Women in Soil Science: Growing Participation, Emerging Gaps, and the Opportunities for Advancement in the USA

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The soil science discipline has undergone significant changes since its establishment in the 1900s; from strong connections with agronomy to a broader focus on ecosystems, earth, and environmental sciences while also during this period experiencing a notable increase in diversity among soil scientists. In this review, we explore soil science from the perspective of gender demographics and disciplinary foci of soil scientists. We examine graduate student enrollment metrics; employment information in academia, the federal government, and the private sector; and membership data from SSSA to gain deeper insight into these changes and the implications for the future of soil science. Women earn nearly half of the advanced soil science degrees. The number of women pursuing soil science careers has also increased, albeit less markedly, as women now comprise 24, 26, and 20% of the soil scientists in academic faculty positions, federal agencies, and private industry, respectively. However, there is reason for concern that women linger in intermediate levels of employment, and further attrition occurs along the career ladder with only ~18% of the highest employment levels held by women; even fewer reach executive leadership levels in any sector. The growing participation of women in soil science is further reflected in a nearly 45% increase in female membership and meeting attendance in SSSA over the past decade, but recognition of their accomplishments and their presence in SSSA leadership positions remains low. We provide recommendations toward greater inclusion and gender diversity as this represents an important pathway to grow and innovate our science.

Core Ideas

- **Despite historic gains, women remain under-represented in soils-related careers.**
- **Women are under-represented in soil science leadership positions.**
- **Women receive SSSA awards at lower rates than their participation in the society.**
- **Women face attrition more than men as they advance the soil science career ladder.**
- **Diversity and inclusion are important pathways to grow and innovate soil science.**

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In 2006, Baveye painted a bleak picture of the future of soil science going into the 21st century (Baveye, 2006; Baveye et al., 2006). He noted the alarming rate of dissolution of soils departments and degree programs within many universities in North America, a dwindling enrollment of graduate students in the remaining soil science programs, and an increase in soil science publications by individuals either not trained in or affiliated with traditional soil science units. Later examinations of student enrollment by Brevik et al. (2014, 2018) indicated a reversal of the earlier observations, with increased soil science enrollment. Brevik et al. (2018) noted an overall increase in both undergraduate and graduate soil science majors and a growing interest in soil science coursework among students with more diverse academic backgrounds, particularly majors outside the traditional agronomy and crop sciences. At the same time, Science, Technology, Engineering, and Mathematics (STEM) fields have shown a marked demographic shift since the late 1970s, with a decline in the proportion of USA-born men and a corresponding increase in the number of women recruited into these fields (Preston, 2004). In soil science specifically, there have been reported increases in the total number of women students in undergraduate soil science courses but a decline in the percentage of women students in the early 2010s (Brevik et al., 2018). This follows a reported increase in the proportion of women among graduate students in soil science degree programs from the 1990s to the early 2000s (Baveye et al., 2006). These trends highlight the need to assess diversity in soil science and implications for the future of the discipline. As an initial effort in this endeavor, we present data on gender diversity in soil science.

In many STEM disciplines, there are ongoing efforts to increase gender diversity and representation (e.g., Fischer et al., 2018; Shields et al., 2011; Pereira, 2014). These efforts have not completely permeated the workforce, as women are still underrepresented at the highest professional ranks (Valian, 1999; Mason et al., 2013). Unlike ecology, biology, and geosciences, soil science as a discipline has not been at the forefront of diversity issues in STEM, and no comprehensive assessment of gender trends in the academic, government, and industry sectors of soil science currently exists. In this analysis, we document gender diversity in soil science. Specifically, we address the following questions: (1) Are women pursuing graduate degrees in soil science; (2) To what extent are women with graduate degrees in soil science transitioning into professional soil science careers; and (3) How does the professional career trajectory of women soil scientists compare to their male counterparts?

To address these questions, we compiled and analyzed gender distribution data along various points of the career ladder from educational preparation through employment and participation in the Soil Science Society of America (SSSA). We constructed temporal trends in gender composition of graduate students pursuing master's (MS) and doctoral (PhD) degrees in soil science from a variety of data sources. We then evaluated the transition into the soil science profession by examining the relative proportion of women among soil scientists employed by academic institutions, federal agencies, and industry, and participating in SSSA in various capacities. To glean information on the extent of gender career advancement and peer recognition, we examined the representation of women among various ranks in the workplace, in leadership roles, and as recipients of formal honors in the SSSA. We then place our findings within the context of national trends and discuss challenges and opportunities for creating a more equitable environment with broad implications for the future of the soil science discipline.

DATA ACQUISITION

Gender distribution of graduate students in soil science was obtained from four different sources. The first source is graduate student enrollment at universities where soil science is offered as a degree, minor, or concentration. Graduate student data from US and Canadian universities for 1992 (n = 68) and 2004 (n = 38) was obtained from Baveye et al. (2006), who examined students within the field of soil science. In 2017, we collected graduate student data from 22 universities (Supplemental Text S1) in the United States, accounting for students enrolled in MS or PhD programs. In addition, we used gender distribution of theses and dissertations reported to the SSSA for 2013 to 2018 and published annually in CSA News. Finally, data on MS and PhD degrees within science and engineering technologies were obtained from the National Science Foundation, National Center for Science and Engineering Statistics (NSF, 2015, 2017, 2018) and used as a proxy to provide a view of the larger trends in women's participation within the STEM fields. Data from NSF aggregated from 1966 to 2016 were used, and nomenclature of some subdisciplines changed somewhat depending on the year of reporting. Representation of academic faculty was collected in 2017 by visiting the departmental websites of 74 universities where soil science is offered as a degree, emphasis, or concentration at the BS, MS, and/or PhD level (Supplemental Text S2). Faculty gender was identified based on information from their faculty webpages (e.g., references to pronouns) and then analyzed by their designated soil subdiscipline and faculty rank.

Federal data were collected for the Federal Soil Science series 0470 coding (Data from OPM FedScope, June 2017; https://www.fedscope.opm.gov/employment.asp). Private industry data were obtained using the SSSA Consulting Soil Scientists database after removing individuals who work for universities or federal, state, or local governmental agencies, who were listed as retired, or for whom the employer, and therefore category of employment, could not be identified (https://www.soils.org/membership/divisions/consulting-soil-scientists/directory/browse).

Data on SSSA membership were collected by membership type for 2006 to 2016, and by discipline (division of first preference) as of January 2019, and were obtained from Alliance of Crop, Soil Science Societies, and Environmental Science Societies (ACSESS), an umbrella organization of SSSA.

The gender of SSSA Fellows and award recipients from 2000 to 2018 were mined from the CSA News (https://dl.sciencesocieties.org/publications/csa-news) issues in the fall

of each year prior to the Annual Meetings. Additional historical Fellows records were obtained from ACSESS.

MAJOR FINDINGS

Women are Pursuing Coursework and Graduate Degrees in Soil Science

Our findings show that women are enrolling in post-secondary education in soil science and related biological or environmental programs in increasing numbers. However, trends differ from the undergraduate to the graduate levels in gender distribution.

Undergraduate Enrollment

Brevik et al. (2018) analyzed undergraduate enrollment trends between 2009 and 2013 at 10 universities that offer soil science degrees, emphases, or concentrations. Although not the focus of their study, the authors examined the enrollment of undergraduate women in soil science courses. The total number of women enrolled in undergraduate soil science coursework over the period of the study (5 yr) increased, but the percentage of women decreased from 41 to 38% due to the greater increase in number of men enrolled in soil science courses during the same time frame. Soil biology and microbiology courses had the highest percentage of women enrolled, about 45%, while the enrollment of women in soil fertility, pedology, soil chemistry, and soil physics was lower, approximately 35%.

Graduate Enrollment

Using historical and present data on reported graduate thesis submissions and collected student enrollment (MS and PhD), we identified emergent trends in gender distribution within the discipline of soil science. In 1992, graduate enrollment data from select US and Canadian universities (n = 68) collected by Baveye et al. (2006) indicated strong disparities between the number of men and women pursuing advanced degrees in soil science. Female students accounted for considerably less than one-third of all soil science graduate students: only 31% of MS degrees and 18% of PhD degrees (Fig. 1). Data collected in 2004 from a subset of these institutions (n = 38), indicated an increase in female graduate enrollment to 46% for MS and 38% for PhD students (Baveye et al., 2006) (Fig. 1). Similar data collected in 2017 exclusively from select US universities that specifically offered soil science graduate degrees (n = 22; Supplemental Text S1), revealed a continued progression in gender distribution among soil science graduate students to near-parity, with women accounting for 54 and 53% of students in MS and in PhD programs, respectively (Fig. 1 and 2). This trend is further supported by information from thesis submissions reported to the SSSA between 2013 and 2018 that indicated on average, 46% of all advanced soils degrees in these 5 yr were awarded to women, ranging from 38 to 53% of all MS and 33 to 53% of all PhD degrees in any given year (ASA, CSA, and SSSA, 2015, 2016, 2017, 2018, 2019).

The NSF database on graduate degrees in STEM does not explicitly parse out soil science as a distinct discipline. Consequently, proxies must be used when analyzing national historic trends. Graduate degrees in Science and Engineering (S&E) indicate a growing proportion of women among advanced degrees across all STEM fields (NSF, 2015, 2017, 2018; National Science Board, 2018), from 13% of all MS degrees (n = 41,049) and 8% of all doctoral degrees (n = 11,570) in 1966 to 46 and 41% respectively in 2017 (Fig. 1). The S&E degrees encompass several natural science fields (e.g., biology, agricultural sciences, natural resources) under which soil science, as an interdisciplinary subject, could appropriately be categorized. The distribution of women among graduate students in soil science mostly falls within biological sciences as the upper boundary and earth sciences as the lower boundary (Fig. 1).

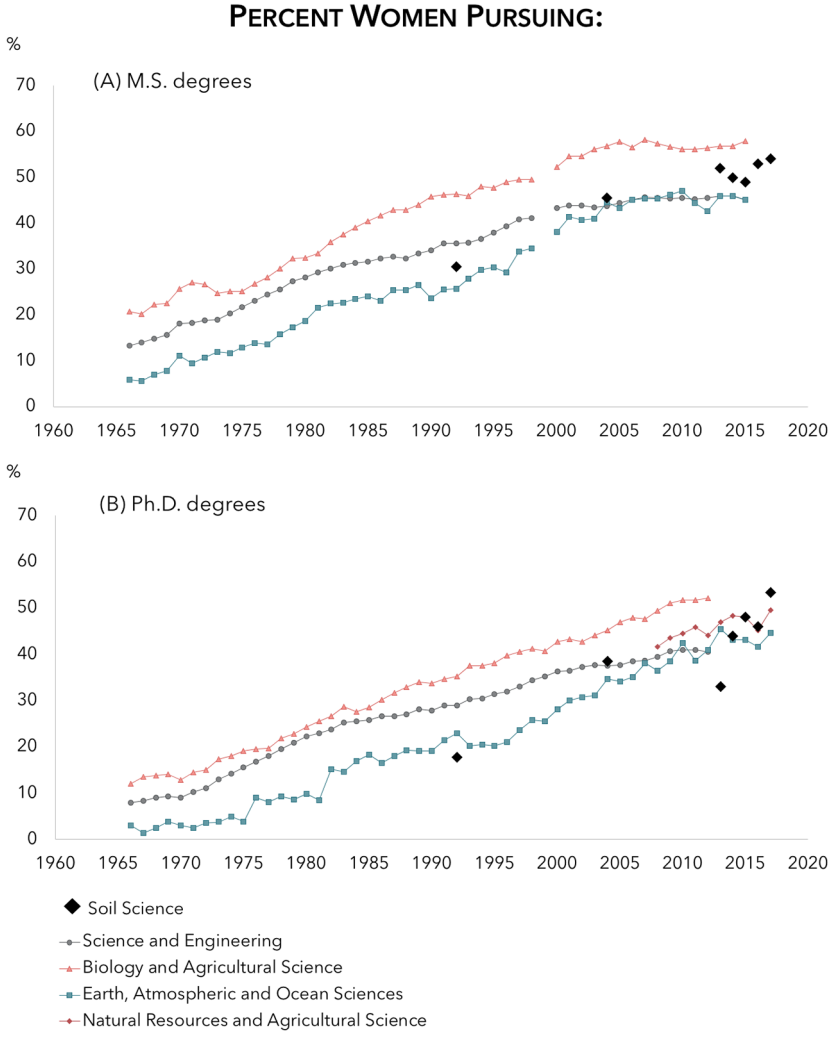

Fig. 1. Relative proportion of women pursuing (A) MS and (B) PhD graduate degrees in soil science compared to demographics of graduate degrees earned across science and engineering and natural science disciplines related to soil science (Biology, Agricultural Sciences, Natural Resources, and Earth Sciences) (Baveye et al., 2006; NSF, 2015, 2017, 2018).

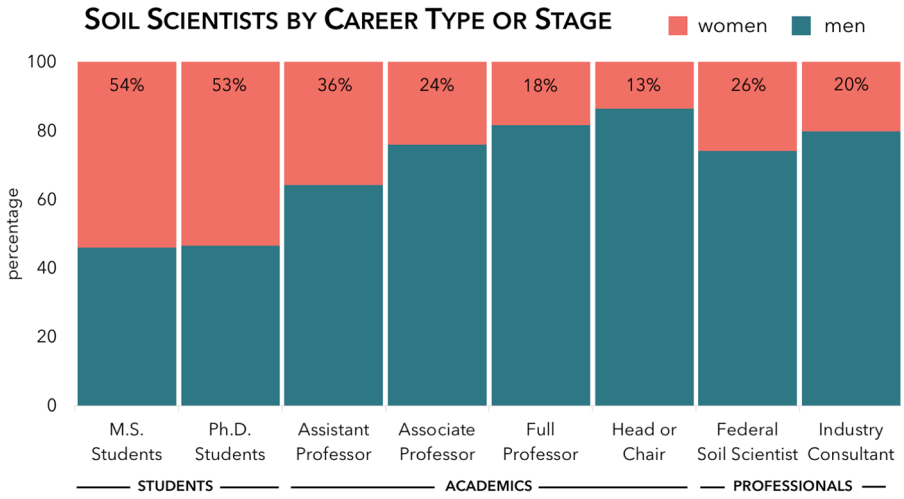

Fig. 2. Gender distribution of graduate students, faculty members, department heads or chairs of departments housing soil science programs, federally employed soil scientists (0470, Soil Science Series), and consulting soil scientists employed by industry (data collected using the Soil Science Society of America consulting soil scientists database). Percentage of women is the percentage of the total for each category.

Collectively, these lines of evidence support similar trends: there is a significant demographic shift toward greater gender parity among students pursuing advanced degrees in soil science at US universities. Graduate students inherently represent the potential future of a discipline, and the above trends signal a strong evolution from the traditional male-dominated discipline with strong ties to agronomy, to a more diverse discipline, both in terms of gender as well as focal area.

Women are Working as Soil Scientists

Women pursue careers as soil scientists in all employment sectors and comprise on average 24% of the soil science faculty, 26% of the soil scientists employed by federal agencies, and account for approximately 20% of soil scientists in private industry (Fig. 2). In each case, the participation of women in soil science careers is lower than the current gender composition of graduate degrees completed in soil science (Fig. 1 and 2) and of enrollment in undergraduate soil science courses (Brevik et al., 2018).

Soil Scientists in Academia

A strong trend emerges with respect to faculty rank with greater balance in gender distribution at the assistant professor rank than at the associate or full level (Fig. 2). Of soil science faculty identified at the assistant level, 36% are women. Representation of women declines to 24% at the rank of associate professor, which decreases further to 18% of full professors in soil science are women. Compared to the gender composition of the corresponding S&E cohorts of PhD holders (i.e., 5, 10, and 15 to 25 yr post-degree, respectively) and with upper and lower boundaries represented by Biological and Earth Sciences from NSF data (Fig. 1), the gender distribution in academia is thus not explained by the graduate student population distribution in the past. Rather it indicates that fewer women than men have transitioned from PhD programs into and/or have remained in faculty positions. As with other STEM disciplines, this indicates an increasing gender gap in faculty positions in the soil science discipline and further attrition of women as they move up the academic ladder. The relative proportion of female to male full professors more closely mirrors estimated gender distribution among graduate students who pursued graduate degrees in soil science (18% women) more than two decades earlier (Baveye et al., 2006; Fig. 1), rather than the gender distribution of today's graduate students. This suggests a slow change but means the gender diversity of full professors may reflect the current graduate student distribution in 20 yr, a sobering, yet encouraging thought.

Examination of department heads and chairs of soil science programs reveals that 13.5% of heads or chairs are women (n = 10 out of 74) (Fig. 2). Less than one quarter of these leadership positions are occupied by soil science faculty (n = 18) because soil scientists are often grouped in with other fields to form academic departments, with 17% of the soil scientists serving as department chairs being women (n = 3). This further illustrates that women are under-represented at all levels in academic soil science compared to the potential source pool, and this under representation increases at higher ranks and leadership positions. It should be noted that this analysis only captures the gender composition in academic units that offer soil science programs. It does not include information on soil science faculty that are dispersed across other academic units (e.g., natural resources, ecology, biological or environmental sciences, geography, geology, earth science, watershed management, engineering) where they teach a limited number of soil science classes in support of another academic program but do not offer a soil science program.

Soil Scientists by Subdiscipline

The distribution of soil science faculty is nearly evenly split by subdiscipline. Between 11 and 20% of the 535 faculty members focus in pedology, soil biogeochemistry, soil biology (microbiology and ecology), soil chemistry, soil fertility, soil management, or soil physics (Fig. 3). There is a difference in the gender composition among subdisciplines in soil science (Fig. 3), with the smallest percentages of women faculty in soil physics (13%) and soil fertility (15%), followed by pedology, soil biogeochemistry, and soil management (19% each), and soil chemistry (23%). The highest representation of women soil science faculty by subdiscipline is in soil biology, where women make up 51% of the faculty.

Federal Soil Scientists

The employment of women as soil scientists in federal agencies has steadily increased over time. Since 1998, the relative proportion of women among soil scientists in federal service has doubled from 13 to 26% in 2017 (Fig. 4, 2). Today, this distribu-

tion closely resembles that of the SSSA membership in 2017 (26% women) but not the distribution of BS, MS, or PhD students in soil science at about this same time (40, 54, and 53% women respectively; Fig. 1; Brevik et al., 2018). There is also a contrast between the historical trend in STEM occupations within the federal government, which has witnessed an 81% increase in overall employee numbers between 1998 and 2017, and the trend in soil science employment, which has seen a 39% decline (Fig. 4). Both overall STEM occupations and soil science have seen similar increases in the percentage of female employees (17 to 28% for STEM and 13 to 26% for women) during that same time period, and even as overall federal soil science employment decreased, the employment of women increased by 42 individuals.

By examining gender distribution as a function of federal soil scientist age and grade level, an inverse relationship emerges between gender representation and age of soil scientists (Fig. 5). Federal soil scientists who are less than 30 yr of age are dominantly women (56%) while those aged 30 to 50 yr are 34% women and 66% men. Among more senior employees (>50 yr) women are far less well represented (14% of this age group) in the federal government. Dissecting gender data as a function of grade level indicates that federal soil scientists employed at lower grade salary (GS) levels (GS-5 and GS-7, technician) are dominantly men (74%) while those at GS-9, a typical federal entry salary grade level for a MS degree, are dominantly women (56%) (Fig. 5). The latter is commensurate with the gender composition of the soil scientists with MS degrees. There is a subsequent decrease in the representation of women soil scientists at higher grade levels (GS-11, generally MS holders or equivalent experience; 31%) and few women (18%) hold the rank of GS-12 to GS-15 (generally PhD holders or equivalent experience). This suggests a gender gap between the pool of PhD holders and those actually employed above mid-level. It is plausible that more women are entering the federal service and reach intermediate levels (GS-9) before their advancement stalls above the GS-11 grade.

The gender distribution between agencies employing soil scientists ranges widely (Fig. 6). The United States Forest Service (USFS) employs 131 soil scientists, of which 42% are women. The largest employer of soil scientists within the federal government, the Natural Resources Conservation Service (NRCS), employs 566 soil scientists comprised of 23% women. One can only speculate as to the wide discrepancy in gender composition of the workforce between agencies, but given the nature of the job descriptions at each agency, the gender distributions may reflect that of the subdisciplines from which they commonly hire.

Industry Professional Soil Scientists

Data are lacking on the gender distribution of soil scientists employed within private industry. Referring to SSSA membership data, 24% of members who selected the Consulting Soil Scientists Division as their first division, are women. In addition, 20% of the people in the SSSA Consulting Soil Scientists database are women (n = 58 of 289). Unfortunately, the database does not allow subdivision of the data based on age of the individuals, number of years with their company, or seniority of their jobs. However, the total percentage of women in the SSSA database of soil scientists in private industry and of those who choose the Consulting Soil Scientists Division as their first division of interest is much lower than current enrollment at both the undergraduate and graduate

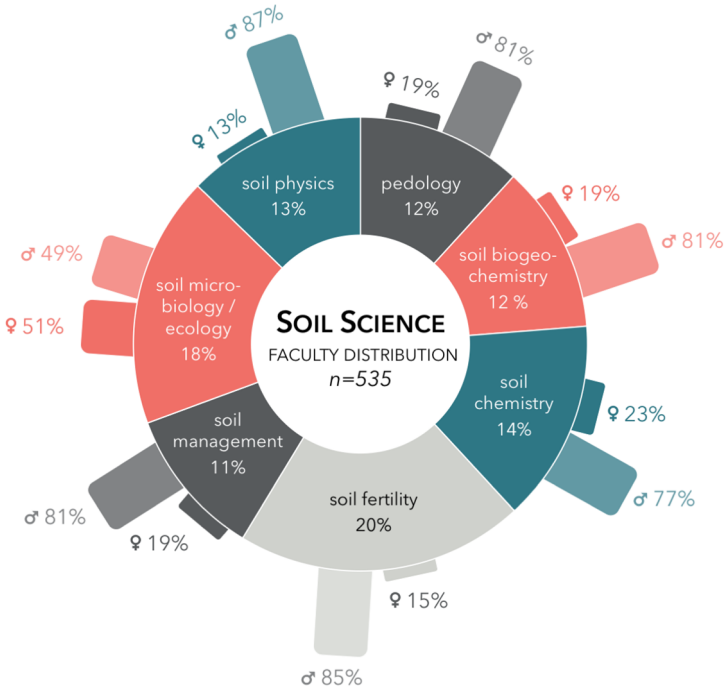

Fig. 3. Distribution of soil science faculty in the United States by discipline and gender from 74 Universities maintaining soil science degree programs in 2017. Numbers within the chart are the percentage of faculty focused in each subdiscipline. Bar charts expanding from central graph represent the percentage of women (♀) and men (♂) faculty members within each subdiscipline.

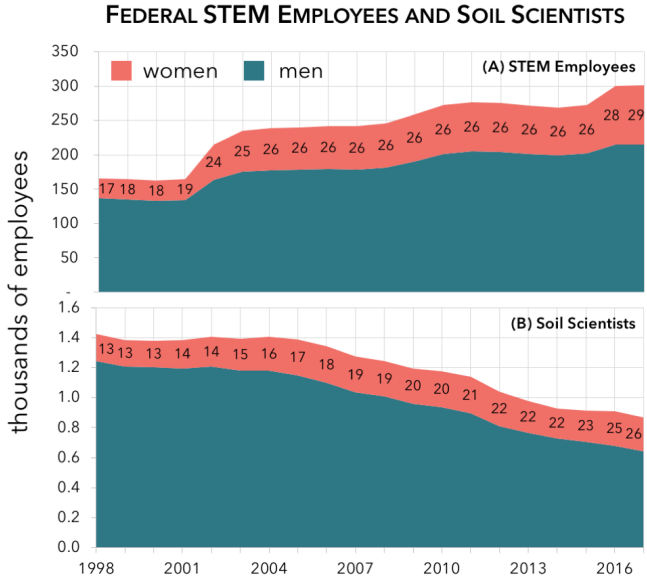

Fig. 4. Federal science, technology, engineering, and math (STEM) employees (A) and soil scientists (B) from 1998 through 2017. The numbers on the graphs correspond to the percentage of female employees during that time. Note different scales on top and bottom graphs (OPM, 2017).

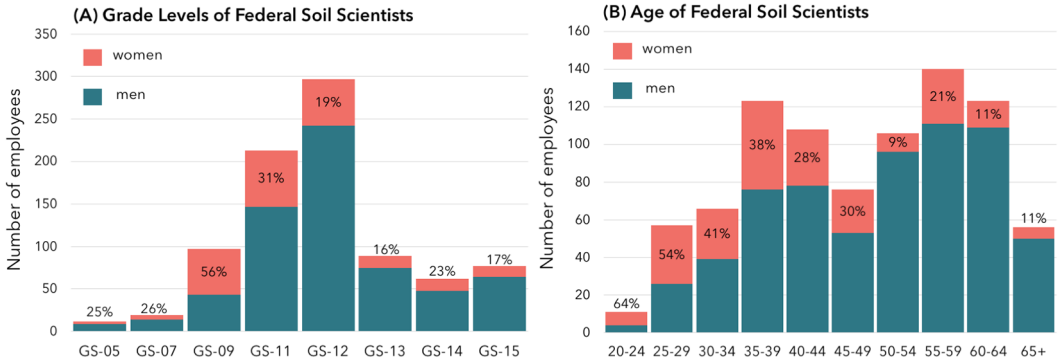

Fig. 5. Gender distribution of federally employed soil scientists by grade salary (GS) level (A) and age (B) obtained in September 2017 (OPM, 2017).

levels. We recognize that this does not provide a comprehensive view of all soil scientists in private industry, but only a record of those who are associated with the SSSA.

Women Identify with the Soils Profession through Membership in SSSA

The growing participation of women soil scientists is also reflected through their professional affiliation with SSSA, which has increased steadily since the 1980s. In the last 10 yr, SSSA has seen an overall 43% increase in the number of women soil scientists who are members, from a total of around 1200 in 2009 (or 20% of total membership) to ~1,700 in 2018 (or 29% of total) (Table 1). In comparison, there was a more modest increase among male student members and an 11% decline in active membership among men, with an overall decline in the number of men from ~4500 in 2009 to ~4,100 in 2018. This is especially notable since the overall membership in SSSA in recent years has stagnated at about 6000 members, after a peak of around 6800 between 2012 and 2015. The proportion of women among soil scientists attending SSSA meetings has similarly increased over time from 22% in 2009 to 29% in 2017. Since 2014, more than 1000 women soil scientists have been attending the annual meetings. Similar increases in the participation of women has been noted in the Agronomy Society of America (ASA) annual meetings (McIntosh and Simmons, 2008). Here too, the time trend for women contrasts with that of their male counterparts, in that we observe a stagnation or even decline among male member attendance (Table 1).

The trend is particularly pronounced among student members, with women student membership nearly doubling from 2009 to 2018, while male student membership showed strong oscillations during that period. Women now account for 41% of the graduate student members and 45% of the undergraduate student members, a demographic representation that closely approximates the gender distribution of STEM degree recipients nationwide (Fig. 1). There is a concomitant increase in the number of women students who attend and present at the annual meetings (Table 1). This increase signals an interest by women students in becoming active in the soil science profession.

As with the representation of women scientists in the workforce, the proportion of women is lower among active (standard, non-student members) SSSA members, and declines with length of membership (Fig. 7). This trend, in part, reflects the lower rates of women seeking degrees in soil science in the past. Of note, however, a comparison of the gender composition of active members with PhD degrees (40% of the total SSSA membership) with the corresponding contemporaneous trend among PhD degree recipients in S&E nationwide (NSF, 2105, 2107) shows a distinct gender gap in our membership (Fig. 8). The fact that the gender composition of student and early career membership approximates the gender composition of the soil science degree-holders suggests that in recent years, male and female soil science students have been making the transition to SSSA in equal proportions. However, student membership does not automatically translate into active membership as evidenced through a preliminary analysis tracking student members between 2015 and 2017. The overall transition rate of student members to active membership is low (<10%) with less than half of the students renewing their membership in a subsequent year. Furthermore, only 12% of the students become ac-

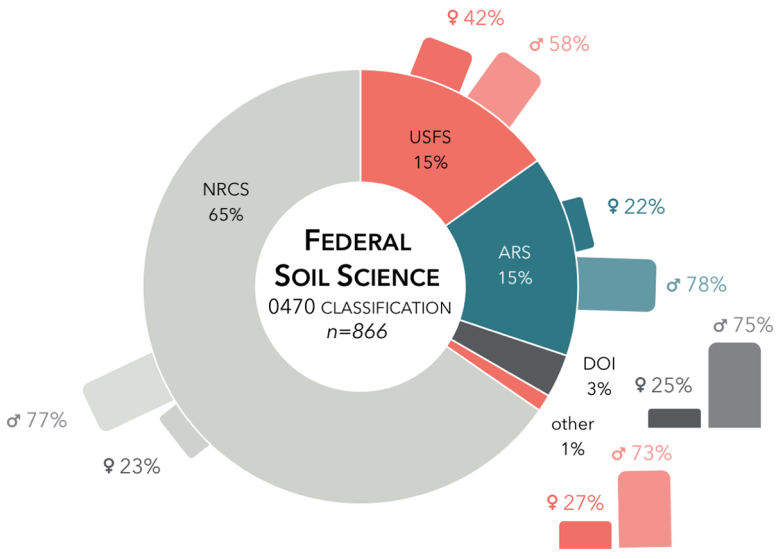

Fig. 6. Distribution of federally employed soil scientists (*n* = 866) by agency (NRCS, Natural Resources Conservation Service; USFS, United States Forest Service; ARS, Agricultural Research Service; DOI, Department of Interior) and gender in September 2017. Bar charts expanding from central graph represent the percentage of women (♀) and men (♂) employed by the respective agency (OPM, 2017).

Table 1. Participation of women in the Soil Science Society of America (SSSA) as members and meeting attendees in 2009 and 2018. The 10-yr change in participation of women vs. men is expressed as a percentage over the 2009 baseline value.

	Membership				10-yr change	
	2009		2018		Women	Men
	No.	% of total	No.	% of total	%	
All categories of membership	1185	20	1697	29	+43	−8
Active	914	17	1407	26	+54	−11
Graduate student	387	36	538	41	+39	+19
Undergraduate student	115	31	242	45	+110	+17
	Meeting attendance				10-yr change	
	2009		2017†		Women	Men
All categories of membership	699	22	1015	29	+45	−1
Active	319	17	437	23	+37	−6
Graduate student	212	32	365	39	+72	+37
Undergraduate student	39	34	154	53	+295	+90

† Attendance data from 2017 were used for the comparison because SSSA did not meet with CSA and ASA in Fall 2018, but held a separate meeting in San Diego, CA, January 2019.

tive members within 4 yr after they were graduate student members. This attrition pattern is unaffected by gender.

SSSA Subdisciplines

Members participate in SSSA along sub-disciplinary lines, with the gender composition among primary divisions somewhat parallel to patterns among faculty subdisciplines. Among active members and graduate student members who select Soil Biology and Biogeochemistry as their primary division, 38 and 53% are women, respectively (note that men and members who declined to select a gender constitute the remaining percentage) (Fig. 9). The distribution of first choice division among SSSA members ranges from the lowest percentage of women selecting Soil Physics (13, 33, and 18% among active, graduate student, and total membership, respectively), to the greatest percentage of women selecting Soil Biology and Biogeochemistry (38, 53, and 43% among active, graduate student, and total membership respectively) and Soil Education and Outreach (41, 55, and 46% among active, graduate student, and total membership, respectively). These data suggest that some subdisciplines may be more gender diverse than others. Graduate student members represent an opportunity regarding the future gender distribution of SSSA members (Fig. 9). Divisions (e.g., Soil Physics, Soil Fertility, Soil and Water Management and Conservation) with student numbers deviating from parity should examine this as a potential for improving recruitment and retention of women.

Women Soil Scientists in Related Professional Societies of the USA

This analysis focuses on SSSA as it is the largest soil scientist professional organization in the Western Hemisphere. However, it should be noted that soil scientists participate in multiple professional societies (e.g., Agronomy Society of America, Geological Society of America, Ecological Society of America, American Association for the Advancement of Science, and American Geophysical Union [2019]to name some of the largest professional organizations for US scientists). Within these other societies, the sections or divisions where soil scientists participate tend to be among the most active. For example, the Biogeosciences and Hydrology sections of AGU, which are home to many soil scientists, are among the largest, fastest growing, and most gender diverse sections (Rhodes, 2006; Landa and Brevik, 2015; AGU, 2019).

Women are not Adequately Recognized for their Contribution to Soil Science

Within SSSA, women are increasingly elected to mid-level leadership positions, which further signals the growing active participation of women soil scientists in the professional arena, as well as a recognition of their leadership abilities by their peers. The relative representation of women among division chairs has increased from 18% (n = 2) in 2003 to 21% (n = 3) in 2013 and 29% (n = 4) in 2018. Women comprised 12% of the Board of Directors in 2003 (n = 2 of 17), 14% in 2013 (n = 2 of 14) and 33% (n = 4 of 12) in 2018. However, these numbers can vary. For example, the 2015 SSSA Board of Directors did not have any elected women on it, as the Graduate Student representative was an appointed position at that time. These recent percentages closely reflect the gender composition of the active membership (26% in 2018). However, women are still under-represented at the highest governance levels. Since the founding of SSSA in

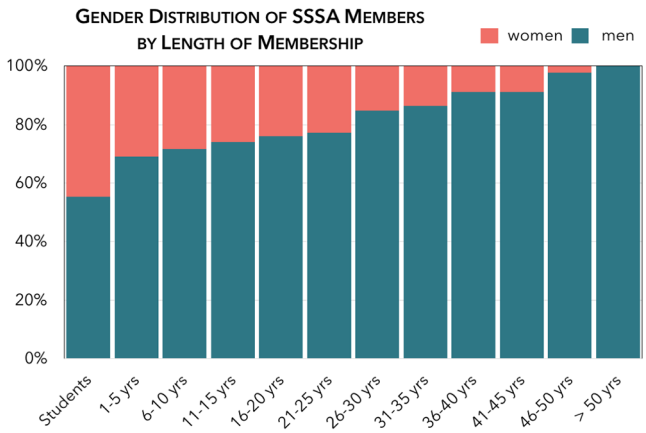

Fig. 7. Gender distribution of Soil Science Society of America (SSSA) members in 2017 as a function of length of membership.

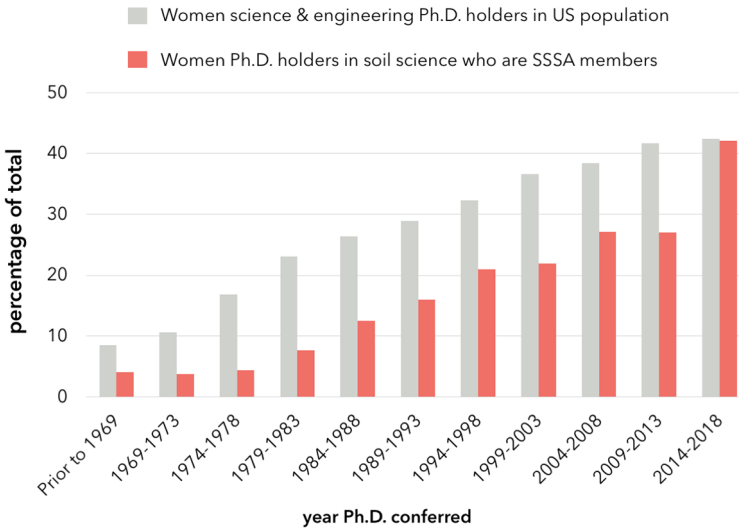

Fig. 8. Percentage of women among PhD Soil Science Society of America (SSSA) members by year degree was conferred compared to the national average of doctoral degree recipients in science and engineering disciplines (NSF, 2015, 2018).

1936, only two women have attained the position of Society President (2.4%), serving in 2005 and 2015.

Diversity in ASA is similar to SSSA, with only three women presidents (2.7%) in their 111-yr history up to 2018, all serving since 2013 (ASA, 2019). The presidency of other scientific societies has also been dominated by men, but women have made greater inroads. For example, 8% (n = 10 of 130) of the Geological Society of America's (GSA) presidents have been women, and 14% (n = 15 of 104) of the Ecological Society of America's (ESA) presidents have been women. Since 1985, 29% of GSA's presidents (n = 10 of 34) and 41% of ESA's presidents (n = 14 of 34) have been women (ESA, 2019; GSA, 2019). While both of SSSA's women presidents have served since 1985, that is still only 6% of the presidents over this time period and SSSA lags far behind these other two related societies.

While election to leadership positions speak to heightened visibility of women within the society, they also entail a significant service component. The more formal recognition of soil scientists' contribution to the discipline per se through the bestowing of awards and title of Fellow has clearly disadvantaged women in the past. Women have been noticeably absent as recipients of SSSA awards. Only 6% of all SSSA awards (15 out of 247) bestowed since 2000 have gone to women, most of which are in recognition of mentoring or educational activities. Only 4 women have been recognized for scientific achievement: two for their graduate research (Truog Soil Science Outstanding Dissertation Award in 2008 and 2016) in addition to the two women soil scientists who received the Jackson Soil Chemistry Award and Kirkham Soil Physics Award in 2007 and 2015, respectively. There is no evidence of women soil scientists receiving SSSA scientific achievement awards prior to this date. It was not until 1987 that the first woman was elected Fellow of the SSSA, which is not unexpected given the modest number of women members, especially among senior soil scientists. In the subsequent 25 yr, the recognition of women has been highly variable and inconsistent from year to year. Between 1995 and 2011, 14 out of a total of 249 Fellows were women (<6%). Since 2012, there has been a noticeable upswing in the number of women soil scientists receiving this honor within SSSA (n = 3–4 out of 14 annually), and the percentages of female Fellows now more closely reflect the membership and seniority of women within the society (Fig. 7; Table 2). This pattern stands in stark contrast to the lower recognition rate of women in SSSA's two sister societies (American Society of Agronomy and Crop Science Society of America) (Table 2).

Table 2. Percentage of Fellows of the Agronomy Society of America (ASA), Crop Science Society of America (CSSA), and Soil Science Society of America (SSSA) awarded to women during each year from 2008 to 2017.

Year	ASA	CSSA	SSSA	ASA, CSSA, and SSSA combined
			%	
2008	11	10	7	9
2009	21	0	14	14
2010	12	0	0	5
2011	6	9	0	5
2012	11	9	21	14
2013	18	9	21	17
2014	6	0	29	12
2015	0	9	21	10
2016	25	27	21	24
2017	6	0	25	11
10-yr†	12	7	16	12

† 10-yr mean reported.

DISCUSSION

The face of soil science has changed dramatically over the last couple of decades. The identity of soil science as a discipline with strong ties to agronomy is transforming into a field that has a broader definition that includes earth and environmental sciences, ecology, and other disciplines (Brevik, 2019). This has been reflected in part by the disappearance of soil science programs at many universities and a changing affiliation of soil scientists away from disciplinary units that bear the word "soil" in their name (Baveye, 2006). Is this change really a crisis? Baveye et al. (2006) argued that soil science was in crisis mode when noting dwindling student enrollments in graduate soil science programs across North America regardless of gender, but more recent studies have indicated that soil science student numbers have been recovering in both the United States and Canada (Brevik et al., 2014, 2018; Diochon et al., 2017). There has also been a concomitant shift in the gender demographics among the scientists who populate the discipline. This important shift helps support the vitality of the field, especially among early career scientists, and may represent an untapped opportunity to grow and innovate our science.

A steady growth in the proportion of women among students in the United States pursuing graduate degrees in soil science has marked the last few decades. This pattern mimics the national trend of increasing participation of women in STEM disciplines since the early 1970s, particularly in biological and earth sciences

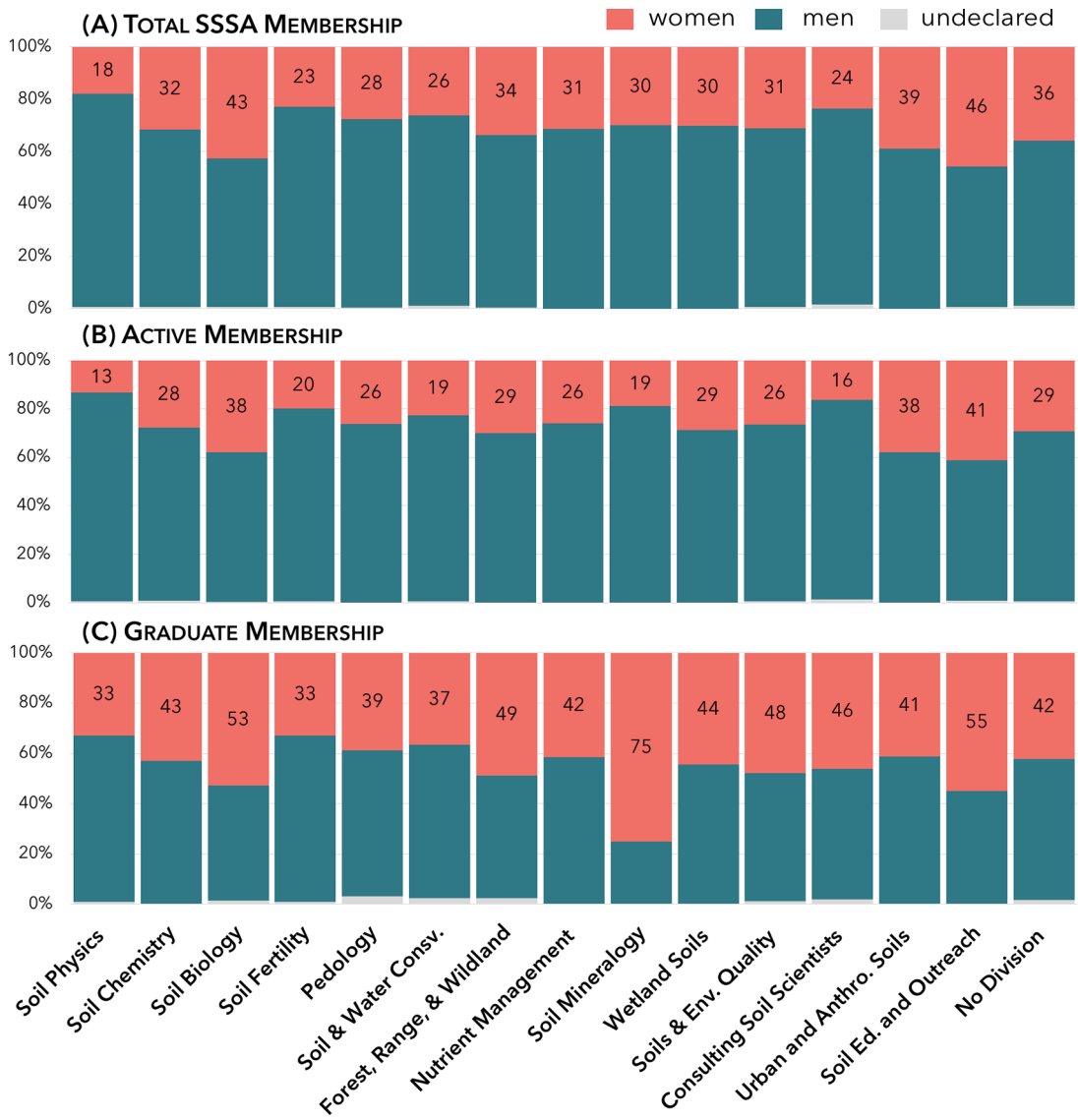

Fig. 9. Soil Science Society of America (SSSA) membership distribution by first self-selected division preference and gender as of January 2019. Individuals who selected undeclared for gender (gray) ranged from 0 to 3 persons per membership type in each division (e.g., 3 individuals in graduate student membership in Pedology and 1 individual in active membership in Consulting Soil Scientists). The numbers noted on the graphs are the percentage of women in the corresponding division. Total membership (A) includes all active (B, *n* = 3536) and graduate student (C, *n* = 1277) members. The following division names were shortened: Soil Physics and Hydrology; Soil Biology and Biogeochemistry; Soil Fertility and Plant Nutrition; Soil and Water Management and Conservation; Forest, Range, and Wildland Soils; Nutrient Management and Soil and Plant Analysis; Soils and Environmental Quality; Urban and Anthropogenic Soils; Soil Education and Outreach; and No Division Selected.

(NSF, 2015, 2017, 2018). Nearly half of the graduate degrees in soil science now go to women. Many of these women enter the workforce and pursue careers as soil scientists in academia, federal agencies and private industry. Women comprise about one-quarter of all soil scientists in each of these three main employment sectors and of the SSSA membership. Yet, the discrepancy between gender composition of the graduate student pool and those in the work force suggests that more women than men choose to transition to alternative career paths or at least to positions in related fields (e.g., ecology, environmental sciences, (bio)geosciences, etc.).

Women are also more prevalent in soil subfields affiliated with the biological sciences and ecology, consistent with national trends that show higher representation of women in life sciences compared to physical sciences and math-intensive fields in the education and employment ladder (Ceci et al., 2014). Interestingly, this trend coincides with a relative shift in the identity of soil science away from the confines of agronomy toward broader applications in ecological, environmental, and natural resource management (Baveye et al., 2006).

As shown by the selection of primary division of interest in SSSA membership, women are well represented in the Soil Education and Outreach and Soil Biology and Biogeochemistry sub-disciplines (Fig. 9). Examining graduate student membership, this influx of women also holds among additional divisions: Soil Mineralogy; Forest, Range, and Wildland Soils; and Soils and Environmental Quality. It would behoove the leadership in these arenas to look toward the future of soil science and harness the energy of new scientists entering the discipline. Encourage these individuals to participate in the division through sharing

of research, sharing of experiences, and inserting their voice into divisional planning and organization.

Importantly, many of these women are active and identify as soil scientists through their participation in professional organizations such as the SSSA. In the last 10 yr, the SSSA has seen a more than 40% increase in the participation of women as members and meeting attendees both in absolute numbers and in relative terms compared to their male counterparts. Here too, women tend to concentrate in certain focal areas or SSSA Divisions including Soil Biology and Biogeochemistry, Soil Education and Outreach, and Urban and Anthropogenic Soils while identifying less actively with others such as Soil Physics and Hydrology, Soil Fertility and Plant Nutrition, and Consulting Soil Scientists (Fig. 9).

Our data suggests a progressive decline, or at least a stagnation, along the professional career path of women in soil science. While the representation of early- career or mid-level women soil scientists more closely approximates the gender composition of corresponding cohorts of graduate degree holders, the gender gap is much higher among the most senior professional positions within academic and government employers and also within SSSA. This is consistent with other comprehensive studies that have shown that the lack of women in top STEM positions cannot adequately be explained by a lack of suitable women to occupy these positions (Goulden et al., 2011; Ceci et al., 2014). Rather it suggests that additional barriers exist to the upward mobility of women soil scientists, both within the workplace and SSSA (Van Miegroet et al., 2019).

This analysis does not allow us to identify the true causes for these patterns. There are those who believe that science is objective, meritocratic, and gender-blind, and explain the lack of professional success of some women as due to a lack of professional commitment, personal choices taking them away from a career, or lack of achievement for whatever reason (Ceci et al., 2014). Such claims are likely wrong, or at the very least overly simplistic, in that they overlook structural barriers such as higher demands for non-research activities for women (Mason et al., 2013; Misra et al., 2011), women's exclusion from critical information and collaboration networks, or mobility constraints due to family obligations (Dean and Koster, 2014).

An alternative perspective focuses on unintended (implicit) gender bias and gender norms in the assessment of scientific achievement that systematically disadvantages women relative to their male counterparts (Valian, 1999) because notions of competence and leadership are often associated with male attributes especially in scientific disciplines that are traditionally male dominated (Acker, 2006; Cech and Blair-Loy, 2010). As a consequence, the achievements of women, especially when they are still numeric minorities, may remain unnoticed or receive greater scrutiny (Kanter, 1977) such that women have to work harder and accomplish more to be recognized compared to similarly positioned male colleagues (Rosser, 2004).

The under-representation of women among SSSA award recipients, akin to patterns observed in many other STEM societies (e.g., Lincoln et al., 2012), hints at a less than equitable nominating or decision-making process. A comprehensive analysis by the Association for Women in Science (AWIS) noted that, while the number of women receiving scholarly awards has increased over time in some STEM societies, the proportion of women recipients remains well below the expected rates based on their academic rank, their seniority within societies, or even the composition of the nomination pool (Lincoln et al., 2011, 2012). When women receive recognition, it is largely for non-research activities such as teaching and student mentoring, consistent with the caring and nurturing female stereotype, a pattern also observed at the national level (Holmes et al., 2011; Lincoln et al., 2012).

Compared to their male colleagues, women are generally less likely to be recognized for their scientific achievement in STEM disciplines. The AWIS study further noted that the preference by men who still dominate most levels in STEM organizations for individuals more like them (i.e., homophily) likely contributes to the lower nomination rates of women in many scientific organizations (e.g., Holmes et al., 2011; Hurley, 2014). To some extent, this need for sameness is also linked to the underrepresentation of women among the nominators (Ball, 2014; Holmes et al., 2011). In other words, lack of representation at decision-making levels reinforces and reproduces gender imbalance in recognition of achievement within these organizations.

Finally, there are subtle, even unrealized, gender biases, where even established women will rate males higher in a situation where male and female candidates with the exact same credentials are evaluated for a position in blind studies (Moss-Racusin et al., 2012). Without formal guidelines and transparent rules in the decision-making process, evaluators (irrespective of gender) tend to activate cognitive shortcuts that favor men (Holmes et al., 2011; Lincoln et al., 2011). The more equitable gender distribution among SSSA members recently elected as Fellows in the last 5 yr suggests that a different mechanism is at work both at the level of nomination and the selection for this honor. Mechanisms responsible for these differences in outcomes deserve more thorough analysis.

IMPLICATIONS AND RECOMMENDATIONS

Benefits of Diversity to the Discipline

While this analysis mainly focused on gender, other aspects of diversity such as race and ethnicity need to be explored further. Diversity and inclusion in any discipline is key to diversity of thinking (Rosser, 2004) and innovation in the sciences (Nielsen et al., 2017). It increases collective intelligence (Woolley et al., 2010), uses expertise more efficiently (Joshi, 2014), and results in higher impact research (Campbell et al., 2013). Women's advancement also maintains our scientific competitiveness worldwide by providing role models that entice young talent, especially in underrepresented groups, to become part of the domestic, highly trained, scientific labor force (Rosser, 2004; Goulden et al., 2011).

The Importance of Professional Societies like SSSA

Professional societies such as SSSA play a crucial role in the career success of their members. Annual meetings are invaluable as a locus for scientific discourse, exchange of ideas, and network-

ing and collaborations, and thus contribute to the advancement of the soil science discipline as a whole. At the individual level, visibility at meetings is a cornerstone in the establishment of a scientist's professional reputation. There is feedback between peer recognition and career advancement, and this is where professional and workplace dynamics intersect. The recognition of members for their contributions to soil science and their standing within the discipline–as signaled by elected leadership positions, fellows, award winners, invited or keynote speakers–are key in the construction of excellence and the peer validation of scientific contributions that lie outside the control of the individual, but can have important career consequences. Such peer recognition often translates into rewards at the scientist's home institution in the form of promotions, raises, or increased resource access (DiPrete and Eirich, 2006), which, in turn, positively impacts a member's future productivity and career trajectory.

Recommendations in Looking Forward

As a professional organization, we need to be cognizant of these drivers and take on a more proactive approach toward increasing the participation of women and other under-represented groups at all levels, unless we are willing to stifle innovation within soil science. Already, changes are taking place in the scope of soil science within interdisciplinary research. It is the responsibility of soil scientists to determine the direction of the discipline by standing up not only for the rigor and quality of our science, but also for an equitable and just treatment of its practitioners. In light of stagnating overall membership numbers, it behooves us to direct our attention and support to a growing segment of the soil science population, that is, students and women, as a way to reinvigorate SSSA and an opportunity for innovation and growth within the discipline.

As scientists in a scientific society we need to guard against the encroachment and unintended consequences of implicit bias in our decision-making process. Implicit bias can occur when we seek out collaborators and invite people into our networks, when we select speakers for named lectures or keynote addresses, when we encourage fellow members to stand for election in leadership positions, and, when we nominate candidates for honors and recognition. Inclusion matters, as it signals to the rising generation of young soil scientists that all have an opportunity to excel and contribute to the advancement of our science, regardless of gender, ethnicity, or field of study.

Good intentions are often insufficient, unless accompanied by deliberate measures to counter unintended bias and gender inequity in our professional dealings. This study represents the first step in such a change process: highlighting trends and visible problems while creating greater institutional attentiveness to gender equity (Sturm, 2006). By itself, this may prove ineffective in achieving gender equity if not associated with structural changes (i.e., policy) that translate these findings into objective and enforceable actions (Kalev et al., 2006; Cho et al., 2017). Improvements in the upward mobility of women and under-represented groups within soil science can be achieved by implementing best practices that include: greater transparency in decision-making processes; greater accountability by decision-makers; formal codification and standardization of procedures, criteria, and responsibilities in decision making; and inclusion of organizational leadership as agents of change (Reskin, 2000). To achieve gender equity goals, we must identify the obstacles specific to the career success of women within the context of the discipline or organization. Then, we must work to remove sources of inequality with the most effective and appropriate methods for the organization, and at the same time, identify and encourage practices that are working.

SUPPLEMENTAL MATERIAL

Supplemental material is available with the online version of this article.

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The authors acknowledge that this examination of gender diversity in soil science is in no way complete. Data are lacking for several dimensions of diversity, including gender, sexual orientation, gender identity, race, and ethnicity. However, we believe that our analysis, though incomplete, has a potential to serve as a valuable starting point for further analyses and fruitful conversations about how our scholarly and professional community can equitably serve all members of our pluralistic society.

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