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A Brief Analysis of the Contribution of Women to Soil Science

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Soil science has traditionally been dominated by men, and women remain a minority in this field today. Despite soil science being more recent than other scientific disciplines, many women have made significant contributions to the field, although these are not generally recognized. Recent studies have shown a lack of gender balance and low levels of diversity and inclusion in soil science in several countries worldwide. Although partial and fragmentary, the information provided by the present study of the involvement of women in soil science research reinforces the idea that science should be looked at from a gender perspective in order to promote real equality between men and women. Science and soil science are both the result of historical and cultural events and social context. Science is not neutral: it is social and gendered and always will be, but we can try to make it more inclusive.

Keywords: reflections on gender perspective, scientific knowledge, women soil scientists worlwide, Russian and Soviet female scientists, foreign female soil scientists

INTRODUCTION

According to UNESCO (2021a; 2021b), men and women must enjoy equal opportunities, power, choices, capabilities and knowledge. Girls and women account for 50% of the world's population and hence 50% of its potential. Gender equality is not only one of the fundamental rights of our society, but it is also one of the fundamental pillars on which to build a peaceful, prosperous and sustainable world. UNESCO's International Women's Day (8 March) highlights actions that encourage gender parity and commemorate the social, cultural, economic and political accomplishments of women worldwide.

For more than 75 years, gender equality has aroused great interest in society. The United Nation's Commission on the Status of Women (CSW) addresses this issue, leading debates on discrimination against women and girls around the world and promoting numerous actions to promote their rights. Regarding the field of science, the NU's resolution of 14 March 2011 and 20 December 2013 recognize that equal access to and participation in education, training and science and technology are imperative in order to achieve gender equality and women's empowerment. In order to draw attention to this issue, in 2015 the United Nations proclaimed 11 February as the International Day of Women and Girls in Science. However, despite the efforts made throughout the years, studies show that full, equitable access and participation of women in science is far from being achieved (Markert, 1996; CSIC, 2021). The inequality is particularly marked in the so-called STEM careers (Fox, 1994; NU, 2020; CSIC, 2021; Davila dos Santos et al., 2022), i.e., those related to science, technology, engineering and mathematics, and occurs both in less developed countries and more developed countries such as European Union countries and the United States.

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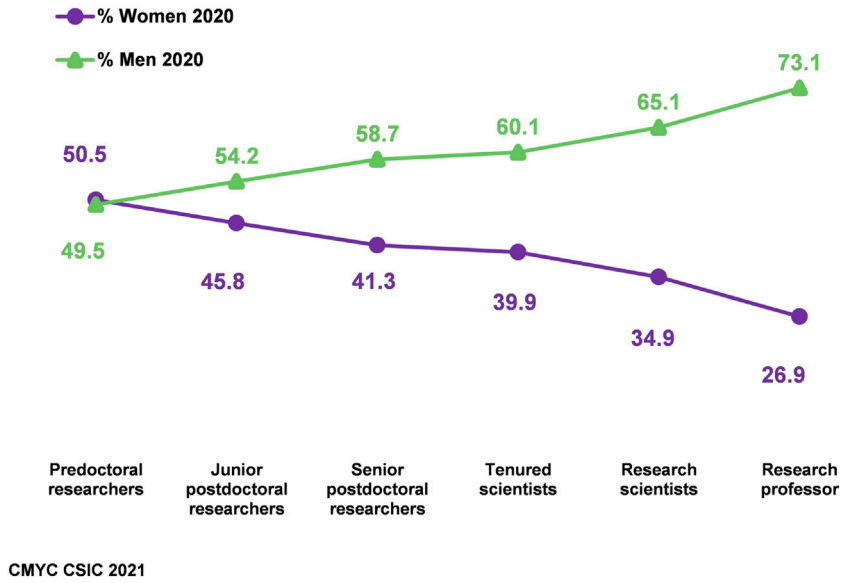

FIGURE 1 | Distribution of the research staff of the Spanish Research Council by gender in 2020 (CSIC, 2021).

Despite the growing demand for data on the involvement of women in science in different countries, to enable statistical analysis and for use in policymaking, information on this topic is scarce. The UNESCO Institute for Statistics (UIS) recently published a report (FS/2020/SCI/60: NU, 2020) including data on research and experimental development and a map depicting the world gender gap in science. In 2017, the average proportion of women scientists worldwide was 30% (range 23%–49%). The proportions were lowest in West and South Asia and the Pacific (23%–25%), followed by sub-Saharan Africa, Western Europe and North America (31–33%) and Eastern and Central Europe and the Arab States (39%–41%), and highest in Central Asia, the Caribbean and Latin America (46–49%). The proportions varied widely in different countries, ranging from 29% (Peru) to 61% (Venezuela) in South America, from 26% (Netherlands) to 53% (North Macedonia) in Europe, from 4% (Chad) to 56% (Tunisia) in Africa, from 8% (Nepal) to 77% (Myanmar) in Asia, and finally from 33% (New Zealand) to 52% (Papua New Guinea) in the Pacific region. Studies concerning changes in the contribution of women to different scientific disciplines at the national level are therefore necessary to identify trends and take actions to achieve a gender balance.

In order to examine the contribution of women in science in Spain, we used data provided by the Spanish National Research Council (CSIC) for the period 2000–2021 (CSIC, 2021). The research carried out in this public research institution, which includes 120 institutes distributed throughout the country, is multidisciplinary and multisectorial, covering all areas of knowledge, organised around three global areas: Society, Life and Material. The CSIC, sensitive to the problem of the relatively low number of women involved in the scientific work of the Institution, created the Women and Science Commission (CMyC) in 2002, with two main objectives: to study the possible causes that hinder both the entry and advancement of women and to propose possible actions aimed at achieving equality between men and women in the CSIC. The annual reports of women researchers prepared by the CMyC are available on the CSIC website.

The results of the report on Women Researchers 2021 (CSIC, 2021) indicated that there are almost no differences between the proportions of men (50.5%) and women (49.5%) undertaking pre-doctoral research (**Figure 1**). However, when the researchers advance in their career through the higher categories, these differences are markedly accentuated (27% and 73% for women and men, respectively). Comparison of scientific careers between 2009 and 2019 reveals that we are moving away from the desired equality (**Figure 2**). Women find it difficult to advance in the research field, as in the last 10 years there has been an increase of only 4 percentage points in the proportions of women in highest categories (from 23% to 27%), partly due to a greater number of retired male researcher lecturers. Women are also promoted less often, remaining in the same category for longer and receiving lower salaries. In the period considered, the proportion of female research staff was 36.2%, while women represented 23% of the staff participating in management of research centres: these values are within the range reported by the UN (UN, 2020). As expected, the presence of women leaders improves the visibility of the scientific achievements of women researchers. When appointed by the CSIC as President in 2017, Rosa Menéndez López became the first female President of this Spanish research institution in the 78 years of its existence. In 2019, López organized an event in recognition of the work of the pioneering scientific women employed by the CSIC (250 women) who have remained anonymous for so long and who have played a very important role in the advancement of scientific knowledge. Recently, in June 2022, Eloísa del Pino Matute became the second female President of the CSIC.

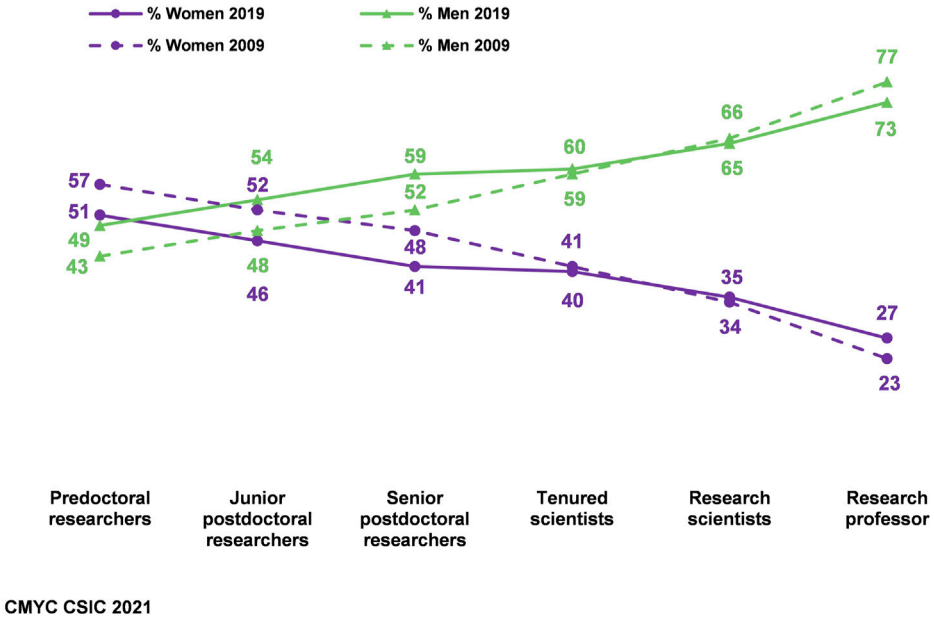

FIGURE 2 | Distribution of the research staff of the Spanish Research Council by gender in 2009 and 2019 (CSIC, 2021).

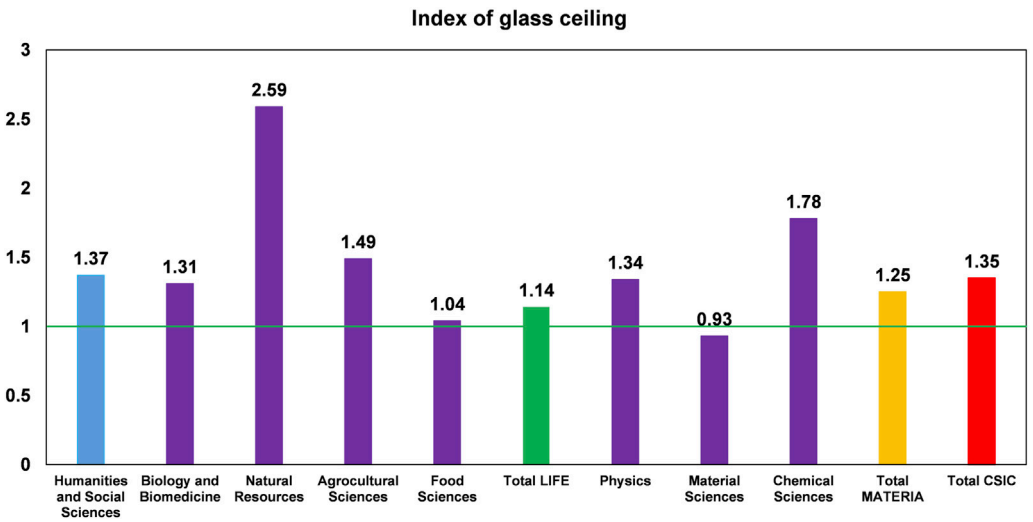

FIGURE 3 | Glass ceiling index of the female scientists of the Spanish Research Council during the period 2000–2020 (CSIC, 2021).

The analysis, disaggregated by gender into social, life and material categories, revealed that gender balance is not reached in any of the categories: Society, 38.8%; Life, 36.8%; and Material, 34.7%. In 2021, the global mean value of the glass ceiling index (GCI) remained at the same value as in the previous year (1.35), breaking the downward trend experienced over the previous 15 years (**Figure 3**). However, the GCI for the sub-area of Natural Resources (2.59) is of particular concern, as rather than decreasing relative to previous years, it has actually increased at a very alarming rate. In the other the sub-areas, the GCI values are similar to those in previous years, with a value of less than one for the Material Sciences and Technologies subarea. Analysis of these reports on Women in Science (2002–2020) (**Figure 4**) clearly demonstrates that the passage of time is in itself not sufficient to achieve changes and that, at least in Spain, active policies are required to promote gender equality in science. It is worthy of note that in Australia the implementation of gender equity strategies encompassing numerous measures of legislation and action plans of the government and university institutions and the individual faith

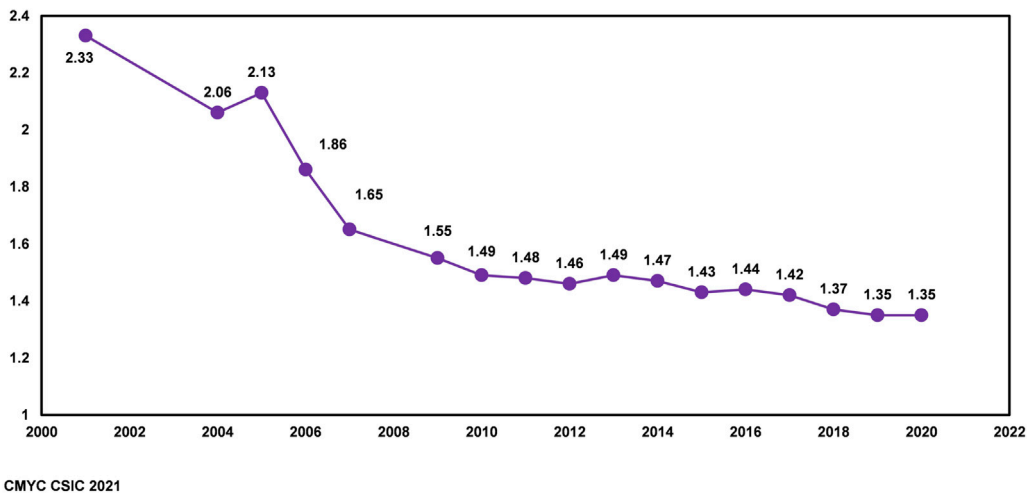

FIGURE 4 | Glass ceiling index of the female scientists of the Spanish Research Council distributed by subareas within the three global areas of society, life and material in 2020 (CSIC, 2021).

of researches have been very effective (Winchester et al., 2006). In the early 1990s, women researchers represented 20% of the teaching and scientific staff, occupying only 6% of the positions of greatest responsibility. Two decades later, the situation in the workplace has changed remarkably given that women now represent 44% of the research and teaching staff and occupy about 31% of the positions of greatest responsibility.

To address the subject of gender equality in science, the work involved in scientific professions must first be defined. Researchers participate in and carry out activities to generate new knowledge in all scientific fields (both natural and social sciences). According to Pérez Tamayo (2009), science is a creative activity aimed at understanding nature and that generates knowledge through a scientific method based on a deductive approach and that aspires to achieve consensus among technically trained individuals. The scientific method includes the following steps: 1) definition of the problem to investigate, 2) establishment of a hypothesis to explain the problem, 3) testing the hypothesis by conducting experiments 4) analysis of the data and drawing a conclusion confirming or reflecting the initial hypothesis (if the latter is the case or the data are not clear a new hypothesis must be elaborated) and f) presenting the findings to others. The conclusions usually lead to new questions that will be pursued, thus enabling advancements in knowledge to be made. Thus, the most important traits of a good researcher are consistent curiosity, open-mindedness, enthusiasm, intelligence, determinedness and good personal and communication skills (Markert, 1996). As these personality traits do not depend on gender, it is theoretically possible to achieve gender equality in all scientific disciplines across the world.

When reflecting on the five steps of the scientific method outlined above, we can conclude that the knowledge obtained through the use of this method should be exempt from any gender bias and, in general, from any factor concerning social order, i.e., scientific knowledge should remain outside of ideology, economics, political interests, etc. However, this seems to contradict the imbalance between the number of male and female scientists, which has been evident (at least since the middle of the 20th century) to institutions (universities, research centres and the scientific community) and to citizens concerned about issues such as equality.

In order to investigate whether scientific knowledge is neutral and universal and remains outside any question of social order, we conducted an analysis of the scientific world from a gender perspective. We first examined how feminist theories, supported by the contributions of philosophers of science in the 1960s and 1970s, incluing Kuhn (1962) and Lakatos (1978), dared to denounce the gender bias that affects the world of science. These philosophers denounced not only the unequal number of male and female scientists, but also other issues such as 1) the biases in scientific research when women are the object of study, 2) the glass ceiling, which is closely linked to the problem of conciliation of family life and work life and 3) the higher prevalence of women in professions in the humanistic field in contrast to the clearly masculinized profile of scientific-technological studies.

After reflecting on the gender perspective in science, we used an example to illustrate the ideas stated. Soil science, the scientific discipline of one of the authors of this work, was selected as the example and hence as the objective of our research. An initial examination led us to focus on a data-based denouncement of the unequal number of men and women dedicated to this area of knowledge. We used the CSIC database to address the situation in Spain, and we used the data on some other countries, included in the scarce published papers to which we had access, for the rest of world.

REFLECTIONS ON GENDER PERSPECTIVE IN SCIENCE

The model of male dominance in the history of humanity is widely recognized nowadays and androcentrism is considered a socio-cultural paradigm. However, this paradigm has not been widely recognized within the framework of science, and the androcentric point of view is not taken into account in relation to the social context or human nature.

The pattern of male dominance has been so widespread that human studies have often only included men as subjects, and innumerable studies have been conducted from the male point of view. Thus, scientific studies of women have primarily been conducted to demonstrate and highlight, with a notably biased viewpoint, the differences—both real and assumed—separating men and women, especially in regard to reproduction and thus "reducing women to their reproductive anatomy" (Maffi, 2016). This approach entails several gender biases, including the following: 1) The choice of study topic. The critical importance of what has been called "funding agencies" that are not very interested in the involvement of women in science (either as researchers or as research subjects) is demonstrated. Although there are many reasons for this lack of interest, most are related to the economy/power axis. 2) Negation of the power relations between genders. In addition to the androcentric vision, which identifies masculine categories with human beings, denying gender and sexual diversity, the power element situates men on a higher plane to which women cannot aspire. 3) The techniques of observation and data analysis (i.e., selecting what is significant and what should be discarded in research) determines the process and the final product. In this respect, increasing the number of variables and conducting analyses of co-variance can minimize reductionist gender biases.

In the androcentric and patriarchal world, science cannot escape from these sources of bias. Demonstrating bias is an important task, although women scientists will usually continue to conduct the science that social conditioning allows. The commitment to gender perspective in science includes the task of unearthing, identifying, making visible, and valuing the number, names and biographies of women scientists, as well as the milestones they have reached, the academic and administrative roles they have occupied and the texts they have written and/or published. This arduous task forces us to reconstruct, in form and content, the history of scientific thought to include this new perspective, a feminist and multidimensional point of view that requires a change in the positivism paradigm. The point is not to add women's names and bodies to the hegemonic normative model: it is to rethink scientific study as social and thereby evaluative, as a product of social interactions between members of a community and their interaction with other objects and subjects involved.

The task of reconstruction began in the 1960s with Kuhn's proposal, outlined in the publication "The structure of scientific revolution" (1962) and later supported by the studies of Hanson (1976), Lakatos (1978) and Feyerabend (2015). These philosophers tried to understand science by highlighting the social component, which changed the traditional concept of scientific knowledge based on logical reasoning applied to data obtained by observation and experimentation using a neutral and context-independent methodology. This led Longino (1979) and Fox Keller (1985), experts in the philosophy of science, to reflect on the biases that gender imparts to scientific knowledge, showing that the idea of scientific study as objective, positivist, rational and formal is a social construct that corresponded to all of the qualities highly valued by and attributed to man. The male gender was identified as rational, objective and positive, while women were characterized as weak, subjective and irrationally emotional. The feminist critique demanded that the category of gender became a fundamental element for understanding and reconstructing the history of science (Harding, 1996). This implies the use of the analytical category of gender and its double dimension proposed by Scott and Amelang (1990), indicating, on the one hand, gender as a constitutive element of social relationships based on the differences between sexes, and, on the other hand, as a primary form of power. Both of these aspects of gender are interdependent in our socio-cultural model and imply considering gender a social, cultural, political and historical construction that encompasses the characteristics that are assigned to people on the basis of their biological sex and that have traditionally placed men in a privileged position and women in situations of political and social exclusion.

From this feminist perspective, in the last 4 decades, significant issues that were previously considered the status quo have been objectively described, including the following examples: the absence of women in science; women's lack of interest in science; the particular natural link between women and the private space, motherhood and care; women's lack of professional ambition; and the existence of exceptional women, often considered freaks, eccentric or degenerate, who have achieved prestige in the world of science. Although the limited space prevents us from considering many other issues, the above examples are considered in more detail below.

1) The late incorporation of women into academia. The late access of women to higher education where one acquires the capacities and abilities to carry out scientific studies is unquestionable. In Spain, free access to higher education did not become available until the in 1910, and the first female University Professor was appointed in 1916. However, true integration in higher education, including specialized training that allows real access to scientific tools, doctoral programmes, master's degrees, etc., did not take place until the 1960s. The importance of this in terms of cause/effect is generally recognized to explain the lack of a solid tradition of women in science in Spain. Nevertheless, the exclusion of rights is also due to the socio-cultural androcentrism that conceived women as inferior beings with a lower capacity to learn, and for centuries male philosophers and scientist created diverse and peculiar arguments to confirm this idea (Maffi, 2016).
2) The deliberate silencing of women's work. Although the presence of women in the world of science has been considerably less than that of men, the data were exaggerated by the names of female scientists being

deliberately hidden or omitted (Guil, 2016). There are more women scientists than are generally named and recognized. In fact, in many cases the important contributions of women to the advancement of scientific and technical knowledge have not been properly recognized (Solsona, 1997; González and Sendeño, 2002). In this sense, science has not been so "alien" to the proclamation, management and justification of the "prejudices" that undervalue feminine nature.

3) The proclamation and dissemination of the masculine nature of science. Science is usually linked to masculinity based on the traditional concept of science as rational, formal and objective, but also because the scientific texts and biographies used in teaching at academic and institutional levels are predominantly written by or are about men. From childhood, boys are pushed towards and motivated by the knowledge and importance of STEM careers: any learning difficulties they have are presented as a challenge accompanied by the consideration that whoever dominates the world of science is an intelligent man who participate in making decisions of great social transcendence, and their prestige in society becomes exemplary. The typical image of a scientist is as a crazy man locked in his laboratory, distancing himself from the people around him with a normal daily life. By contrast, women are typically characterized by their particular abilities in contextualized knowledge; their skills in mastery of language are exalted, along with their ability to empathize and their natural ability to care and to deal with education. All this is reflected when girls choose what to study and/or which professions to pursue. Thus, although in Spain about 50% of university students are women, only 20–30% choose to study careers in scientific or scientific-technological careers, while the remaining 70% choose careers in the field of teaching, health and social sciences (Agudo, 2003).
4) The idea of exceptional and/or the degenerate. Women who love and work in science are not rare birds, nor are they necessarily endowed with exceptional abilities that allow them to do something not accessible to other women. Nor are they degenerate beings who break with their nature by cross-dressing as males and adopting male practices and presuppositions. There are many women who are scientists, and many are both scientific professionals and mothers: they are women because of their biological condition and their social commitment to their gender, and they are scientists because they opted to train seriously in their chosen fields to generate knowledge.
5) The brake on women's professional ambitions, which are often considered to limit the development of personal life. The limited access to the highest positions and degrees is linked to the late and partial incorporation of women in science. However, the glass ceiling often also emerges from a "voluntary" renunciation by women of their legitimate aspirations of professional power or work-related ambitions. They do this, as they understand that advancing their careers is an obstacle to the development of their personal lives, fundamentally related to the tasks of caring for others in the family setting (children, elderly, dependents). This dilemma is crucial in relation to motherhood (Aguinaga, 2004), and family conciliation policies must be implemented and men and women must be involved in care on an equal basis, given that we can all do this and all of us at some point in our lives need to be cared for (Camps, 2021).

Identifying the traits that are determined by gender requires recognition of several variables, including gender but also social class and race, among others, which have determined a large part of the categories, classifications and descriptions through which we know and describe the not only human world but also the physical world. The new viewpoint is committed to showing how scientists study subjects within specific social contexts. Scientists are not abstract subjects endowed with universal faculties; they are privileged members of society who build images and explanations of nature that reinforce their hegemonic position in the world. Thus, since the 1970s, feminist critics have striven to denounce normative science as an activity that reproduces and/or legitimizes discrimination against women, which is supported by the activity of philosophers of science, led by Kuhn in the 1960s and 1970s. With this impulse, the feminists of the second wave (which in the 1970s and 1980s are consolidated in the academic world) have focused on returning to the essence of science itself, reclaiming its hypothetical character, which had been so subtly forgotten by those who created and used it (Agudo, 2003). The gender/science system (Fox Keller, 1985) was established and the new scientific epistemology of women's studies emerged, first in the Anglo-Saxon world and by direct influence throughout Europe, including Spain. These studies are framed within feminism and, as indicated by Flores (2013) "what characterizes feminist research compared to other non-feminist research is its political commitment and activism in order to improve the situation of women and other marginal groups. It is contextual, socially relevant, inclusive and takes into account the role of experience and subjectivity in research. This research is guided by different methodological approaches and theoretical paradigms that conform to the feminist principles of emancipation and social change." Such studies and research have increased enormously over the last decades, addressing different options and conceptualizations and proposing constructive alternatives aimed at defending this new model of scientific knowledge. This is an essential tool for science informed by a moral and emancipatory policy with participative, antiracist, anticlassist and antisexist values, despite being immersed in an "occidental, bourgeois and masculine framework" (Harding, 1996). The new epistemology of science with a gender perspective recognizes that extracting androcentric values from science will not make it neutral and objective, but it will get rid of coercive and discriminatory values. Science with a non-sexist gender perspective must assume the impossibility of objective science/research, as it can never be exempt from social values and interests. In summary, the idea is that good science is not that which is value-free, but rather that which incorporates good values.

WOMEN IN SOIL SCIENCE

Soil is a natural, non-renewable resource that takes a long time to develop, but which can be quickly destroyed or degraded. Soil hosts a quarter of our planet's biodiversity and provides ecosystem services needed for the correct functioning of natural systems (such as supplying nutritious food, clean drinking water and raw materials, and carbon sequestration) and which are essential for overcoming societal challenges like climate change, food security, biodiversity loss and the safeguarding of human health (Montarella and Panagos, 2021). In 2015, the UN established the sustainable development goals (SDGs) promoting awareness and citizen responsibility regarding the importance of soil and its protection. Soil health is enhanced by promoting its sustainable management in order to achieve the following SDGs: 1 (End poverty), 2 (Zero hunger), 3 (Good health and well-being), 5 (Gender equality), 6 (Clean water and sanitation), 7 (Clean and affordable energy), 9 (Resilient infrastructure, inclusive, sustainable industries, and innovation), 11 (Sustainable cities and communities), 12 (Production and responsible consumption), 13 (Climate action) and 15 (Life on land) (Lal et al., 2021). These goals are also associated with the European Green Deal, approved in 2020, which includes a set of initiatives whose overall objective is to achieve climate neutrality in the EU. However, in most developing countries, less than 1% of the GDP is invested in research related to the study and knowledge of soil, at both regional and national scales. The scientific community of soil scientists is currently actively discussing gender equality given the inequality and low diversity and inclusion of women relative to other subdisciplines within the earth, natural and agricultural sciences (Brevik, 2019; Vaughan et al., 2019; Carter et al., 2021; Dawson et al., 2021). Female and male soil scientists around the world must have equal opportunities to contribute their knowledge and experience towards the sustainable management of soils and hence to achieve sustainable development goals. Research and education centres must train young male and female soil scientists who will have the ability to approach and solve problems related to soil productivity and ecosystem services.

Many women have made important contributions to the advancement of knowledge in soil science but are unknown, even within the field itself. Women role models are needed to maintain soil health and promote scientific vocations in soil science in order to reduce gender discrimination in this field. We used the list of Honorary Members of National Soil Science Societies (in this case, the Spanish Society of Soil Science, SECS) and International Union of Soil Science (IUSS) as databases in order to find the names of such women. The IUSS, founded on 19th May 1924 as the International Society of Soil Science, is the global union of soil scientists. It currently has 60,000 scientists around the world, of which 134 are honorary members (130 men and 4 women). Maria Mikhaylovna Kononova was the first women to became an Honorary Member of the IUSS (1974, USSR) and was then followed by Maria Gerasimova (2016, Russia), Mary Beth Kirkham (2016, United States) and Rosa M. Poch Claret (2020, Spain). The alarming, significant gender inequity among honorary members (3% women versus 97% men) clearly shows that women's contribution to soil science during an entire century has not been recognized, i.e. since the development of this science in the late 19th century. Surprisingly, 75% of women have been included in the list of honorary members in the last 4 years. During the period 1924–2016, women accounted for only 1.05% of the total (94 men versus 1 woman), whereas the percentage increased notably during the period 2016–2020, reaching a value of 12.5% (21 men versus 3 women). Likewise, women are also under-represented in Presidential and executive Committees, Divisions, Commissions and Working Groups of the IUSS (20–37% in 2022). When appointed by IUSS president in 2019, Laura Bertha Reyes Sánchez became the first female president in the history of IUSS (95 years).

The Spanish Society of Soil Science (SECS), founded in 1957, has 564 members (325 men and 239 women). The proportion of women (42%) is higher than that observed by Dawson et al. (2021) for 44 national soil science societies worldwide (32%). The SECS has 14 honorary members (11 men and 3 women). Tarsy Carballas Fernández was the first female honorary member (2011, Spain), followed by Laura Bertha Reyes Sánchez (2020, México) and Montserrat Díaz Raviña (2022, Spain), respectively. As in the IUSS, most female honorary members have been included in the last 4 years (67%) and greater inequality was observed for honorary members than for the total number o f members (21% versus 42%). The data demonstrate that the presence of women in leadership positions in the ISSS and SECS remains very low and that urgent actions towards greater inclusion and gender diversity should be implemented. Therefore, there is an urgent need for female soil scientist role models to help give visibility to the soil and promote scientific vocations in this field. In this sense, we consider that the honorary members of the national societies of soil science worldwide should be viewed by others as successful soil scientists. The photographs of the mentioned female honorary members of IUSS and SECS are shown in **Figure 5**.

Collection and analysis of information concerning the lives and achievements of women in soil science is of great interest both for gender studies and for promoting scientific vocations. Nowadays, the internet can be used as an information search tool, and many investigators are taking advantage of the potential of internet-based searches to provide large amounts of worldwide data to assist their studies. However, since the birth of the internet in the 1980s, this channel of information in electronic format has shown some limitations when used for studies of the history of the development of soil science. Therefore, for information on topics prior to this date, printed documents that are not available on the internet will probably also have to be used.

Finding written sources of documentation can be time-consuming and expensive. In addition, there may be difficulties associated with our level of knowledge of the different languages in which the documents are written. In

FIGURE 5 | Laura Berha Reyes Fernández, Maria M. Kononova, Maria Gerasimova, Mary Beth Kirkham, Tarsy Carballas Fernández, Montserrat Díaz Raviña and Rosa M. Poch Claret. The photograph of M.M. Kononova, which is a courtesy of Elena Rusakova (Deputy Director of the Museum), is in the Archive of the Dokuchaev Central Soil Science Museum. F.3. Op.1. D.55. L.8.

this respect, information is available on internet about all of the female honorary members of the soil science societies mentioned above, except Maria Mikhaylovna Kononova (1898–1978). This is surprising as Kononova is the author of "Soil organic matter: its nature, its role in soil formation and in soil fertility" (1963), which is still considered the reference book for specialist in soil organic matter worlwide. The book is available in print version in Russian, Polish, Chinese, German, Japanese, English and Spanish, and it includes around 1,000 references. Kononova acted as chief editor and/or member of the editorial board of the journals "Soil Science" and "Geoderma" and actively participated in the "International Symposium Humus et Planta", which was held in Prague (Czech Republic) during a period of 14 years. Of her private life, it is only known that she had a daughter and a grandson (Pavel Krasilnikov, personal communication). Due to the lack of biographical details and information about her scientific achievements, we asked P. Krasilnikov (a soil researcher at Karelia Research Center RAS, Petrozavodsk, Russia and an honorary member of the IUSS) for assistance. He sent us a book written in Russian by Svetlana Arsenievna Sycheva on the role of Russian women in soil science (Sycheva, 2003). Reading this interesting monograph, made us realize that the contribution of Russian and Soviet women to soil science is probably greater than that of women scientists from other countries (345 women soil scientists, including M.M. Kononova), owing to political, socioeconomic, cultural and geographic circumstances.

CONTRIBUTION OF RUSSIAN AND SOVIET WOMEN TO SOIL SCIENCE

The history of Russian soil science is closely associated with Vasily Vasilyevech Dockuchaev, widely regarded as the father of soil science, and his colleagues and followers. At first, women worked together with these researchers as laboratory assistants, secretaries, technicians and engineers. Women then became researchers and many of them developed new lines of investigation. Women's contribution to soil science in Russia and the Union of Soviet Socialist Republics (USSR) is immense and diverse. In the 1930s, women represented 30% of researchers; however, their scientific achievements have not been widely recognized, and in fact, publications on the history of soil science in Russia and the Soviet Union only included men. However, as mentioned above, a comprehensive reference book on the contribution of women to the various soil science disciplines in Russia over the last century was written at the beginning of the century (Sycheva, 2003). This 244-page book includes information on 345 women soil scientists, regarding both their careers (research lines, scientific accomplishment most relevant publications) and biographical details directly related to their scientific careers (dates of birth and death, family members, studies and teachers, dates when doctoral theses defended, activities related to teaching and management and distinctions in recognition of their work). Although the book is written in Russian, we found brief summaries of the content written in

English by Sycheva (2006) and Prikhod´ko (2006), and we translated the book from Russian to English using a Google application.

For centuries Russia was a nation with a largely rural population subjected to an absolutist monarchical regime. The situation of poverty, the devastating effects of the First World War and the economic and social crisis led to a situation of famine that caused the Russian revolution at the beginning of the 19th century (1917). The autocratic regime was overthrown and a new model of the Leninist state was gradually built, i.e. communist Russia, which later gave rise to the creation of the Union of Soviet Socialist Republics. In this social democratic regime, there were great cultural changes that included improvements in the social rights of women, including the right to free, compulsory education that notably influenced the incorporation of women in soil science. The 1917 revolution marked a turning point in the training of Russian women, as although they had been able to attend advanced courses in the schools of Agronomy and the Faculties of Natural Sciences before this time, they were not granted full access to university courses until after 1917.

Sycheva (2003) distinguished several stages in the process of the incorporation of women in soil science. The first generation is represented by women who were born before 1898 (total number = 11 researchers) and those born between 1898 and 1918 (total number = 75 researchers). The first women soil scientists were microbiologists, chemists and agronomists, and the results of their research studies were published in 1906–1907 by V.A. Bal´ts and V.A. Domracheva (1906–1907). The first female scientists known to be successful soil scientists were E.N. Ivanova, N.N. Sushkina and Z. Yu. Shokal´skaya. Most female soil researchers (born between 1898 and 1918) began their careers in the mid-1920s–1930s. They worked in research centres and universities created in the republic of the Sovietic Union in the study of the soils of these regions, also occupying positions of responsibility, acting as Laboratory and Department Heads and managing different scientific organizations/entities.

The second generation of female soil researchers (born between 1919 and 1938) began their careers in the mid-1940s–1960s (total number = 157 researchers). Many male scientists were killed in the Second World War, and in the postwar period, the proportion of female soil scientists who carried out educational and research tasks increased considerably as females occupied the vacant positions. In addition, large scale research programmes were undertaken, including the development of practices for the management and conservation of agricultural and forest soils with the ultimate goal of increasing soil productivity. At this time, the proportion of females in leadership roles reached the highest levels in the entire history of Russian soil science.

The third generation of female soil researchers (born between 1939 and 1958) began their careers in the mid-1960s–1980s (total number = 93 researchers). This period, during which Brézhnev´s government was in power, is associated with an economic recession that also had an enormous impact on the development of soil science. The research programme for the implementation of soil management practices aimed at increasing soil productivity continued, and women held leadership positions, although fewer than in the previous generation.

The fourth generation of female soil researchers (born between 1959 and 1978) began their careers in the mid-1980s (total number = 11). This period coincides with the economic crisis that caused a drastic reduction both in the number of soil scientists and in the government budget for research in soil science, especially fieldwork. Foundations such as the Russian Foundation for Basic Research were created to finance soil science investigation.

These female scientists contributed enormously to the advancement of soil science in Russia, given that, on the one hand, they developed new lines of research and, on the other hand, they continued the work of other lines developed by men and mainly involving fieldwork (i.e., genesis and soil formation, soil classification and soil mapping). These women scientists opened up new research lines related to the living fraction of the soil, i.e., study of the dynamics and composition of the soil organic matter (biochemistry and microbiology, micromorphology, processes) and also to the ecology and protection of soils (**Supplementary Table S1**). The study of processes related to the organic matter dynamics is complex and requires a great deal of meticulous work. It is precisely these lines of research developed by women and related to the concept of soil as a living system (soil quality and health, ecosystem services, microbial biodiversity, soil recovery) that have been longer to become accepted in Europe and in other countries worldwide. By contrast, the lines developed by men have undergone enormous development throughout the history of soil science.

Many of these outstanding women not only initiated new lines of research but also created schools of thought that have been fundamental to the economic development of Russia since they are related to the exploitation of virgin soils in different regions located in the countries that were incorporated the Soviet Union (**Supplementary Table S2**). These researchers later studied several aspects of the conservation and recovery of the productive capacity of soil after the implementation of various agricultural and forestry practices. They were supervisors of numerous doctoral theses by scientists from several countries (Russia and Soviet Union, Poland, Bulgaria, Romania, Yugoslavia, German Democratic Republic, China, Vietnam) who visited and worked in their laboratories. Likewise, the secretarial work and that of laboratory and field assistants and technicians was also largely carried out by women. Despite its great importance in the development of research, this work is generally not recognized by the scientific community. On the other hand, these scientists are women, wives and daughter, who must reconcile their work with the other family-related tasks, such as caring for children and the elderly.

The number of PhDs and the total number of papers published per author are considered indicators of the excellence of the researchers in a country: 132 of the 345 women soil scientists in Russia (132 PhDs and 60 postgraduate soil researchers) produced more than 50 publications. The scientific productivity is as follows: 300 publications, 6 authors; 200–299 publications, 31 authors; 100–199 publications, 76 authors and

50–99 publications 53 authors. Six outstanding women soil researchers published around 300–400 scientific papers (N.I. Bazilevich, L.M. Burlakova, A.A. Shtina, T.N. Kulakovskaya, G.Y. Merzlaya and V.V. Tserling). The most significant scientific papers were published in review journals; i.e., 148 women researchers published articles in the well-recognized internal Journal "Soil Science". Taking all of this into account, it is not surprising that many women took part in the leadership of the Russian and Soviet Society of Soil Science, such as members of the Central Council and science managers and therefore received numerous awards from both the government and various scientific institutions in recognition of their teaching, research and management work in the field of soil science (**Supplementary Tables S2, S3**).

The previously mentioned book (Shyeva, 2003) reports the first study that covers the contribution of Russian and the USSR women scientists to the development of soil science since the early 19th century, using a very reliable database. Soil scientists worldwide should have access to this valuable, detailed information on gender equity in soil science (names, fields and lines of research, scientific achievements, relevant publications and detailed biography of 345 women). We encourage Russian women scientists to translate this book into English and update it with the information about the new generations of female soil scientists.

Shyeva (2003) distinguished four generations of Russian and Soviet women soil scientists (one generation covers a period of about 20 years). As the book was published in 2003, there is now a fifth generation of women soil scientists (born between 1979 and 1998), who began their careers in the mid-2000s–2020s. In 2006, women constituted more than 60% of soil scientists (staff members of research and educational institutes); however, they did not influence the future of soil science in Russia due to the fact that their role in decision making was reduced to a minimum, especially in Moscow (Sycheva, 2006).

CURRENT CONTRIBUTION OF WOMEN FROM DIFFERENT COUNTRIES TO SOIL SCIENCE

The gender perspective is a key aspect that must be taken into account in numerous activities, such as resource distribution, legislation and policy development, as well as in encouraging dialogue and in the planning, implementation and monitoring of initiatives and proposals (UN, 2001). However, studies concerning gender equity in soil science are scarce and very recent. To date, we have found only one relevant international study (Dawson et al., 2021) and a few national studies, in the USA (Vaughan et al., 2019) and Indonesia (Fiantis et al., 2022; Hairiah et al., 2022). Overall, despite the greater number of women occupying postdoctoral and PhD positions in soil science in the last decade, the field remains dominated by men (in relation to senior, permanent positions, success rates in obtaining grants, keynote speakers at soil science conferences, editorial boards, invitations to referee scientific journals) (de Vries, 2017, 2020). In response to this problem, de Vries has established a network as a resource for use by event/conference organizers, journal publishers and sponsors to include women's participation in such activities (https://franciskadevries.wordpress.com/women-insoil-science/). We encourage women soil researchers in all countries to register in the "List of women in soil science" created by de Vries. Other studies include a brief biography of the women who are pioneers in soil science in Western countries (Helms, 1992; Levin,1998; Koziell 1999; McIntosh and Simmons, 2008; Cordero et al., 2021; Gerasimova, 2022; Reyes-Sanchez and Irazoque, 2022). Likewise, the mission of the organization Women in Agriculture Science is to increase the visibility of women´s roles in the agricultural sciences by sharing their life stories, successes and obstacles (https://www.womeninagscience.org/). It has been shown that reading biographies of scientists, especially about the struggles they have overcome, stimulates students learning and their interest in science (Hong and Lin-Siegler, 2012). Therefore, we call on teachers of soil science worldwide to use biographies of women soil researchers to inspire scientific vocations in girls and women.

The first paper on international gender equality in soil science was published recently (Dawson et al., 2021). This study used data on the memberships of 44 national soil science societies in 2020, the keynote speakers at three international conferences held in recent years (the International Union of Soil Science, IUSS, the World Congress of Soil Science, WCSS, the Soil Science Society of America, SSSA, and the European Geosciences Union Soil System Science Division, EGU-SSS) and the editorial board of nine Q1 soil science journals in 2020 (Applied Soil Ecology, Biology and Fertility of Soils, Catena, Geoderma, European Journal of Soil Science, SOIL, Soil Biology and Biochemistry and the Soil Science Society of American Journal). The study findings showed the following: 1) in most of the soil science societies, the proportion of men was much higher than that of women (68% versus 32%); 2) the average proportions of women speakers at WCSS and SSSA meetings were very low, 6% and 21%, respectively; and finally, 3) the proportion of women soil scientists holding positions on the editorial boards of the journals was 30%. The study also showed that the number of women who acted as keynote speakers have increased notably over time.

In the US, there has been great interest in the last 40 years in the status of soil science education. Several aspects related to undergraduate enrolment in universities and to guidelines for degree programmes that attract and recruit young male and female students to work as soil researchers have been addressed (Brevik, 2019). In addition, the status of girls and women in soil science in the US has been studied from the perspective of gender, and statistics concerning the level of participation, the obstacles and the challenges and opportunities that girls and women encounter throughout their scientific careers have been reported (Vaughan et al., 2019). These researchers observed that the enrolment of women in soil science has increased remarkably in the past 4 decades, with similar numbers and women and men undertaking advanced and master's studies. However, the proportion of women who have continued their studies and who have found positions as soil scientists is still much lower

than that of men (with women representing 25% of the total). The study also revealed that women encounter more obstacles than men throughout their scientific careers. Thus, women soil scientists are under-represented in leadership positions and, despite the increasing involvement of women in soil science, their accomplishments are not well recognized. Available data on the representation in soil science of historically marginalized groups in the United States, including women, as well as the mechanisms involved in this process have recently been examined from historical and contemporary perspectives (Carter et al., 2021). These researchers also provide recommendations for implementing actions aimed at enhancing and emboldening diversity and inclusion in soil science. To broaden participation in soil science, the SSSA now provides several options for the (voluntary) recording of gender data on members: female, non-binary gender, male, and prefer not to answer. Thus, using this new database of SSSA membership (2019), which includes gender and ethnicity, these researchers have shown that women are generally represented in the same proportions as members from minority groups (21%).

The first study concerning the participation of women and men in soil science in Indonesia was also recently published (Fiantis et al., 2022). These researchers found that the number of students enrolled in soil science courses has increased notably in recent years, with the proportion of women reaching, on average, 56% (range 30%–70%). By contrast, a gender imbalance was observed among the course lecturers (average proportion of women lecturers, 30%). This observation was attributed to the fact that women must reconcile their careers with the tasks of caring for the family (children and the elderly). The data showed that women lecturers remain underrepresented, only 3% of soil science academics, while men accounted for 12%. Students considered that soil science would be better taught by male lecturers, but preferred female lectures as supervisors of final projects and master's or doctoral theses.

The greater participation of women in teaching and research in the discipline of soil science is reflected in the number of publications (Hairiah et al., 2022). Thus, proportions of male and female authors of scientific publications were similar (in 2019). However, the participation of women and men in the different tasks involved in the study of soil science (laboratory, greenhouse and fieldwork) is still not equitable, given that fieldwork is generally carried out by men, and greenhouse studies and, above all, laboratory studies (soil physical, chemical and biological analyses) are carried out by women.

The information presented here provides a brief analysis of the historical contribution of women to soil science from the perspective of two researchers who are specialists in respectively soil microbial ecology and philosophy. Therefore, the study has many limitations related to both the scarce knowledge about the history of soil science and soil science education of the authors and the scarce information available. The data presented, though incomplete, are meant to serve as a critical starting point to raise awareness among researchers about the urgent need to carry out gender equality studies in soil science worldwide, especially in Spain.

CONCLUSION

In summary, this study reinforces the idea that soil science is not neutral, that it is social and gendered and always will be. However, we must try to make it more inclusive. The data also reveal that although information on the role of women in soil science is limited, women are under-represented in all countries included in gender equality studies. Continued efforts must be made towards achieving gender equality in soil science. Equality between men and women is a very complex issue that depends on many factors (family, society, government, politics, geographical location, institutions and culture) that must be taken into account in any study of this type. Further research should be carried out worldwide, as the economic, political and cultural contexts determining the incorporation and changes in the contributions of women to soil science vary widely across countries. Therefore, recognition of and support for women soil researchers worldwide is needed to attain gender equality and improve education and research in soil science in order to better serve and protect soils and humanity.

AUTHOR CONTRIBUTIONS

MD-R: conceptualization, data analysis, and writing original draft. CC: conceptualization and writing original draft.

CONFLICT OF INTEREST

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontierspartnerships.org/articles/10.3389/sjss.2022.10658/full#supplementary-material

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