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Hundred fifty years of soil security research in Indonesia: Shifting topics, modes of research and gender balance

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ABSTRACT

In Indonesian development policy, soil security is primarily understood as part of food security, expansion of the plantation economy, and resettlement schemes rather than as soil-related Sustainable-Development-Goal concerns for health, water, energy, jobs, protection from disasters, changing climates, life in water and life on land. A recent paper reported a shift of Indonesian soil science towards equal participation by men and women. Here we explore a parallel change in focus. in the scientific analysis of (1) the 'what/where/when' of soil patterns, (2) the 'how' of soil processes and functions, (3) the ways soils can be managed and used, and (4) the 'so what' and 'who cares' of related to societal interests. We compared shifts in soil science research in literature from the colonial period, with the themes discussed in Indonesian soil science meetings of the past 40 years. Four research themes (patterns, processes, management, environment) were reflected in 29, 21, 49 and 2% of the 1406 publications in the 1890–1963 soil bibliography. In Indonesian soil science meetings of the past 40 years the themes formed 10, 28, 53 and 9% of the 1703 publications, respectively. Gender balance emerged in the past 20 years, with almost a 50:50 ratio of men and women as authors in 2019. However, women's participation is still uneven, with underrepresentation in the soil survey fieldwork and overrepresentation in laboratory-oriented soil process research. International publications about soils in Indonesia shifted earlier to these parts of the sustainable development agenda, but the national discussion followed the trend.

Introduction

Soil security is concerned with the understanding, maintenance and improvement of global, national and local soil resources in the context of the full spectrum of sustainable development goals (SDGs) (McBratney et al., 2014; Bagnall et al., 2021). Soil security as a concept has relationships with soil quality, soil health and soil protection, and connects biophysical understanding of patterns and processes to social, economic and political feedbacks (Keesstra et al., 2016; Bünemann et al., 2018; Bouma, 2019a, 2019b). The soil security literature calls for greater policy integration in the way science agendas are defined. Soils are foundational for the security of income (SDG1), food supply (SDG2), health (SDG3), water (SDG6), energy (SDG7), jobs (SDG8), protection of people and infrastructure from disasters (SDG9,11), changing climates (SDG13), life in water (SDG14) and life on land (SDG15) (Lal et al., 2021). Meanwhile, land use interacts with socially defined securities such as education (SDG4), gender equity (SDG5), social equity (SDG10), responsible consumption (SDG12), peace and justice (SDG16) and international cooperation (SDG17). However, the relative emphasis on different parts of the Sustainable Development Goal agenda has shifted

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over historical periods and is contested among stakeholders, especially in the balancing of growth and sustainability. SDG5 targets gender equality and women's empowerment. Its relation with soil security and thus with the full set of SDGs through soils has not yet been explored.A recent study on the shifting gender balance in soil science in Indonesia among students, researchers, lecturers and professors (Fiantis et al., 2022) and the broader international debate on the topic (Dawson et al., 2021), raised a question about the way soil science itself is changing in interaction with gender. Are shifts in soil science topics and research methods facilitating greater gender equity among the practitioners, or is greater participation of women scientists shifting the agenda? As this may well be a chicken-or-egg question on interacting influences, within broader societal changes, a description of the two separate components is needed to clarify interactions: how has soil science changed?, and how is the gender balance among soil scientists changing?

In fact, there may be four types of emancipation at play, with potential interactions:

(A) Connecting science to local knowledge and the concerns in society at large (beyond the economic powerfull that tend to dominate in market-based research funding) in the emergence of 'soiol security' as central concept.
(B) Tropical soil science as part of global soil science (from an 'afterthought' or 'special case' to a foundational and essential part of current science).
(C) Indonesian scientists vis-à-vis scientists born elsewhere (in the period before and after political independence).
(D) Women versus men as scientists, with gender-based societal expectations on roles, capacities and contributions.

To provide context, the paper starts with a brief account of the history of soil science in Indonesia. It then describes the data sources and classification system used for the quantification of the interaction of soil reseach themes and gender, followed by results and discussion.

The start of institutionalized soil science in indonesia

Local ecological knowledge of soils, probably accumulated since the start of language, has been documented from many parts of Indonesia. Criteria for soils that will be productive after land clearing are often a combination of soil color, how it feels (linked to soil texture), soil structure, how wet it is, and which plants are present (Mulyoutami et al., 2009; Iskandar et al., 2018; Silvianingsih et al., 2020). Change of soil conditions during crop-focussed swiddening and subsequent fallow restoration is often described in local knowledge systems in the terminology of 'becoming hot' (infertile) and 'becoming cool' (fertile) (Joshi et al., 2004a; van Noordwijk et al. 2008), rather than in the terms used by contemporary soil science as a change in soil organic matter pools, available phosphorus, soil water content, pH and cation saturation (van Noordwijk et al. 1997). European observers of Indonesian agriculture in the 18th and 19th centuries expressed concern about the destruction of forests as part of swidden/fallow cycles (Marsden, 1784) or erosion as a consequence of upland farming (Karel Holle in mid19th Century West Java, as documented in van den Berge, 1998). The colonial economy was based on forced cultivation of cash crops by local farmers, with little incentives for yield increases, and on a well-developed local bureaucracy (Svensson, 1991). Under the Agrarian Law of 1870, this pattern changed as all land that had not been recently cropped or planted were claimed by the state as forest lands, with opportunities for the government to lease it as concessions for plantation establishment, mostly to European entrepreneurs. The law reduced tenure security for local communities but increased it for large-scale plantation crops. This legal change influenced the development of soil science in two ways: it set off a quest for the best lands for various types of plantation crops (top-down soil science, choice of location). In contrast, the emerging private sector funded applied research on soil management practices (bottom-up soil science, based on existing site conditions), along with agronomy of the main cash crops (Widijatmoko et al., 2018). The sugarcane industry in East Java was among the pioneers of applied soil fertility research. At the same time, the tobacco enterprises in Deli (North Sumatra) relied on detailed soil surveys as the choice of location for further expansion crucial to economic success (Minasny et al., 2020b).

Chin A Tam (1993) collated a bibliography of soil science research from the Dutch colonial period in 1880s until 1963 (when Papua became part of Indonesian administration). The oldest reference in Chin (1993) was from 1883 and referred to a geological survey. A formal, publicly funded soil science started in 1905, called 'Laboratory for Agrogeology and Soil Research' associated with the Botanical garden in Bogor (West Java). The first director, Mohr, became one of the pioneers of tropical soil science (Mohr, 1944; Mohr et al., 1972), with a keen interest in the characterization of the diversity of soils, understanding the genesis of soils (climate, geology, edaphic factors), as well as practical implications for use and misuse in agriculture and forestry. As there was no effective language to describe the multidimensional concept of soil quality, the first connection was made to geological surveys and climate typologies, as basis for the geomorphology of landscapes and the soil types that developed through weathering of rocks, erosion, colluvial and alluvial sedimentation. One of the first publications of the soil institute (Mohr, 1908) provided an analysis of sediment loads, sampled in the mornings and afternoons of a number of rivers in Central Java, trying to establish the source of a specific silt fraction that was damaging rice crops. The observations in practice that the eventual success of irrigation schemes was to a high degree connected with the quality of the irrigation silt, called for more predictability of silt erosion rates, loading rivers (Edelman and van Beers, 1939). The logistics of such a study (a weekly horse cart to Bogor bring samples, sample bottles borrowed from the local milk factory), the necessary development of standardized filtration techniques and data analysis of what proved to be log-normal distributions with few events contribution most of the silt loads, before that concept was recognized, showed that soil scientists had to have an all-round skill set to thrive. A similar situation with small areas of highly erodible soils in a mosaic with soils less sensitive to forest cover change was more recently described in Lampung (Verbist et al., 2010).

The tropical soil science that emerged aimed at solving practical problems, borrowing the toolboxes of geologists, physical, chemical, and biological sciences. Tropical soil science (Sanchez, 2019) relied on the same set of processes recognized in temperate soils, but with greater intensity due to higher temperatures and rainfall. Indonesia has a wide range of soils associated with variation in soil forming processes and geomorphic settings, from mountain slopes through upland valleys and peneplains, riparian zones, lowland alluvial areas, interfluvial peat domes and mangroves on the interface with the marine environment. The diversity of soil conditions within Indonesia is further increased by the contrast between geologically young islands with high volcanic and tectonic activity (Sumatra, Java, Sulawesi and many of the smaller islands), and those dominated by old tectonic plates (Kalimantan and Papua) (Michaux, 1991). Indonesia has more than 100 active volcanoes and many more that are dormant, as it is part of the global ring of fire linked to tectonic plate subduction zones. Densely populated Java and Bali reflect both the long-term soil fertility benefits of volcanic ash and a large number of people at risk during fresh eruptions, ash deposition, and lahar flows (Fiantis et al., 2019; Ishaq et al., 2020).

The initial soil classification system based on the agroecological approach (parent materials, soil color, and texture) was created in the absence of a definitive classification system (e.g., Druif, 1938). Later, soil classification systems that emerged in Indonesia were reconciled with those developed elsewhere, with a major contribution by Dudal and Soepraptohardjo (1957) to adjust to FAO nomenclature. Later in the 1980s, the soil science society of Indonesia adopted the US-based Soil Taxonomy was (Sukarman et al., 2013; Sulaeman et al., 2013). Currently, the Indonesian national system is based on both soil morphology and genesis (Subardja et al., 2016).

Soil science remained primarily a biophysical science, with sparse interactions with the agrarian issues of land allocation, tenure rights, and equity (van Noordwijk et al. 2018). Soil science in higher education in Indonesia is still primarily managed as part of Faculties of Agriculture. In the colonial period, economic gains from a plantation economy prevailed (and funded its own research on plantation crops). Post-independence, since the 1950s, the opportunities for economic growth, resettlement schemes and a nationalized and then re-privatized plantation sector called for increased soil survey activity. Agricultural expansion out of Java made acid upland soils and their management a priority topic. Concerns over soil and water conservation remained closely aligned with the protection of forests and the return of trees to the landscapes. Our research questions were how these shifting thematic interests and associated methods had changed over time and how this related to the gender balance among Indonesian soil scientists.

Methods

Thematic classification

For a thematic analysis of Indonesian soil science, we used the terminology from the International Union of Soil Sciences (IUSS) (2021) based on its four commissions:

(I) Soils in Space and Time deals with patterns. It looks at the soil as a body and how it was formed, the extent of its global coverage, and the many complex interactions and interactions with the biosphere, hydrosphere, atmosphere, and lithosphere. It focuses on the "what" of the pedosphere and the extent of its current understanding.

(II) Soil properties and processes deals with the "How" or the fundamental science behind our discipline, the understanding of fundamental processes. It is concerned with the integration of physics, chemistry, biology, mineralogy, and pedogenesis to understand fundamental soil properties and processes that control transport, cycling, speciation and bioavailability of elements or molecules. These phenomena are studied at multiple scales ranging from atom to the world.

(III) Soil Use and Management deals with the importance of soils to society, in the application of fundamental knowledge to solving high priority social, economic, and environmental challenges of major societal and scientific interest. It can be considered the applied segment of patterns and process science.

(IV) The Role of Soils in Sustaining Society and the Environment entails the transfer and outreach of our knowledge base to segments of our society where soils and soil science are frequently misunderstood or sometimes under-appreciated. It takes the soils information generated in the other three divisions and develops new scientific information, and addresses public literacy in soil science, education, international conventions, consequences of human activities on soil ecosystems, policy issues, food security, history of the discipline, etc.

The first is essential about 'theory of place' (how do patterns change in space), the second 'theory of change' (dominant processes), and the third 'theory of induced change' (human influence on patterns and process to achieve anthropocentric goals), while the fourth is about communication beyond the circle of soil scientists (van Noordwijk, 2021). The four themes were subdivided (Table 1).

Table 1
Classification of topics of soils research (slightly condensed from IUSS commissions structure).

1 – Soils in Space and Time
1A Soil morphology and micromorphology
1B Soil survey, mapping, and classification
1C Soil genesis and paleopedology
1D Pedometrics (statistical & mathematical soil studies) and digital technologies
2 – Soil properties and processes
2A Soil physics
2B Soil chemistry and mineralogy
2C Soil biology
2D Soil chemical, physical and biological interfacial reactions in relation to plants
3 – Soil Use and Management
3A Soil evaluation and land use planning
3B Soil and water conservation
3C Soil fertility, fertilizers, and plant nutrition
3D Soil engineering and technology
3E Soil degradation control, remediation, and reclamation (incl. Salt-affected Soils)
4 – The Role of Soils in Sustaining Society and the Environment
4A Soils and the environment (incl. GHG emissions, soil C stock, peatlands. Mangrove, ecosystem services)
4B Soils, food security, and human health
4C Soils and land use change (e.g. forest conversion, deforestation, urbanization)
4D Soil education and public awareness
4E History, philosophy, and sociology of soil science

Data sources

We used two main sources of data. First, we reviewed the themes of the soil science literature from the Dutch Indies and Indonesia from 1890 until 2019. Literature of soil science from 1890 to 1963 was assessed from the bibliography compiled by Chin A Tam (1993), here called Soil Bibliography in Indonesia or SOBIN. SOBIN contains abstracts (in English) of reports and scientific papers mostly in Dutch. A total of 1406 titles were recorded. On the basis of the number of abstracts in SOBIN, we divided the publications in SOBIN into five periods: Before 1905, 1905–1930, 1930–1940, 1940–1955, 1955–1963 Table 2.

Soil science investigations in the last forty years in Indonesia were derived from abstract books or proceedings of the ten national congresses of the Indonesian Soil Science Society (HITI = Himpunan Ilmu Tanah Indonesia) that had been conducted regularly from 1977 until 2019. The books of abstracts of national congresses could be retrieved, from the following references: (Suhardjo et al., 1977; HITI, 1981, 1985, 1989; Subagyo et al., 1997; Djakasutami et al., 1999; Fiantis et al., 2003; Radjagukguk et al., 2007; Cahyani et al., 2012; Utami et al., 2016; Nurbaity et al., 2019). The papers are in Bahasa Indonesia. Two more specialized symposia on minimum tillage (Utomo et al., 1993) and soil conservation (MKTI, 1996) were added to the data set to reach a total of 1557 post-1970 data points (titles). In addition, the gender of the first author was also recorded (as in the current author team the scientists involved are known where names as such might be ambiguous). We focused on first authors rather than full authorship as otherwise multi-authored papers would get additional weight, or arbitrary rules for assigning credits would have to be used. Each title (abstract) was allocated to one of the research topics defined in Table 1.

The third source of Indonesian soil science literature was derived from international publications in the Clarivate Web of Science database. Papers published in international refereed journals were retrieved using the search term "soil" and "Indonesia" for publications between 1990 and 2020. A total of 3492 publications were retrieved, the year of publication, title, address of the first author, journal title, and topic classification were recorded. As the number of publications was large, we could not manually allocate them according to the categories of Table 1. Instead, we used the topic classification of the journal according to Web of Science to indicate the trend of research topics.

Data analysis

To test a null-hypothesis of the randomness of the gender distribution among themes at any point in time, we applied a Pearson Chi-squared test, based on $\chi^2 = \sum(o\text{-}e)^2/e$, where o = observed and e = expected value.

Word clouds were constructed to represent the frequency of technical terms used in titles and keywords, with the word cloud online

Table 2
Distribution of SOBIN references (1890–1963) by theme and period, expressed as percentages.

	Before 1905	1905–1930	1930–1940	1940–1955	1955–1963	All periods
Number	31	398	484	384	109	1406
Soil typology (1A+1C)	16.1	9.8	7.2	9.6	11.9	**9.2**
Soil survey (1B)	0.0	4.3	16.1	33.1	47.7	**19.5**
Soil chemistry (2B)	16.1	9.5	6.8	12.0	11.0	**9.5**
Soil biology (2C)	9.7	7.5	7.9	3.9	1.8	**6.3**
Plant-soil (2A+2D)	12.9	5.0	5.4	4.2	3.7	**5.0**
Soil conservation (3A+B + E)	6.5	10.3	13.0	10.9	0.9	**10.6**
Soil fertility (3C)	38.7	52.0	41.9	24.0	21.1	**38.2**
Soils and society (4)	0.0	1.5	1.7	2.3	1.8	**1.8**
All themes	**2.20**	**28.31**	**34.42**	**27.31**	**7.75**	**100**

Data source: author's classification of references in Chin A Tam (1993).

software (https://www.wordclouds.com/). The titles of the publications from the HITI conference were translated to English using Google translate. The titles were then fed to wordclouds.com to identify the most common keywords. The same word clouds analysis was performed for titles of international publications retrieved from Web of Science.

Results

Indonesian soil science topics in the first century (1870–1963)

The basic understanding of the diversity of soil physical, chemical, and biological characteristics (2A-D) and its explanation in terms of parent material, climate, and topography (1A and 1C), were a relatively large part of the Indonesian soils literature for the first period (Table 2). Work on soil survey and classification gained in prominence in the 1870–1963 period. The practical translation of soil properties into opportunities for soil fertility management (green and brown manures, cover crops, chemical fertilizer) dominated in the second period, with a special focus on tree crops such as coffee, cacao and rubber. Soil conservation and erosion control formed only a small part of the soil literature peaking in the third period, but with the 'land degradation' message, they informed soil fertility management. In the fourth and fifth period, soil survey became the dominant topic of Indonesian soils literature. Soil survey results informed development planning, but throughout the 1870–1963 period, only a small part (2%) of the literature dealt with the relationship between soils and society.

Only around 5% of the authors included in the SOBIN database had Indonesian names, while the rest were European, indicating that Indonesian scientists started to play a role after 1930. The gender of authors cannot be inferred from the European author names or other information in SOBIN, but they were dominantly men. One woman stands out among these soil scientists, indicating both the opportunities and constraints to a role in the science of those days. Dr. Betje Polak (Havinga and Muller, 1981) pioneered the study of peatlands in Indonesia, after her PhD research clarifying the origin of peat soils in the Netherlands. She developed palynological (pollen-based) methods for studying the historical dimensions of peat profiles, clarified that trees in peat swamps may be rooted in underlying mineral soils, initiated research on agronomic opportunities for crops in various types of peat, and towards the end of her life warned against the destructive types of peat reclamation that were emerging. Polak (1952) estimated the area covered with peat in Indonesia to be about 16.5 million ha; recent estimates show 13.4 M ha with a peat depth of more than 50 cm (Anda et al., 2021), with the re-classification of wetland soils in Southwest Papua responsible for most of the difference. Her biographers remarked that the travels for her initial fieldwork in Indonesia "appear out of tune with her somewhat un-athletic disposition, slow and deliberate way of movement and lack of orientation ability" but "demonstrated her considerable enterprise and courage." Yet, she was a pioneer in a topic of high current societal interest in the following decades, first as last frontier for agricultural expansion, then for environmental research to repair the damage done. Peatlands in Indonesia is still a topical research in the international community (Minasny et al., 2020a).

Indonesian soil science society meetings

The research themes from the proceedings of national congresses of the Indonesian Soil Science Society (1977–2019) indicate relatively small shifts in the proportions of the various themes (Fig. 1, Table 3). While most of the focus was on soil use and management, there is a clear trend that the soil and society theme increased over time. There is a clear trend in the gender balance in the authors, with less than 10% of women as first authors in 1977 to 25% in 1999, reached 40% in 2011, and an almost 50:50 gender ratio in 2015 and 2019.

When calculated across the 1703 post-1970 data points, woman-authored fractions of the four themes were 0.113, 0.204, 0.267 and 0.467, respectively, and 0.306 overall. These data show a 46% underrepresentation by women in theme 1, 23% overrepresentation in theme 2, 5% underrepresentation in theme 3 and 10% overrepresentation in theme 4. From 1999 onwards, the data for each year indicated the clear rejection of a null-hypothesis of the absence of theme-by-gender interaction in a Pearson chi-squared test; for the pooled 1979–1995 data (that meet the assumption of expected values of at least 5) the same conclusion holds.

Indonesian soil science topics in current international literature

A search on the keywords "soil" and "Indonesia" in the international literature in the 1990–2020 period showed the number of papers increased sharply since 2011 (Fig. 2). Fig. 2 shows the number of publications grouped according to the journal's categories defined by Web of Science. The top publication categories showed that "soil" papers were traditionally published under soil science and agronomy/ agriculture journals (1990–2000). However, since 2011, soils studies were mostly published in environmental sciences journals. In addition, soils were studied more extensively in plant sciences, forestry, and ecology. The trend indicates a shift of publication from traditional soil science and agronomy focus towards addressing environmental issues.

We further grouped the publications into 4 periods: 1990–1999, 2000–2009, 2010–2015 and 2016–2020, as the number of publications listed increased in the last decade. The data suggest that the more basic sciences dominate over land use and engineering applications in this database (Fig. 3). Again, environmental science and ecology have dominated publications since 2010.

To understand the contribution of Indonesian authors in international publications, the country of the first author was registered and presented as the percentage of papers per year (Fig. 4). The number of papers led by Indonesian authors on average was around 45%, and in the last 5 years the number has increased to 60%. There was much interest in the studies of Indonesian soils by authors from Australia, Japan, the USA, Germany, Netherlands, UK, and other developed countries (Minasny et al., 2020a).

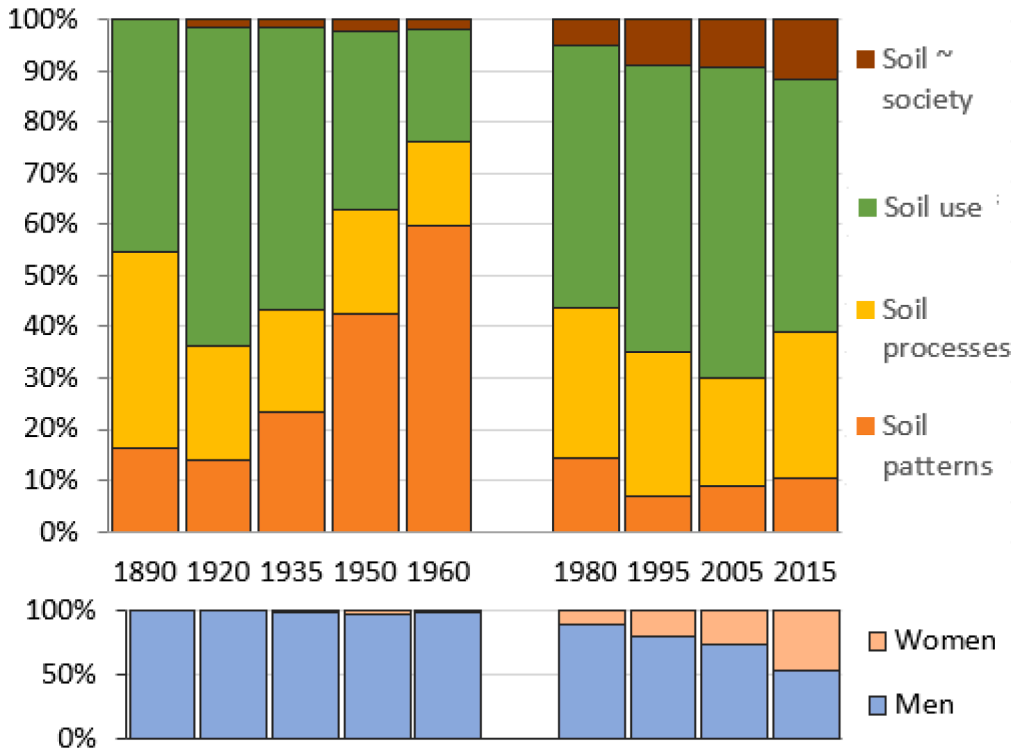

Fig. 1. Themes and gender of first authors on Indonesian soils as represented in (before 1963) the SOBIN bibliography and (after 1980) meetings of the Indonesian Soil Science Society (and related organizations); the years are midpoints for the periods reviewed.

Table 3
Women as first authors (speakers +poster presenters) as fraction of the total (N) at national congresses of the Indonesian soil science society; as the expected numbers of women as authors in some themes were low, data for the 1977–1996 period were pooled for a valid X^2 test.

Year	1977	1981	1985	1989	19,93[1]	1995	19,96[2]	1999	2003	2007	2011	2015	2019
N	45	43	76	146	36	111	47	172	94	123	187	269	261
Patterns	0.00	0.00	0.11	0.00	n.a.	0.14	0.33	0.10	0.11	0.00	0.31	0.28	0.26
Processes	0.17	0.20	0.04	0.10	0.14	0.23	0.29	0.39	0.42	0.29	0.43	0.66	0.58
Use	0.06	0.11	0.27	0.11	0.00	0.11	0.00	0.20	0.31	0.27	0.43	0.48	0.41
~ Society	0.17	0.50	0.00	0.17	0.00	0.25	0.20	*0.33*	0.18	0.22	0.29	0.43	0.77
Overall	**0.09**	**0.14**	**0.16**	**0.09**	**0.08**	**0.16**	**0.13**	**0.25**	**0.29**	**0.25**	**0.40**	**0.49**	**0.49**
X^2(3 df.)	—	—	—	*50.9***	—	—	—	*51.4***	*47.4***	*26.3***	*73.3***	*69.1***	*19.4***

1. Utomo et al. (1993); 2. MKTI (1996); * Critical values for the X2(3 df.) test statistic are 7.81 ($P < 0.05$) and 11.34 ($P < 0.01$); n.a. = not applicable.

Indonesian soil science research themes

We examined the research themes of the publications using word clouds, listing most occurred words in the paper titles (excluding words such as: soil, Indonesia, effects, land, use) (Fig. 5). In the 1990s, literature on soils in Indonesia was dominated by concerns over rice, growth, root, water, nitrogen, soil acidity, aluminum, and tolerance. The studies mainly focused on Java, followed by Sumatra. Around the millennium, the topics of research shifted towards forest and management, equal attention to carbon and nitrogen balance, methane emission, erosion, and sedimentation. The area of studies now focused on Sumatra. This trend continued in the 2010–2015 and 2016–2020 periods, with oil palm, diversity, emissions, and plantations getting more prominence. Nevertheless, (plant) growth and yield still were still important.

In contrast, we compared the words used in Indonesian soil science publications during the same period. Fig. 6 shows the word clouds of the titles from the proceedings of the Indonesian Soil Science (HITI) Congress from 1999 to 2019. There is a common theme in the 1999 publication that both Indonesian and international publications focused on rice and fertilizer. In Indonesian publications, fertilizer, organic (matter), rice, and water are consistent themes across all periods. One theme that dominated in 2003 and 2015, not reflected in international publications, is dryland. Dryland in the eastern part of Indonesia had been the focus of agriculture development in Indonesia. In 2019, oil palm and peat appeared as one of the important themes but less obvious than in international publications.

Discussion

The thematic attention of soil science in Indonesia has changed over the past 150 years, in parallel with the relative importance of the plantation economy, food crop production, sustainable soil fertility management, concerns over soil and water conservation and broader environmental concerns. Within each of the themes the topics changed as well. Soil fertility management research in the 1920′s included cover crops, organic inputs and potassium concentrations in irrigation water, while it later on dealt primarily with synthetic fertilizers, soil pH and liming rates, for example.

Meanwhile, the shift towards equal participation by women and men as scientists gradually reached a 50:50 distribution in the 2010–2020 decade. Still, the gender distribution within soil science remains non-random, with an underrepresentation of women in the soil survey topics (associated with ‘tough’ fieldwork), and overrepresentation in (more laboratory oriented) soil process studies. Of the two hypotheses

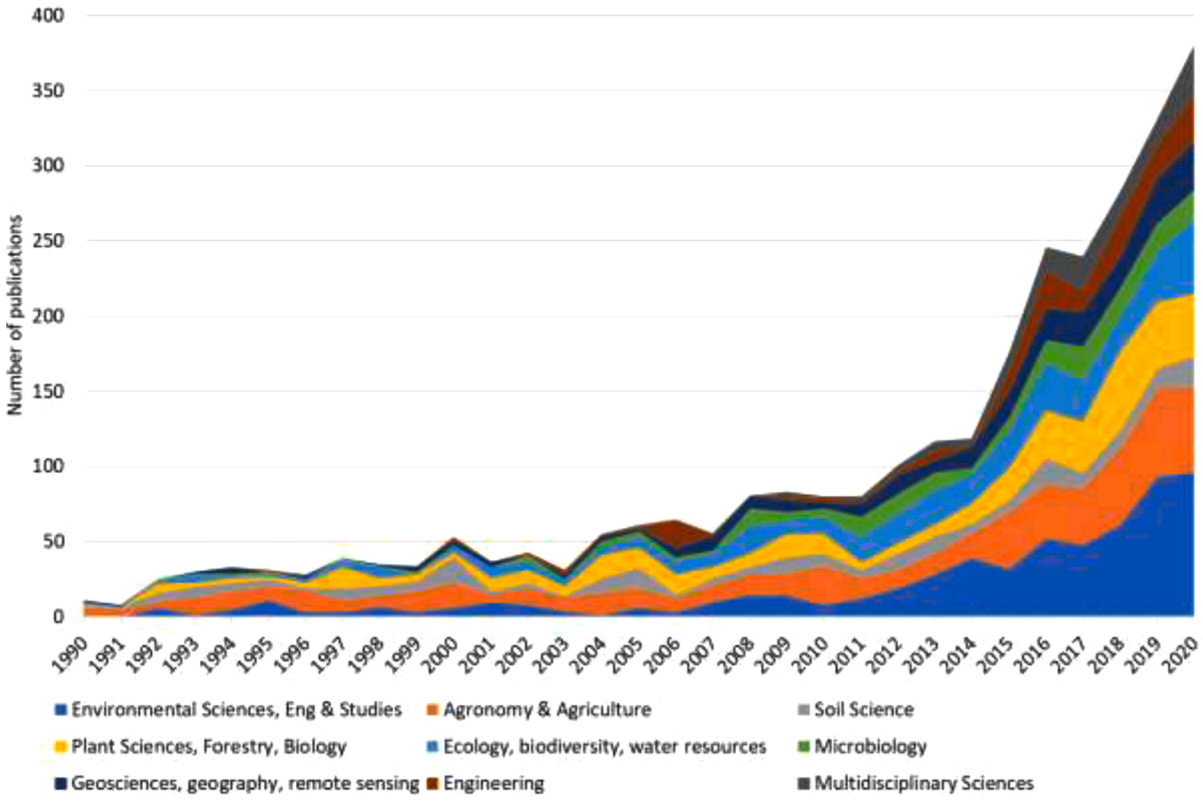

Fig. 2. Number of international publications on "soil" and "Indonesia" from the top 9 research topics from Web of Science.

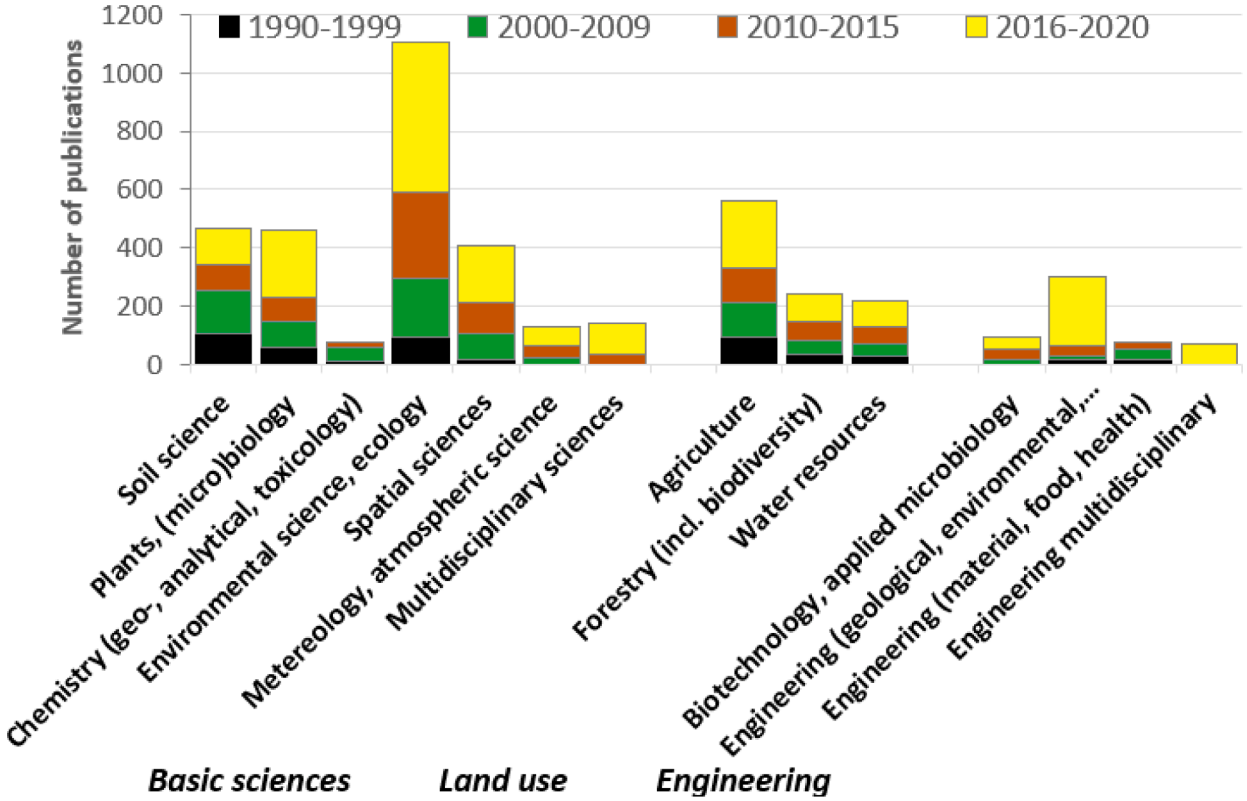

Fig. 3. Classification by topic and period of international literature on soils in Indonesia.

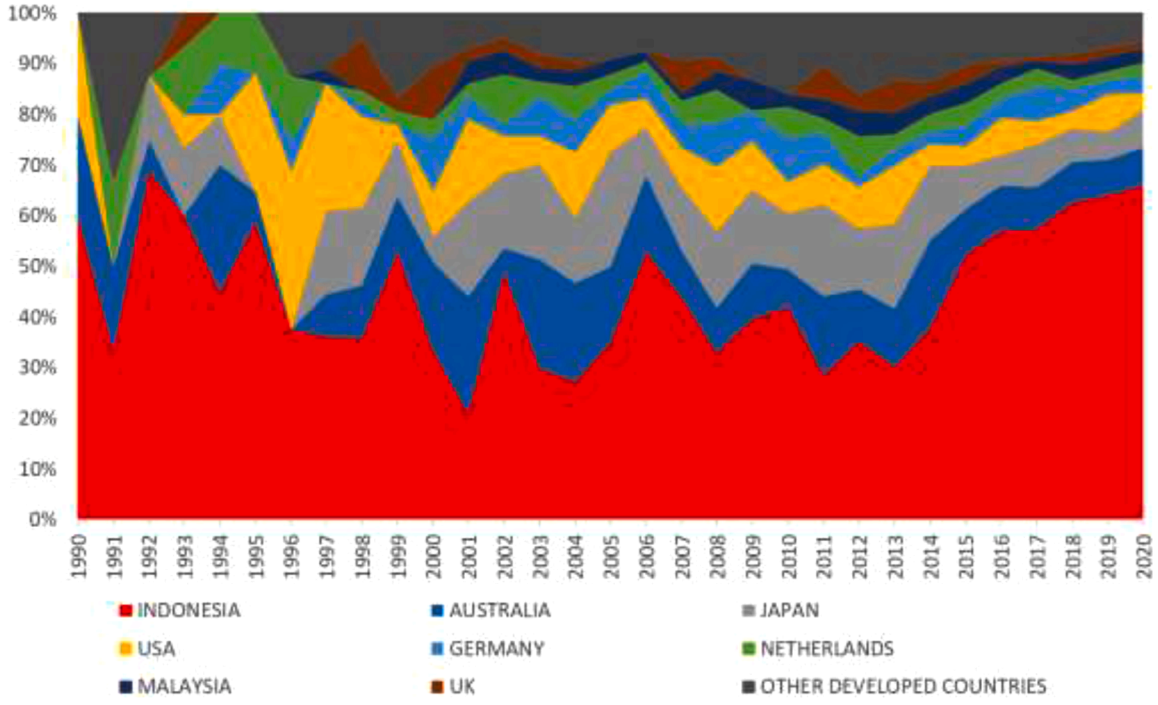

Fig. 4. Percentage of first author's country of affiliation of international literature on soils in Indonesia.

Fig. 5. Word-clouds of titles of publications (top panel) and keywords (bottom panel) from international publications of 'soil' and 'Indonesia' in the Web of Science database.

(soil science topics changing, making it a more woman-friendly type of science; greater women participation shifts the type of science done) the first may have more explanatory power than the second, as the gender shift is recent and most of the shift in themes preceded it. The similarity in balance between the themes in recent decades and what was found in the 1920s is striking (Fig. 1), even though the nationality and gender of scientists was very different. From the current data we cannot judge to what extent general shifts in societal acceptance of women in the work force led to more women in soil science.

Parallel changes in gender balance may have occurred in fields such as forestry (Colfer, 2021) and field biology, where the 'masculine' image of working in remote places was challenged by an increasing proportion of women scientists. The emancipation of women as soil scientists was part of broader emancipation issues in a use-oriented tropical soil science, balancing national and international concerns. Reconciling local and science-based knowledge at the process level (Joshi et al., 2004b; Astiani et al., 2019). The start of formal soil science in Indonesia was a gradual emergence of research methods, exploring the huge diversity of

Fig. 6. Word-clouds of the titles of publications in proceedings of specific HITI Congresses.

soils in Indonesia, how it was represented in local knowledge, and the various ways it had relevance for society. The roots of Indonesia soil science research and university education are in agriculture, they are weakly connected to other types of security: water management, geo-hazards (such as landslides, floods), soils as foundations for roads, bridges and buildings, soils as basis for industries (such as ceramics), and mining (especially small-scale, shallow mines). These require soil science involvement, but are constrained by the institutional basis. Social aspects of land rights and agrarian issues that can have major impacts on soil security are generally not seen as part of soil science, although they have been discussed occasionally in keynote addresses at soil science congresses. If Indonesian soil science wants to align with global understanding of soil security, the traditional view of soil science needs to be reassessed towards greater policy integration in the way science agendas are defined.

A limitation of our current data analysis is its focus on publications, be it in the more applied domain explored in the SOBIN bibliography, the Indonesian soil science congresses or international literature. The SOBIN bibliography acknowledges that it was incomplete, as political sensitivities forced its early project closure. It may well be that the primary output of soil surveys (maps, geo-referenced databases) is underrepresented in the recent data relative to other types of soil science. Between the endpoint of SOBIN in 1963 and the first HITI congress in 1977 there is a gap in the evidence we could trace; it was a period with major political change in Indonesia and the gradual rebuilding of research traditions.

Similarly, the international publications based on soils and Indonesia may not cover all aspects of soils or include a broader view of soils beyond what is deemed to be relevant to (global) soil science, rather than taking local relevance as main criterion (as might be the case if government documents would be systematically classified and assessed).

Around the year 2007–2008 all undergraduate university education in agriculture in Indonesia was re-organized into only two streams: agro-eco-technology and social-economics, respectively. Soil science remained as one of the options for specialization in 3rd and 4th year of study, but disappeared as separate 'Study program' (and in many universities as a separate 'department'). From 2011 to 2019, a number of universities (but not all) reversed this decision and started to offer Soil Science as a full study program. It is interesting to note that the largest increase in women participation in soil science coincided with the more integrated approach to teaching soil science as part of wider systems, rather than as a separate 'discipline'. Following the gender balance data presented by Fiantis et al., 2022, it would be interesting to explore whether the earlier or later choice for soil science within agricultural studies, interacts with the gender balance of future soil scientists.

Conclusion

The shift towards gender balance in Indonesian soil science has not been independent of changes in the thematic focus. A persistent underrepresentation of women scientists in the 'soils in time and space' theme, that includes soil survey, is coupled to a relative overrepresentation in the more laboratory-oriented study of soil (physical, chemical and biological) processes. Nevertheless, there is a global trend of increasing studies based on application of statistics, GIS, and desktop-based studies categorized as Pedometrics, which may lead to increase participation of women exploring the spatial and temporal soil diversity.

Where Indonesian soil scientists maintained a strong focus on soil productivity (especially for rice) and soil fertility management, papers published in international journals in the past decades shifted attention to environmental effects of forest conversion, the (mis)management of peatlands, and expansion of oil palm. These topics are gradually picked up in the national fora for discussing soil science, including in the global 'soil security' discourse, linked to the full spectrum of SDGs. However, the national soil science agenda is still dominated by increasing crop production. Soil science in Indonesia may further evolve to address all aspects of Sustainable Development Goals, including SDG3 (Good Health and Wellbeing), 5 (Gender Equality), 6 (Clean Water and Sanitation), 7 (Affordable and Clean Energy), 9 (Industry Innovation and Infrastructure), 11 (Sustainable Cities and Communities), 12 (Responsible Consumption and Production), 13 (Climate Action), and 15 (Life on Land). The more diverse the pool of scientists is, the greater the chance all these aspects will be covered.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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