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Advancing the intersection of soil and well-being systems science

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ABSTRACT

Innovation for soil research can advance multidimensional outcomes for production and environmental quality through consideration of human well-being components. Integrating components from social and soil sciences builds the capacity to foster research and innovations that promote human well-being in conjunction with soil health. We propose The Integrated Soil Well-being Framework to understand the linkages between individual and social well-being related to soil science research and innovation. To facilitate transformative research, we present lines of inquiry of human dimensions research that may support well-being outcomes of soil research and innovation. We then present opportunities in the area of human dimensions of soil science to innovate ways of transformative research that can integrate well-being and soil health: recognizing and fostering a universe of soil knowledge, enabling soil connectivity to increase well-being, and evaluating capability. Finally, we propose three steps to promote soil and well-being integration: multi-disciplinary soil science training, a normative change in the identity of a soil scientist, and diverse methodologies. We aim to create a broader dialogue and open the conversation between scholars from various disciplines and methods studying soils to formulate research agendas with the advancement of human well-being for soil security.

Introduction

In 2015, the United Nations Food and Agricultural Organization celebrated the international year of soils to raise awareness of soil degradation. The International Union of Soil Science expanded the effort to the decade of soils, 2014-2024, to create an agenda for furthering the understanding of human-soil relationships related to protecting soils and ensuring soil security (Lal, 2016). The critical role that soils play in reaching the United Nation's Sustainable Development Goals (SDGs) has continued to raise the importance of soil for supporting global well-being (e.g., gender equality, peace, justice, and strong institutions) (Bouma and Montanarella, 2019; Lal et al., 2021). However, limited scholarship within soil research and innovation directly accounts for and documents social and cultural co-benefits of soil stewardship (Adhikari and Hartemink, 2016; Amin et al., 2020; Lehmann et al., 2020; McElwee, 2021). In particular, individual and societal well-being have received little attention from the soils literature (McElwee, 2021). This gap in the literature is mainly attributed to the shift in agricultural research paradigms since the Green Revolution. The outcome of the focus of agricultural research has shifted from first focusing on producing more food than on improving environmental quality, and recently to positively supporting social processes and impacts. With the shift from conservation- to sustainability-focused research in conjunction with the rise of the transformative paradigm in agricultural research, soil science needs to begin focusing on multidimensional research outcomes to include human and societal well-being. This article aims to

- Propose The Integrated Soil Well-being Framework, which provides common language and unifies existing human-soil frameworks to facilitate communication on well-being outcomes of soil research and innovations.
- Advance the transformative soil science process by identifying human diemensions of soil science research lines that contribute to human and community well-being outcomes.
- Identify emerging action areas where transformative research can integrate advancement of well-being and soil health.

The article prompts interested scholars in the field for dialogue among transdisciplinary scientists on how to enhance human-soil relationships and contribute to individual and social well-being outcomes of soil science innovations.

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The intersection of soil health and well-being

Soil influences society and, in turn, is created by society (Krzywoszynska and Marchesi, 2019). Soil and human health efforts promote the connections between human physical health and soil with the aim to increase societal awareness and perceived value of soil (food nutrition, nutrition deficiency, disease, toxicity, gut-microbial diversity, etc.) (Oliver, 1997). However, synergies between soil health and subjective elements of well-being remain poorly articulated across the soil science literature (McElwee, 2021).

Human subjective well-being or quality of life within the eudaimonic western perspective is the state of living life fully and meaningfully (Deci and Ryan, 2008). The field of political ecology has documented the interrelationships between soil degradation and well-being reflected in global patterns of social, political, and economic conditions that create exploitative pressures on the soil's condition reducing soil's functionality (Andersson et al., 2011). Preliminary research has documented the link between sustainable soil management and its relationship with the producer's well-being. For example, wheat producers in the Pacific Northwest of the United States perceived soil health management as supporting their well-being through creativity and learning, decreased dependency on agricultural inputs, dignity for their livelihood and respect within the agricultural community, connectedness to nature and their community, and improved mental and physical health with reduced synthetic pesticide usage (Friedrichsen et al., 2021). Perceived relationships between well-being and soil health outcomes are culturally-dependent (Stronge et al., 2020).

Integrated Soil Well-being Framework

The Integrated Soil Well-being Framework that we propose here establishes a vocabulary and unifies existing human-soil frameworks to understand how to promote well-being through soil sciences (Figure 1). The framework facilitates transformative research across biophysical and social sciences by creating common terminology,delineating the knowledge gap and solution of focus in order to facilitate communication across disciplines (von Wehrden et al., 2019). Several human-soil frameworks exist to examine the relationships between biophysical and social components of soil systems related to soil stewardship: ecosystem services, soil security, and nature's contribution to people (Adhikari and Hartemink, 2016; McBratney et al., 2014; McElwee, 2021). Within the soil ecosystem services framework, as articulated by Adhikari and Hartemink (2016), human well-being outcomes of soil are often only perceived as cultural ecosystem services (art, storing geological and archaeological artifacts) and providing material needs (food, clothing, shelter, human health). Soil security identifies specific system components and processes (i.e., condition, capital, connectivity, condition, and capability) that drive soil care and soil threats (McBratney et al., 2014). Limitations with the soil security framework are its focus on protecting the soil. Neither of these frameworks conceptualizes intangible benefits of soil stewardship, such as subjective well-being or community well-being. Nature's contribution to people does include social-cultural co-benefits of human-soil relationships or non-material values derived from the soil. These include learning and inspiration, physical and physical experiences, and supporting identities (McElwee, 2021).

Transformative research addresses the root causes of challenges

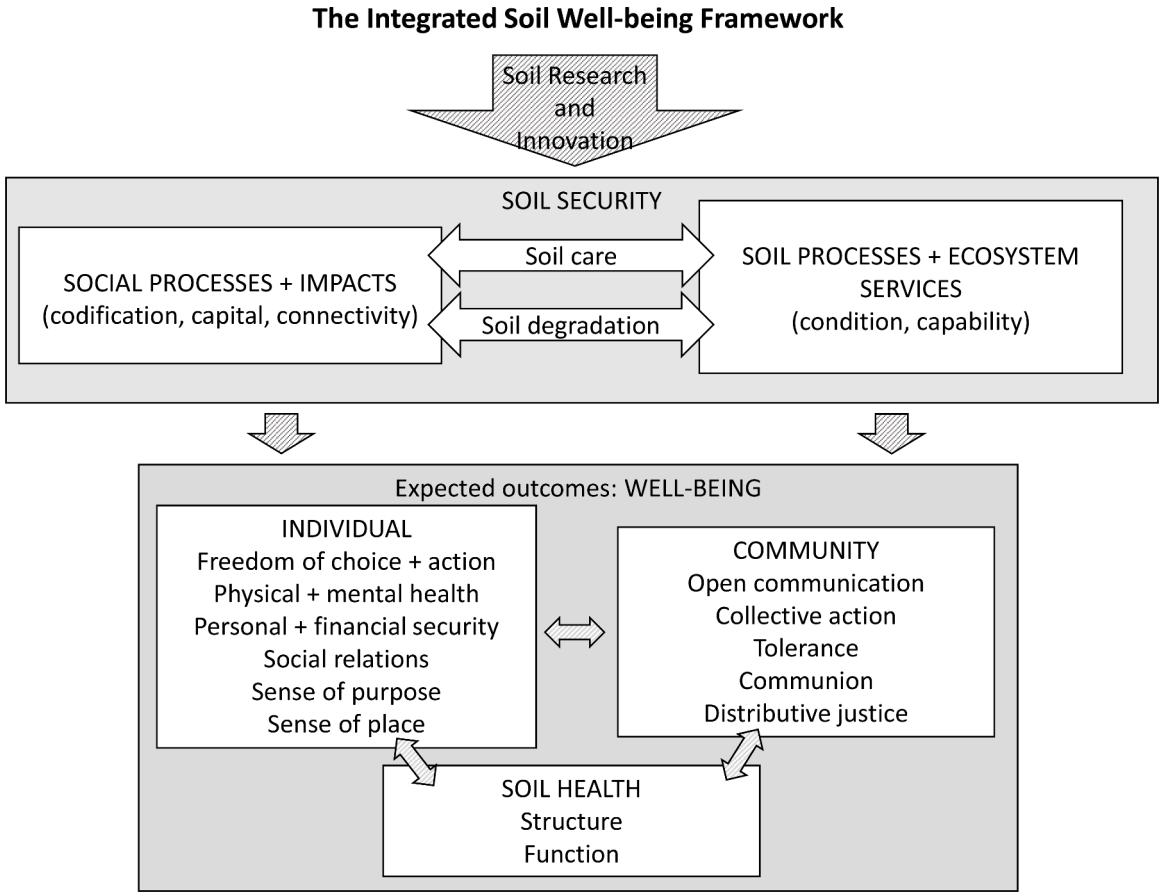

Figure 1. The Integrated Soil and Well-being Framework. The figure was adapted from the Bentley Brymer et al. (2020) integrated framework by focusing on soil research and innovation as the driver of change to the social and biophysical soil security dimensions (McBratney et al., 2014), which underlie processes that either benefit or degrade individual well-being (Millennium Ecosystem Assessment, 2003), social well-being (Wilkinson, 1991), and soil health.

within complex adaptive systems and creates new futures that synergistically address improved human and environmental well-being (Herrero et al., 2020; Hubeau et al., 2017). The Integrated Soil Well-Being Framework is proposed to facilitate transformative soil science research by integrating existing human-soil relationship frameworks to provide a common language for scientists from diverse disciplinary backgrounds to communicate with one another.

The Integrated Soil Well-Being Framework examines how an intervention such as soil science research and innovation can either benefit or degrade soil health and individual and social well-being by disrupting the dynamic interrelationship between humans and soil processes, impacts, and functions. The Integrated Soil Well-being Framework integrates components of the Integrated Agroecosystem framework (Bentley Brymer et al. 2020), Soil Security (McBratney et al., 2014), and Nature's Contribution to People (Díaz et al., 2018) frameworks. The Integrated Soil Well-Being Framework recognizes that soil is a system consisting of biophysical and social components driven by ecological and social processes that support individual, social, and ecosystem health.

The Integrated Soil Well-being Framework then represents the reciprocal relationship between soil security and well-being. Well-being is then conceptualized into three interrelated social-ecological states: individual and community well-being and soil health. Supporting the Janzen et al., (2021) definition, *"Soil health is the vitality of a soil in sustaining the socio-ecological functions of its enfolding land."*

Advancing transformative soil science

Transformative efforts integrating natural and social sciences are necessary to foster soil science innovation to support well-being outcomes (Janzen et al., 2021). As soil science shifts its focus to answer complex, adaptive systems management, the transformative capacity of the field will also expand. Most often, soil science research and innovation characterizes social science as providing a unique outreach function to encourage the adoption of innovation through extension and education (Hou et al., 2020; Klerkx et al., 2012). However, when applied effectively, social science provides new tools to advance innovation within soil science to synergistically advance human and environmental well-being (Meredith et al., 2021). Examples of social science lines of inquiry and methodologies that can advance soil research and innovation at each step of the research and innovation process for and contribute to well-being outcomes are found in Table 1.

In the sections below, three priority transdisciplinary topic areas are highlighted, where the application of human dimensions can advance soil science to achieve well-being outcomes of soil management.

Table 1
Examples of human dimensions inquiry in social science that support well-being outcomes

Research Process	Examples of Human Dimensions Lines of Inquiry
Knowledge Gap Identification	Political ecology (Blaikie, 1985), Public health and soil remediation (Ramirez-Andreotta et al., 2016), Misalignment of soil codification and management (Daeli et al., 2021)
Conceptualization and Design	Participatory research (Davis and Ram, 2021), Collaborative adaptive management (Fernández-Giménez et al., 2019), Co-created citizen science (Ramirez-Andreotta et al., 2015), Soil knowledge networks (McInnes-Clarke et al., 2019)
Data Collection and Analysis	Qualitative methodologies (Prokopy, 2011), Citizen science (Head et al., 2020), Decolonizing methodologies (Smith, 1999)
Application of Innovation	Monitoring and evaluation of well-being outcomes (Brown et al., 2021), Social media (Mills et al., 2019), Message and policy framing (Braito et al., 2020)

Recognizing and fostering a diversity of soil knowledge

An important area in which social sciences can greatly support well-being outcomes of soil science occurs through recognizing and fostering a diversity of soil knowledge and ways of knowing. Colonization led to western science privilege, domination, and knowledge genocide erasing many forms of soil knowledge (Pena, 2017). The discipline of ethnopedology highlights the diversity of local and indigenous soil classifications and taxonomies (Barrera-Bassols and Zinck, 2003). Soil science has homogenized our soil management, recognizing a limited breadth of acceptable norms for soil stewardship (conventional, conservation, organic, permaculture, and biodynamic) (Marchesi, 2020).

Local soil knowledge, once seen as something to be observed, documented, and validated against scientific knowledge, has now shifted towards promoting co-innovation and integration of local soil knowledge within the research process (Huynh et al., 2020). Culturally responsive science recognizes multiple ways of knowing, knowledge creation processes, and knowledge transmission. It also builds knowledge that fosters culture and well-being (Stephens, 2001). Stronge et al., (2020) developed a soil well-being framework shaped from the Te Ao Māori (Māori world view) in Aotearoa New Zealand. The framework outlines the interconnections between soil values, threats, policy, and monitoring supporting well-being and highlights the importance of how one's group's well-being should not be priviledged over the well-being of anothers.

Much of the knowledge integration in the current soil science literature focuses on soil fertility, yield, or soil health indices (Álvarez et al., 2021; Nath et al., 2016). Broadening the scope of local soil knowledge to include intangible material outcomes of soil stewardship provides a more comprehensive understanding, promotes diverse knowledge systems, and nourishes cultures, communities, and individuals (Stronge et al., 2020). For example, in Aotearoa New Zealand, the Hua Parakore framework is centered around the Te AoMāori of the interconnectedness between soil health and human well-being (Hutchings et al., 2018). Instead of research being a process of homogenizing and globalizing soil knowledge, prioritizing the integration of social science ontologies, methodologies, and epistemologies into the research process could support cultural diversity through identity expression (e.g., local soil management techniques, art, religious expression) (McElwee, 2021).

Fostering soil connectivity to increase well-being

Integrating social sciences within the research process can facilitate inquiry that promotes people's connection to the soil as the physical resource they steward. Soil connectivity is the emotional cognizance or the perceived importance between an individual or society and the soil. Human-nature connectivity exists as a dimension of well-being (Millennium Ecosystem Assessment, 2003). As knowledge of soil health continues to grow, so does the potential ability to value soil's capital by identifying diverse ways people connect with soil and value it. We currently have a limited conceptualization of societal values of soil based upon economic value such as carbon markets and soil production capacity. Compared to other resources, soil's value is mainly communicated and defined through the soil's ability to provide fertility through net profit and yield (Tironi et al., 2020). Social science contributions facilitate understanding and knowledge of diverse experiences of connection to soil and soil valuation (Janzen et al., 2021). An emphasis on awareness, appreciation, and connectedness to soil through education is one step towards improving valuation of soil by society (Lal et al., 2021). However, facilitating societal behavior change to increase connection to soil and soil-awarded value will require more than education.

Behavior change theories provide insight into encouraging soil stewardship behavior. For example, Ericson et al., (2014) hypothesize the link between mindfulness practices, values, empathy, compassion, well-being, and pro-environmental behavior. Social science may help

apply and build social theories to understand how connection to soil and connection to humans as organisms can be fostered and measured, and which actors and connections are privileged or exploited (Puig de la Bellacasa, 2015; Tironi et al., 2020). Smith (2004) found that cultivating soil care in youth in Portland, Oregon, resulted in the promotion of other caring behaviors that promote societal well-being. Application of game theory to agriculture to understand how individuals process information and make decisions, which may be applied for soil science (Hernandez-Aguilera et al., 2020), provides another example of using social theory to inform multidimensional soil security outcomes.

Knowledge of how consumers value and connect to soil beyond the over-simplified food dichotomy of organic vs. conventional remains limited. Little information is known on how to change consumers' behavior to generate value for soil health, especially related to what matters, identities, and motivations that underlie consumptive behavior. The concept of *terroir* within viticulture has given aesthetic, and intrinsic value to soil but has had relatively little success in increasing soil's value within other agronomic sectors. Currently, soil carbon markets are receiving attention as a possible means for providing an alternative mechanism to provide value to producers for caring for their soil beyond production yield. Soil carbon markets provide a way for consumers to directly measure their connection to the soil through their consumptive behavior (Tironi et al., 2020). Expanding and emphasizing transdisciplinary research that supports various ways consumers could develop multiple values for soil health may facilitate broader outcomes of human and society well-being.

Evaluating soil capability

What is the capability of soil to support human and societal well-being? Soil capacity is what soil can theoretically do in a standardized/controlled environment; Soil capability is what soil can do within the context of its embedded social-ecological system (Holsbeeke et al., 2009). Pedo-econometrics and biocultural indicator approaches may be useful to understanding soil's capability to support individual and community well-being within specific social-ecological systems.

Pedo-econometrics, the integration of quantitative economic methodologies with soil science, creates new opportunities for determining soils' capability by accounting for social drivers and outcomes of soil management (Bouma et al., 2012; Field, 2017; Mizuta et al., 2021). For example, Mizuta et al. (2019) applied the economic methodology of Data Envelopment Analysis (DEA) to elaborate on how to improve the measured soil performance and achievable soil capability. In addition, DEA and other economic methods can provide a set of data-driven reference points/lines/multi-spheres without arranging "control" treatment, which would be extremely useful to evaluate the capacity and capability of soil in various environmental-human circumstances.

Biocultural indicator approaches, such as participatory research, provide culturally grounded perspectives on developing metrics and evaluation of well-being. Specifically, biocultural indicator approaches incorporate placed-based values and knowledge of holistic systems capturing the social and ecological feedback loops and non-material outcomes of soil's capability to support well-being (Sterling et al., 2017). For example, semi-structured interviews with producers in the African highlands identified the presence of weeds as an indicator of soil health (Eze et al., 2021).

Building soil research and innovation capacity

Soil science is traditionally defined as a set of acceptable chemical, physical and biological methodologies. In order to support transformative soil science, research soil science needs to be no longer defined by a list of acceptable methods but by the topic of soil (Morgan and McBratney, 2020). A shift in the discipline of soil science towards a transdisciplinary collaborative effort that promotes human and societal well-being will require concerted effort and change in soil science training, a normative change in the identity of who is a soil scientist, and normative acceptance of diverse methodologies.

For example, currently in the United States, the federal government's Office of Personnel Management (OPM) does not recognize any social science courses as contributing to the qualification of working as a soil scientist. Coursework qualifications to be a soil scientist include "30 semester hours or equivalent in biological, physical, or earth science, with a minimum of 15 semester hours in such subjects as soil genesis, pedology, soil chemistry, soil physics, and soil fertility" (Office of Personnel Management, 2020). To meet the demands of industry, soil science graduates will need to have the capacity to think and collaborate on a systems level and identify problems and challenges to address soil-related issues beyond concentrations of the biophysical space (Bouma, 2001). Soil science students in Australia identified key learning priorities including systems knowledge that spans social and economic contexts at various scales (Field et al., 2011).

Transdisciplinary soil research that fosters well-being may be further facilitated by broadening the scope of the identity of what a soil scientist does, broadening training to include human dimensions, and promoting transdisciplinary scholarship. The identity of being a 'soil scientist' needs to be inclusive of individuals from diverse backgrounds, ways of knowing, knowledge belief systems, epistemologies, and methodologies that contribute to soil innovation. This could be achieved through professional recognition, and respect for the diversity of scientific skillsets within soil science. The discipline of soil science benefits from inclusive approaches, as with any large organizational endeavor. This normative perspective differs from historical patterns that have shown professionals using diverse methods and epistemologies often face systematic disenfranchisement within what it means to belong, associate, and participate in the collective. For instance, diverse approaches or perspectives in soil science may lead to exclusion from standard academic roles such as opportunities for engagement within professional organizations, textbook creation responsibilities, and curriculum design within university departments.

A disciplinary inclusion of the study of humans should be acknowledged not as disrupters to the ecological system but as an integrated essential part to the socio-ecological systems (Puig de la Bellacasa, 2015). The breadth of disciplines needed to foster soil security includes, but is not limited to food and culture studies, sociology, anthropology, law, political science, economics, conservation psychology, and geography. New skillsets to tackle diverse data sets, axiologies, methodologies, and epistemologies will be the foundation of the training. Expanding the breadth of soil science will require creating space and opportunities for new scholars to flourish founded in understanding and respect for diverse epistemologies and methodologies. Fostering new sub-disciplines of soil knowledge that stem from human dimensions of soil will foster a broader understanding of human-soil relationships and how to support soil, human, and societal well-being synergistically.

In the context of soil science, collaboration across diverse methodological and epistemological backgrounds needs recognition as a valued and meaningful process. The transdisciplinary scholarship will require reflection on recognizing and accounting for disciplinary impact and career development through our current scientific reward systems. Interdisciplinary journals with diversely trained editors and reviewers who can make informed decisions and informed peer reviews within their skillset and topic of knowledge will provide high-quality research and innovation. New methods, data sources, and collaborations will fuel a paradigm shift in soil science to be inclusive of human well-being outcomes.

Through our effort here, we support a broader call to action: diverse scholars globally applying social science methods, epistemologies, and ontologies to outline research priorities to advance well-being outcomes from soil science.

Declaration of interests

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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