek philosopher-scientists developed a clear technical understanding of soils, dividing them according to color-texture (Xenophon and Theophrastus), fertility (Plato and Strabo) and medical considerations (Hippocrates and Theophrastus)[4] .

The Romans inherited the knowledge of agriculture and soils from the Greeks. Roman writers such as Columella, Varro, Cato, Virgil, and Pliny delved in farming practices and emphasized the need of taking and returning to the land[5], a recognition that soils must be replenished in their fertility. The Romans took steps beyond the Greek practices like terracing their fields to reduce erosion[6], a development that we can see today in the Douro Region, for instance.

[3]Burkert, W. *Greek Religion*. Cambridge: Harvard University Press, 1985.
[4] Retallack, Gregory J. "Rocks, Views, Soils and Plants at the Temples of Ancient Greece." *Antiquity* 82, no. 317 (2008): 640-57. http://dx.doi.org/10.1017/S0003598X00097283.
[5] Savio, Hannah L. "Sustainable Agriculture in Ancient Rome." Last modified 2011. Accessed 11 November, 2018. https://digitalwindow.vassar.edu/senior_capstone/2/.
[6] Brevik, Eric C. and Alfred E. Hartemink. "Early Soil Knowledge and the Birth and Development of Soil Science." *Catena* 83, no. 1 (2010): 23-33. http://dx.doi.org/10.1016/j.catena.2010.06.011

In China there are reports mentioning agriculture practices to ameliorate the land that date back to the 23rd century BC. Records from 956 BC mention soil conservation[7] and Fan Sheng-chih wrote of soil properties and of optimal times for tillage in the 1st century BC[8] .

During the Middle Ages, Islamic societies were the world's leaders in science, math, and technology. Their knowledge included agricultural sciences and Muslim mathematics advanced the engineering of irrigation systems, Muslim agronomists could identify soils most suitable to the crops being grown, Muslim libraries usually included agricultural books, and in 10th century the scholar Cordoba developed and agricultural calendar that included monthly tasks to prepare the soil for agriculture[9].

The Renaissance in Europe starting in the 15th century brought a renewed interest in science and a few studies about soils were carried out by several authors including Francis Bacon and Leonardo da Vinci. In 16th century Europe, the land was considered the most important economic factor and there was a direct relationship between the land (soils) and government. The philosopher Niccolò Machiavelli (1469–1527) believed variations in population density were primarily a function of soil fertility, therefore, governments could address problems of population distribution through fertilization of deficient soils. Baron de Montesquieu (1689–1755) believed that soil determines the economic vitality, governance, and national character of a country[10].

From 19th century to mid-20th century

Soil science, recognized as a true science, was not developed during those ancient times because Human knowledge of soil was based on observation of nature, no experimentation and testing of theories were conducted. Soil as a true science has its roots in the 19th century with the work developed by Vasily Vasilievich Dokuchaev (1846-1903) a world-known Russian naturalist, geologist and soil scientist. Russians and Soviet soil scientists would become the leading authorities and most prolific authors in soil science till the decade of 70's of 20th century. The first scientific journal dedicated to soil science – Pochvovedenie - was published in 1899; in the early 1960s, some 23% of all internationally published research papers in soil science were produced in the Soviet Union and the first book exclusively dedicated to the history of soil science was authored by I.A. Krupenikov in 1971[11] .

[7] Idem.
[8] Fan, Shengzhi. *On "Fan Sheng-Chih Shu," an Agriculturist Book of China Written in the First Century B.C.*. Edited by Shenghan Shi. Peking: Science Press, 1959.
[9] Brevik, Eric C. "The Teaching of Soil Science in Geology, Geography, Environmental Science and Agricultural Programs." *Soil Survey Horizons* 50 (2009): 120–23. http://dx.doi.org/10.2136/sh2009.4.0120
[10] Krupenikov, I.A. *History of Soil Science: From Its Inception to the Present*. Rotterdam, Netherlands: A.A. Balkema, 1993.

[11] Yaalon, D. H. "On the Importance of International Communication in Soil Science." *Eurasian Soil Science* 32, no. 1 (1999): 22-24. https://www.iuss.org/files/intcommunication.pdf.

The foundations required to build a modern soil science were laid down in the 19th century as it evolved from other scientific fields that included biology, chemistry, physics and, in particular, geology in such extent that soil science was often referred to as agroecology at the time when scientists studying soils in the field were trained geologists. Soil science lagged 50 to 60 decades behind geology in becoming its own independent field of scientific study and during the 19th century soil science was mostly concerned with agriculture chemistry[12]. In the 1860s and 1870s a simple concept for understanding and studying soils become known as the A-B-C soil profile fruit of the work of English, German, Danish and Russian scientists[13].

However, that century saw also the development, no matter how timid, of separate disciplines in soil science like soil biology championed by Charles Darwin (1809-1882), best known for his work in evolution[14]. Since its inception some 150 years ago, soil science received still other inputs coming from mathematics, hydrology, geostatistics, ecology and become a true science in its own right concerned with a material that has unique features and behavior, with its own set of tools, techniques, terminology and classification where many descriptive practices were replaced by systematic observations coupled with inductive reasoning and deductive experimentation[15,16]. Soil science had evolved from qualitative and descriptive knowledge to a quantitative approach including assessments of uncertainties.

Soil science had a regional focus until the early 1900s but during the 20th century the soil science knowledge base rapidly expanded fostered by scientific papers and books. A great help has provided by the creation of the International Society of Soil Science (ISSS, now IUSS — International Union of Soil Sciences) in 1924[17].

The history of soil has been in step with the history of the use of soils to grow plants and the earlier works in soil science related to agriculture and it has made large contributions to the increase of agricultural production[18]. However, in second half of the 20th century became also important for non-agriculture purposes such as construction, environment management, climate change, ecosystem services,

[12] Hartemink, Alfred E. "The Depiction of Soil Profiles since the Late 1700s." *Catena* 79, no. 2 (2009/11/15/ 2009): 113-27. http://dx.doi.org/10.1016/j.catena.2009.06.002
[13]Tandarich, John P. , Robert G. Darmody, Leon R. Follmer, and Donald L. Johnson. "Historical Development of Soil and Weathering Profile Concepts from Europe to the United States of America." *Soil Science Society of America Journal* 66 (2002): 335-46. http://dx.doi.org/10.2136/sssaj2002.3350
[14] Berthelin, Jacques, Ulrich Babel, François Toutain, and Beno Warkentin. "History of Soil Biology." In *Footprints in the Soil. People and Ideas in Soil History*, edited by Benno Warkentin, 279-306. Amsterdam: Elsevier, 2006.
[15]Mermut, A. R. and H. Eswaran. "Some Major Developments in Soil Science since the Mid-1960s." *Geoderma* 100 (2001): 403-26. http://dx.doi.org/10.1016/S0016-7061(01)00030-1.
[16] Bouma, Johan. "The Role of Quantitative Approaches in Soil Science When Interacting with Stakeholders." *Geoderma* 78 (1997): 1-12. http://dx.doi.org/10.1016/S0016-7061(97)00014-1
[17] Hartemink, Alfred E. "On Global Soil Science and Regional Solutions." *Geoderma Regional* 5 (2015): 1-3. http://dx.doi.org/10.1016/j.geodrs.2015.02.001.
[18] Bouma, J. and A. E. Hartemink. "Soil Science and Society in the Dutch Context." *NJAS - Wageningen Journal of Life Sciences* 50, no. 2 (2003/01/01/ 2003): 133-40. http://dx.doi.org/10.1016/S1573-5214(03)80002-7.

community planning, taxation, and so on[19]. Soil science has taken an important role in solving environmental problems like pollution, groundwater contamination and carbon sequestration[20].

Archaeology has a great demand for soil information because it is important to know whether a particular layering has a natural pedogenetic origin or is due to the accumulation of different sediments with anthropogenic origin[21]. Soils can transmit diseases and a number of medicines have been isolated from soil organisms, thus soils and human health will receive increasing attention in coming years[22, 23] . Soils are now of great interest in sustainable food production, biofuels, erosion control, nutrient depletion and many other issues. The holistic approach to soil science has a reflex in teaching that no longer is confined to agriculture and agronomy but it has expanded to be included in other courses like botany, ecology, geography, hydrology, etc.[24, 25] in expectation that soil science teaching will provide knowledge, skills and capacities to work across disciplines, to produce a wide range of problem-solving scenarios and to address increasingly complex environmental problems[26, 27].

Soil science has made significant contributions to the quality of human life and increased our capacity to manage the soil resource to meet our needs for food and fiber but in the last 60 or so years it become clearer that our needs only can be met in the context of a functional ecosystem. Soil is a fragile, slow forming resource under increasing pressures due to human activities. The challenge we face today is to balance human demands with ecosystem services and their integrity and it has spurred new areas of soil research such as soil quality, land degradation, cycling of bio-geochemicals that, in turn, increased our

[19] Tinker, P. B. "Soil Science in a Changing World." *Journal of Soil Science* 36 (1985): 1-8.
[20] Hartemink, Alfred E. "Soil Science in Tropical and Temperate Regions—Some Differences and Similarities." In *Advances in Agronomy*, edited by Donald L. Sparks, vol 77, 269-92: Academic Press, 2002.
[21]Shelley, Steven, Jeffrey Homburg, Antony R Orme, and Eric Brevik. "Environment, Soils, and Stratigraphy." In *At the Base of the Bluff: Archaeological Inventory and Evaluation Along Lower Centinela Creek, Marina Del Rey, California*, edited by Jeffrey H. Altschul, Anne Q. Stoll, Donn R. Grenda, and Richard Ciolek-Torrello, 77-99. California: Statistical Research, Inc., 2003.
[22] Brevik, Eric C. "The Teaching of Soil Science in Geology, Geography, Environmental Science and Agricultural Programs." *Soil Survey Horizons* 50 (2009): 120–23. http://dx.doi.org/10.2136/sh2009.4.0120.
[23] McBratney, Alex, Damien J. Field, and Andrea Koch. "The Dimensions of Soil Security." *Geoderma* 213 (2014/01/01/ 2014): 203-13. http://dx.doi.org/10.1016/j.geoderma.2013.08.013.
[24] Wessolek, Gerd. "Some Reflections on the Future of Soil Science." In *The Future of Soil Science*, edited by A. E. Hartemink, 150-52. Wageningen, Netherlands: International Union of Soil Sciences, 2006.
[25] Hartemink, Alfred E., Megan R. Balks, Zueng-Sang Chen, Patrick Drohan, Damien J. Field, Pavel Krasilnikov, David J. Lowe, Martin Rabenhorst, Ken van Rees, Peter Schad, Louis A. Schipper, Marthijn Sonneveld, and Christian Walter. "The Joy of Teaching Soil Science." *Geoderma* 217-218 (2014/04/01/ 2014): 1-9. http://dx.doi.org/10.1016/j.geoderma.2013.10.016.
[26] Field, D. J., A. J. Koppi, L. Jarrett, and A. McBratney. Engaging Employers, Graduates and Students to Inform the Future Curriculum Needs of Soil Science. Proceedings of The Australian Conference on Science and Mathematics Education Australian National University, 2013.
[27] Field, D. J., D. Yates, A. J. Koppi, A. B. McBratney, and L. Jarrett. "Framing a Modern Context of Soil Science Learning and Teaching." Geoderma 289 (2017/03/01/ 2017): 117-23. http://dx.doi.org/10.1016/j.geoderma.2016.11.034.

awareness of ecosystem health and quality. It was created the concept of sustainable development formed and given scope and depth by Agenda 21[28].

Late 20th century to our days

Since the last two decades of the 20th century to the present, the traditional role of soil science is diminishing as it has increased the need of soil information to support a sustainable land management and the health of the ecosystems. Soil science today is more concerned with resource assessment and monitoring, new information technologies through the innovative use of Geographic Information Systems (GIS) and remote sensing allow for higher quality of information with ever increasing applications[29]. We can say that it is now uncontroversial that soil and soil science are integral players in the global challenges of environmental sustainability, of food and water security, energy sustainability, climate change, biodiversity, and ecosystem services[30].

These challenges gave rise to the broad concept of soil security with multidimensions, generally laid out as 1) capability (the intrinsic capacity of a soil to produce products and ecosystem services), 2) condition (the current state of the soil, including modification by human activities), 3) capital (economics of soil services to Health, Environment and Food production), 4) connectivity (the social connection of soil managers and custodians and users of soil products and services to the soil), and 5) codification (policy frameworks: identification of policies that degrade soil security and those that secure soil) of soil entities which encompass the social, economic and biophysical sciences and recognize policy and legal frameworks[31].

The concept of soil security (fig. 1) creates the possibility to understand soil and its role in delivering ecosystem services and it is used to quantify the soil resource by measuring it, mapping it, modelling it, managing it and forecasting its change with the aggregated contributions of soil scientists, economists, social scientists and policy makers for decision-making process about soil[32]. Soil security is inextricably linked to the soil functions that are the inherent capabilities of the soil that include biomass and

[28] United Nations, UN. "United Nations Conference on Environment and Development, Agenda 21." United Nations Last modified 1992. Accessed 11 November, 2018. https://sustainabledevelopment.un.org/content/documents/Agenda21.pdf.
[29] Mermut, A. R. and H. Eswaran. "Some Major Developments in Soil Science since the Mid-1960s." Geoderma 100 (2001): 403-26. http://dx.doi.org/10.1016/S0016-7061(01)00030-1.
[30] McBratney, Alex, Damien J. Field, and Andrea Koch. "The Dimensions of Soil Security." *Geoderma* 213 (2014/01/01/ 2014): 203-13. http://dx.doi.org/10.1016/j.geoderma.2013.08.013.
[31] Morgan, C., A. McBratney, D. Field, A. Koch, and J. Bouma. "Report on 2015 Global Soil Security Symposium." Last modified 2015. Accessed 11 November, 2018. https://www.soils.org/meetings/global-soil-security.
[32]Field, D. J., D. Yates, A. J. Koppi, A. B. McBratney, and L. Jarrett. "Framing a Modern Context of Soil Science Learning and Teaching." *Geoderma* 289 (2017/03/01/ 2017): 117-23. http://dx.doi.org/10.1016/j.geoderma.2016.11.034.

food production, maintaining soil biodiversity, carbon and nutrient sequestration, water filtration and transformation, landscape and heritage, and source of raw materials[33].

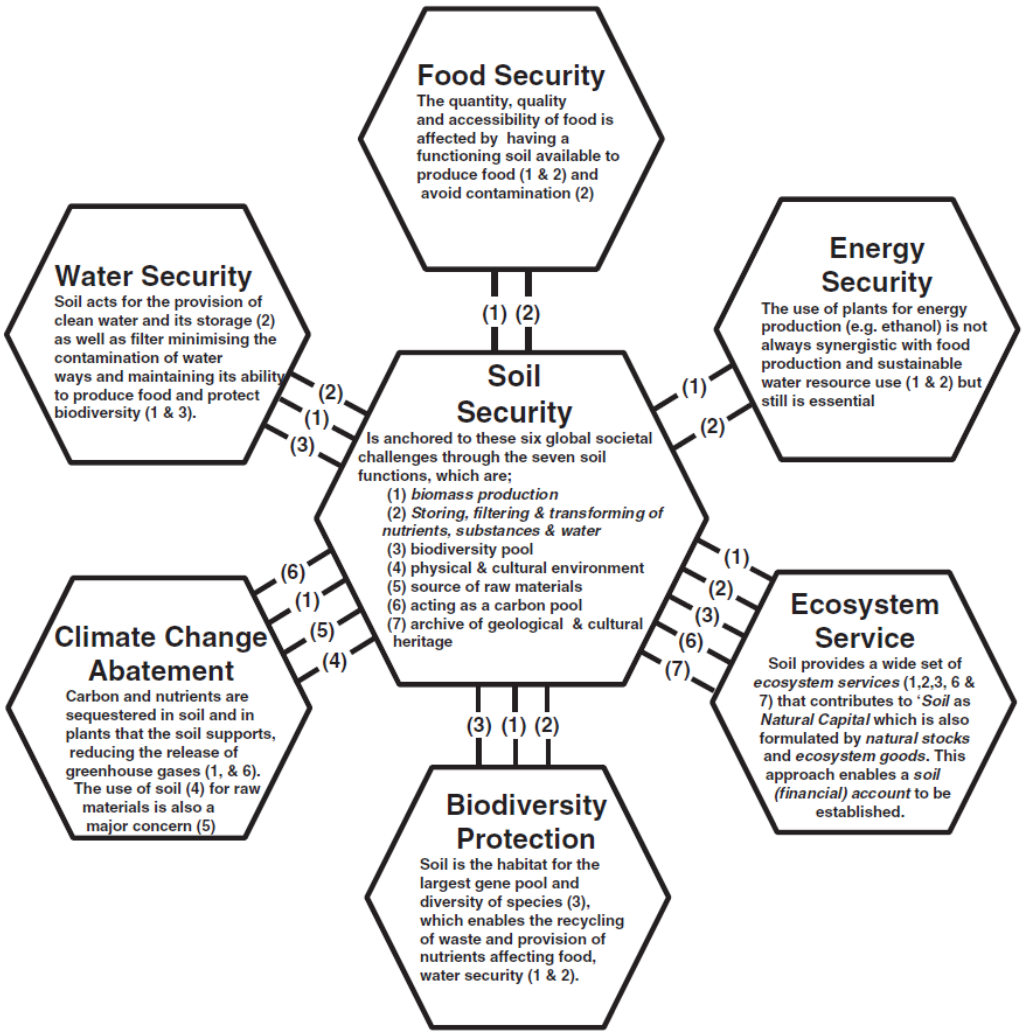

Figure 1: Alignment of the concept of soil functions[34].

Seen in figure 1, soils as one of the more species-rich habitats of terrestrial ecosystems render a wide of services to humans[35].

[33] Giannakis, GV, NP Nikolaidis, J Valstar, EC Rowe, K Moirogiorgou, M Kotronakis, NV Paranychianakis, S Rousseva, FE Stamati, and S Banwart. "Integrated Critical Zone Model (1d-Icz): A Tool for Dynamic Simulation of Soil Functions and Soil Structure." In *Quantifying and Managing Soil Functions in Earth's Critical Zone: Combining Experimentation and Mathematical Modelling*, edited by DL Sparks and SA Banwart, vol 142, Advances in Agronomy, 277-314. London: Academic Pres, 2017.
[34] McBratney, Alex, Damien J. Field, and Andrea Koch. "The Dimensions of Soil Security." Geoderma 213 (2014/01/01/ 2014): 203-13. http://dx.doi.org/10.1016/j.geoderma.2013.08.013.
[35]Blum, Winfried E. H. "Functions of Soil for Society and the Environment." Reviews in Environmental Science and Bio/Technology 4, no. 3 (2005): 75-79. http://dx.doi.org/10.1007/s11157-005-2236-x.

The term ecosystem service emerged in the early 1980s and it has received considerable attention. It can be defined as the capacity of natural processes and components to provide goods and services that satisfy human needs, directly or indirectly, divided in four categories: supporting, provisioning, regulating and cultural services[36].

Soil ecosystem services are attributed an economic value that ranges from US$2 to an excess of US$20000 per year and hectare[37]. If there is an economic output, then the service is provided by a "capital", in this case a natural capital defined as "the stock of materials or information contained within an ecosystem"[38]. Natural capital and stocks are relevant to soil science, given the worldwide assessment of soil stocks through survey and inventory[39].

Now the task at hand of soil science is to judge objectively the values of soils in all services they provide, both tangible and intangible. In the words of Greenland[40] "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".

Soil science in Portugal

A number of illustrious Portuguese gave a precious contribution to soil science in Portugal and in its former colonies now independent countries. Let's mention only two of them:

- Abade Correia da Serra (José Francisco Correia da Serra, 1750-1823) was co-founder of Lisbon Royal Science Academy. He was one the first scientists in the world to recognize that the rock (parental material), relief and time as factors in soil formation.
- Professor Joaquim Botelho da Costa (1910-1965). He is considered the founding father of soil science in Portugal.

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[36] Robinson, D. A., N. Hockley, D. M. Cooper, B. A. Emmett, A. M. Keith, I. Lebron, B. Reynolds, E. Tipping, A. M. Tye, C. W. Watts, W. R. Whalley, H. I. J. Black, G. P. Warren, and J. S. Robinson. "Natural Capital and Ecosystem Services, Developing an Appropriate Soils Framework as a Basis for Valuation." Soil Biology and Biochemistry 57 (2013/02/01/ 2013): 1023-33. http://dx.doi.org/10.1016/j.soilbio.2012.09.008

[37] Jónsson, Jón Örvar G. and Brynhildur Davíðsdóttir. "Classification and Valuation of Soil Ecosystem Services." Agricultural Systems 145 (2016): 24-38. http://dx.doi.org/10.1016/j.agsy.2016.02.010

[38] Costanza, Robert, Ralph d'Arge, Rudolf de Groot, Stephen Farber, Monica Grasso, Bruce Hannon, Karin Limburg, Shahid Naeem, Robert V. O'Neill, Jose Paruelo, Robert G. Raskin, Paul Sutton, and Marjan van den Belt. "The Value of the World's Ecosystem Services and Natural Capital." Nature 387, no. 6630 (1997/05/01 1997): 253-60. http://dx.doi.org/10.1038/387253a0.

[39] Robinson, D. A., N. Hockley, D. M. Cooper, B. A. Emmett, A. M. Keith, I. Lebron, B. Reynolds, E. Tipping, A. M. Tye, C. W. Watts, W. R. Whalley, H. I. J. Black, G. P. Warren, and J. S. Robinson. "Natural Capital and Ecosystem Services, Developing an Appropriate Soils Framework as a Basis for Valuation." Soil Biology and Biochemistry 57 (2013/02/01/ 2013): 1023-33. http://dx.doi.org/10.1016/j.soilbio.2012.09.008

[40] Greenland, D. J. "The Contributions of Soil Science to Society - Past, Present, and Future." Soil Science 151 (1991): 19-23. https://journals.lww.com/soilsci/Abstract/1991/01000/The_Contributions_of_Soil_Science_To_Society_Past,.4.aspx

The work of many Portuguese soil scientists can be appreciated in this short list of historical marks:

1949 – Carta dos Solos de Portugal (*Soil Map of Portugal*) (1:1 000 000)

1952 – Criação da disciplina de Pedologia e Conservação do Solo no Instituto Superior de Agronomia (*Creation of the course Pedology and Soil Conservation at the Instituto Superior de Agronomia*)

1953 – Publicação "Solos de Angola" (*Published "Soils of Angola"*)

1954 – Mapa Provisório dos Solos de Moçambique (*Provisional Map of Soil of Mozambique*)

1961 – Os Solos de Portugal. Sua Classificação, Características e Génese. I. A Sul do Rio Tejo (*Soils of Portugal. Classification, Characteristics and Genesis. I. To the South of Tagus River*)

1971-1973 – Carta de Solos de Portugal (*Soil Map of Portugal*) (1:1 000 000), SROA

1982 - Reserva Agrícola Nacional (*National Agriculture Reserve*)

Concluding remarks

The study of soil was born out of necessity to grow food and remained as a simple empirical observation for millennia. Trained geologists of the 19th century approached the study of soil with the methods of a science and, step by step, soil science emerged as a science on its own right. The past century saw the development of a multidisciplinary science incorporating more diverse technologies. Today, soil science addresses almost every corner of Human existence from its physical world to its social and economic needs. Many challenges of Human development are now incorporated and worked out in soil science. This complexity creates different approaches in scope and depth to teach and educate students and society in general.

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