Received: 31 March 2022 | Accepted: 21 September 2022

DOI: 10.1002/jpln.202200120

REVIEW

Why do we need interdisciplinary cooperation with anthropologists and archaeologists in soil science?

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This article has been edited by Lydia Pohl.

Abstract

Looking at soils from the perspective of an environmental scientist or agronomist might neglect various dimensions of valuation that can be attributed to soils. Especially social and cultural connoted values including ecosystem services cannot always be measured in terms of scientific values or classified as soil types or soil qualities in a modern, economic way.

Even though soils are a fact and have been present on the Earth's surface and used by people, at least for food production, at different times and in different cultures, the ways of dealing with soils and the valuations of soils are extremely diverse. Researchers in anthropology, archaeology, and agriculture, for example, are investigating different perspectives like soils as common good or as private property. This concerns not only different knowledge orders about soils, but also beliefs, techniques, foodways, practices, and power relations concerning soils and cereal cultivation.

Based on the example of agriculture with a focus on cereal cultivation, we argue that there is still a great need for interdisciplinarity between the sciences and humanities. However, there is also a need to distinguish and explain between fundamental interdisciplinary research and application of findings in a socio-economic context. It is necessary to understand different knowledge orders and valuations in time or space and to reevaluate today's perspectives on soils and agriculture for facing modern problems such as soil degradation, erosion, salinization, and an overall loss of soil fertility.

KEYWORDS
cereal cultivation, ecosystem services, interdisciplinarity, pedology, resources, ResourceCultures, soil functions

1 | INTRODUCTION

Soil cultivation as a multidimensional process affects the environment and human societies alike. While soil scientists often focus on soil properties or soil fertility when they study soil cultivation, some of them tend to overlook that social and cultural dimensions affect how people use soils and knowledge about them develops. The impact of humans on soils has already been pointed out by Jenny (1980), who argued that humans need to be considered separately from the other biotic factors of soil formation as not only genetic properties but also the "cultural environment" affect their soil use. While the question remains, what "cultural environment" encompasses, expertise about social and cultural processes or dimensions is needed to understand how humans value soils in different regions of the world and in different times, how this affects and affected their awareness of soil as a basis of their life, and how in return it might influence and influenced their soil management practices. The research of these cultural and social processes is needed, if the soil scientific community in collaboration with society and politics wants to maintain soil quality and soil health. While soil quality refers to soil functions, the concept of soil health sees soils as living, biological entities, which affect the health and growth of plants and, thus, the health of the entire ecosystems, which rely on the plants—including humans (Lal, 2016). Thus, understanding soil health is needed to guarantee humanities development. However, it is also essential that humanity values soils and for soil scientists to understand which processes and practices lead to societal valuation. Thus, it is necessary to research valuation processes and land-management practices related to soils. This is a prerequisite to raise awareness within societies around the globe for the value of soils for each and every person on the planet. If soil scientists and policy makers understand the relation people in different regions have to their soils, educational and developmental programs can be devised that take these values in consideration and fit the needs of the local people. Further, soil scientists can learn from the humanities but also from people around the world how differently soils are perceived and how this affects practices and the use of soil in everyday life.

Soil scientists often do not have the kind of expertise to understand valuation processes of local people (including the populations in the Global North), their practices and belief systems, as they tend to focus on natural processes and not on culturally defined values of soils. Thus, interdisciplinary cooperation is needed to ensure that the soil quality is maintained or increased so that the different soil functions are preserved and the soils can continue to provide ecosystem services (ES) to humanity (e.g., Bouma, 2014; Drobnik et al., 2018).

The need of interdisciplinary studies has long been addressed by various scientist. Richter et al. (2011), for example, call for an anthropedology to foster an understanding of human–soil relations by combining different disciplines from the natural sciences and the humanities. Based on this understanding, one can ensure the sustainability of the soil's ES, minimize detrimental impacts of soil management to the environment, and conserve natural soil bodies (Richter et al., 2011). Brevik et al. (2015) also emphasize that the collaboration of scientists of different disciplines ranging from geologists, physicists, and biologists to anthropologists, medical professionals, and artists is needed to address current crises such as biodiversity loss, water scarcity, and land degradation as well as energy security, the latter a most important topic of our current times. Similarly, Bouma and McBratney (2013) call for a re-framing of soils and a focus on the contributions soils can play in solving current environmental problems. This requires interdisciplinary but also transdisciplinary work, which involves stakeholders and practitioners (Bouma & McBratney, 2013). Bouma and Montanarella (2016), thus, advocate to use the Agenda 2030 with its 17 Sustainable Development Goals (SDGs) to address how soil science as a discipline can contribute toward reaching these SDGs. With the focus on sustainable and resilient soil use, the above-mentioned scientists acknowledge that human–soil relations need to be investigated in order to achieve the overarching sustainability goal. This is urgently needed as soil degradation is an eminent problem and global processes outside academia and soil science currently show, how dependent societies around the globe are on the cereal and sunflower yield of a single nation, Ukraine. Thus, it is necessary to show people worldwide that human societies rely on soil quality and soil health and need to care for the soils they have. However, in order to raise awareness within societies, soil scientists must understand how these societies value soils and agriculture, what practices they use and which belief systems they follow. Further, Krzywoszynska and Marchesi (2020) argue that within social science and the humanities, soils need to become visible and need to be seen as indispensable. For this, interdisciplinary research is urgently needed to understand knowledge orders, valuation processes, practices of care and—generally speaking—people. Further, as Puig de la Bellacasa (2010) wrote: "Taking responsibility for what and whom we care for doesn't mean being in charge. Adequate care requires knowledge and curiosity regarding the needs of an 'other'—human or not—and these become possible through relating, through refusing objectification." Thus, in order to protect or care for soils, we need curiosity for soils and a broad understanding of them. We as soil scientists need to understand that we are not in charge of human–soil relations but need to be curious about the many relations that exist between people and soils. Several sub disciplines within soil science and other disciplines already address human–soil relations. These include archaeopedology (Pietsch & Kühn, 2017; Scudder, 2001), ethnopedology (Barrera-Bassols & Zinck, 2003a; Williams & Ortiz-Solorio, 1981; WinklerPrins & Sandor, 2003), and studies using the ecosystem service (ES) framework (Jónsson & Davíðsdóttir, 2016) put forward in the Millennium Ecosystem Assessment (2005). These different subdisciplines use a variety of methods and rely on the cooperation of soil scientists with scientists from the humanities. This is often based on mutual understanding of the cooperating scientists and accompanied by certain challenges. This perspective paper wants to draw attention to these subdisciplines as they might provide insights into the cultural and social aspects connected to soil use in time and space. The present paper, thus, identifies benefits but also challenges of the existing approaches. Further, the present paper proposes a way to increase interdisciplinary collaboration through an analytical tool that can facilitate communication between scientists of different fields. To address these objectives this paper:

(1) illustrates the benefits of existing collaborations in the field of archaeopedology and geoarchaeology, ethnopedology and the research area of ecosystem services (ES) that provide information about interdisciplinary research taking place in the soil scientific community. While the existing collaborations are considered, this paper does not offer complete reviews of the respective subdiscipline as this would exceed the scope of the paper. It merely offers thought-provoking insights into these valuable collaborations and

cites some authors who, in our opinion, are a good starting point to look into these subdisciplines;

(2) identifies challenges of interdisciplinary collaborations;

(3) introduces a resource framework, which shifts the perspective toward social and cultural practices and valuations. This framework hopefully facilitates communication between scientists of different disciplines—it did for us.

2 | INTERDISCIPLINARY COLLABORATIONS BETWEEN SOIL SCIENTISTS AND OTHER DISCIPLINES FROM THE HUMANITIES

2.1 | Archaeopedology

As of today, diverse collaborations between soil scientists and archaeologists, anthropologists, and economists exist, but the socio-cultural aspects connected to soils are not necessarily their research focus. Soil scientists and archaeologists, for example, are collaborating in archaeopedology (Ahlrichs et al., 2016; Ballasus et al., 2022; Bork et al., 1998; Dreibrodt et al., 2022; Gerlach et al., 2012; James et al., 2021; Kühn et al., 2010; Miera et al., 2019; Pietsch & Kühn, 2017) to understand how past societies affected the soils and landscapes around their settlements.

Although early human influence on the landscape can already be proven for the Mesolithic period (e.g., Dotterweich et al., 2013), humans began to cultivate soils on a larger scale with the transition to the Neolithic when the first farmers settled down (Davison et al., 2006; Teuber et al., 2017; Tresset & Vigne, 2011). This also started their dependency on soils for subsistence. One might argue that the soil was already providing food for hunter-gatherer communities, but with the advent of agriculture, including arable farming and animal husbandry, humans actively worked with the soil to grow food. With this, humans also increasingly became an element of landscape formation (Kadereit et al., 2010; Kühn et al., 2017; Wolf & Faust, 2013).

Traces of soil cultivation, which led to a transformation of the landscape, are also analyzed in geoarchaeological research, showing the extent to which humans have altered the landscape and the soils they used in their daily life (Henkner, Ahlrichs, Downey et al. 2018; Henkner, Ahlrichs, Fischer et al., 2018; Kappler et al., 2018; Poręba et al., 2019). As cultivation of soils usually causes unintended soil erosion (McNeill & Winiwarter, 2004), colluvial deposits—as the correlate sediments of soil erosion—can be particularly suitable for the reconstruction of (pre)historic agricultural activities as they also archive signals of past land use practices (Glaser & Birk, 2012; Prost et al., 2017; Scherer, Deckers et al., 2021; Scherer, Höpfer et al., 2021).

Combining the research on colluvial deposits with archaeological research at the same location provides in-depth knowledge about settlement patterns and agricultural practices (Höpfer et al., 2018). Collaborations of soil scientists with archaeologists in the field of archaeopedology, thus, show that researchers from both disciplines can learn from each other and provide supplemental information concerning specific regions or sites.

Archaeologists further provide a cultural perspective on soils. Salisbury (2012), for example, sees soils not only as something, which covers archaeological finds, but which might have affected "the construction of community through the practices of soilscape formation, sensual experience and via social memory" (Salisbury, 2012). However, archaeologists rarely excavate features, where they find direct access to cultural meanings of soils, for instance religious connotations (see Knopf [2010] with reference to a deposition of special ceramics in the context of soil tillage).

In general, archaeological finds, features, and soil formations like colluvia have to be interpreted by the use of analogies coming from historical observations or ethnographic evidence (McNeill & Winiwarter, 2006; Warkentin, 2006; Wilshusen & Stone, 1990). Thus, the successful application of archaeopedological methods usually depends on the discussions that archaeologists and soil scientists have in advance about the research question to be answered. The simple application of the same methods in different archaeological contexts does not necessarily lead to the expected results, that is, the application of archaeopedological methods has to be adjusted for its suitability with the respective questions and geofactors at each site.

2.2 | Ethnopedology

The connections between soils and people are also investigated in the field of ethnopedology, particularly by anthropologists, soil scientists and geographers (WinklerPrins, 1999). Barrera-Bassols and Zinck (2000) compiled a dataset encompassing 895 references and found that most studies are located in Africa, Asia, and Latin America.

Geographer and anthropologist Barrera-Bassols and soil scientist Zinck investigated people's approach to soils and to soil management from a socio-cultural as well as from an ecological and economic perspective. Based on the theoretical framework of Ethnoecology (Toledo, 1992) they applied the Cosmos–Corpus–Praxis complex to their fields of studies (Barrera-Bassols & Zinck, 2003a,b). In doing so, their research on local soil knowledge included—next to research on soil classification systems (Corpus) and land-use strategies (Praxis)—the spiritual dimension of soil and soil fertility (Cosmos). The latter combines local symbols, the religious meaning of soil and nature, and agrarian rituals.

Soil scientist Krasilnikov and epidemiologist as well as soil scientist Tabor recognized that "[e]conomic, infrastructural, cultural, and social assumptions are inherent in [soil] classification systems and are factors for determining value" (Krasilnikov & Tabor, 2003). Even in the current German soil classification system, such assumptions exist, for example, colluvial deposits were seldom mapped during soil surveys in the 20th century, even though recent research indicates that they are widespread (Henkner et al., 2017; Scherer, Höpfer et al., 2021). Thus, cultural and social valuations are integral parts of ethnopedological investigations, which are usually located in the (sub) tropics and are often conducted interdisciplinary.

However, little research about local soil knowledge and valuation exists for the Global North or the so-called West (Krzywoszynska &

Marchesi, 2020). Exceptions are found in a few studies on small-scale agriculture in Europe, for example, Christanell (2007), Engel-Di Mauro (2003), Krzywoszynska (2020) or Wahlhütter (2011), but also in Northern America, as the example of the Zuni, a southwestern American Indian tribe, shows (Sandor et al., 2002). First insights into the socio-cultural dimensions connected to soil cultivation in the Global North are also provided by a limited number of studies in the context of urban agriculture and urban gardening. Even though these studies do not necessarily focus on subsistence practices, as urban gardens are created for various reasons, for instance food production (Aptekar & Myers, 2020; Barthel & Isendahl, 2013; Pourias et al., 2016), aesthetic purposes (Lindemann-Matthies & Marty, 2013), recreation (Bhatti & Church, 2000; Langemeyer et al., 2016), or civic engagement (Krasny & Tidball, 2009), some address soils and include socio-cultural aspects of soil cultivation (Dewaelheyns et al., 2013, 2014, 2018; Engel-Di Mauro, 2019; Kim et al., 2014; Scheromm, 2015; Teuber et al., 2019). They do not use the Cosmos–Corpus–Praxis complex, though. This might be related to the limited anthropological knowledge in soil science or the fact that the Cosmos component might not seem applicable to communities in the Global North, where spirituality seems to lose importance. This neglects the fact that many worldviews in the Global North have their origin in Christian or “pagan” rituals that existed in the so called “Old World.” For example, Thanksgiving (German = *Erntedank*) was and still is celebrated in many regions in Germany and the biologic-organic German brand Demeter still applies rules to agriculture that belong to a more spiritual plane of existence, compared with the scientific approaches practiced in soil scientific laboratories.

2.3 | Ecosystem services

A further aspect of the socio-cultural dimensions of soil cultivation concerns ES. As countries around the world are part of the free market and a globalized trading network, economic considerations based on the global market economy are omnipresent and an integral part of ES research. The soil’s ES, however, are often not a direct part of economic considerations of ES. Generally, the Millennium Ecosystem Assessment (2005), written by an interdisciplinary team of scientists from disciplines such as economy, ecology, biology, environmental economy, environmental science, mathematics and physics, chemistry, and agricultural science, focuses on sustainability. In its preface, it is specified that “Ecosystem services are the benefits people obtain from ecosystems. These include provisioning services such as food, water, timber, and fiber; regulating services that affect climate, floods, disease, wastes, and water quality; cultural services that provide recreational, aesthetic, and spiritual benefits; and supporting services such as soil formation, photosynthesis, and nutrient cycling. The human species, while buffered against environmental changes by culture and technology, is fundamentally dependent on the flow of ecosystem services” (Millennium Ecosystem Assessment [MEA], 2005). Soils are mentioned in the MEA under the heading of supporting ES. However, Robinson et al. (2013) show that the soil’s ES go beyond the supporting category of MEA and attribute the different soil functions to the four ES categories of MEA—provisioning, regulating, cultural, and supporting ES (Robinson et al., 2013). This will likely facilitate the use of the ES framework within the soil science community because this community usually uses the concept of soil functions (Vogel et al., 2019). The latter, however, is of little relevance outside the soil scientific community. The ES approach, thus, provides a link to connect soils to a widely applied framework, which can be helpful to put soils on political agendas. However, the work of Robinson et al. (2013) only mentions cultural and social valuation of soils that go beyond the economic realm without specifying or elaborating what is included in these cultural ES of soils. Thus, cultural aspects connected to soils seem of minor importance. This is also indicated in the literature review of Jónsson and Davíðsdóttir (2016) about the soil’s ES. They focus on the economic functions that were used to assign a monetary value to the soil’s ES. However, they also address possible cultural ES of soils, such as the protection of cultural heritage, or cognitive and recreational services and found that very few studies exist, which address cultural ES of soils. The exceptions are studies related to the recreational services soils contribute to (Jónsson & Davíðsdóttir, 2016). On the Swabian Alb in Germany, Plieninger et al. (2013) investigated cultural landscapes in the context of ES. While soils were not the research objective, the study participants assigned high importance values to soil fertility, which they also determined as a critical ES. Similarly, the study of Smith and Sullivan (2014) did not focus on soils but analyzed farmer’s perceptions of twelve ES in Australia. While the farmers perceived their vulnerability to a loss of any of the twelve ES as moderate, they indicated that they were highly vulnerable if soil health was lost and identified poor land management including agro-chemicals and soil degradation as threats to the ES (Smith & Sullivan, 2014). These studies suggest that the research of soils ES is still in an early stage. However, especially the work of Robinson et al. (2013) is promising as it connects the two frameworks of soil functions and ES with each other. As many other scientists already use the ES approach, this work can be used to facilitate interdisciplinary collaboration. However, the ES framework itself is not known to the general public. Also, cultural practices and understanding seem to differ from the ES framework. Thus, social and cultural practices need to be addressed differently to understand how they affect soil cultivation.

3 | CHALLENGES RELATED TO INTERDISCIPLINARY RESEARCH AND APPROACHES TO OVERCOME THEM

Soil scientists and their respective donor organizations call for interdisciplinary collaboration between the sciences and the humanities concerning human–soil relationships. The initiative on Anthropedology (Richter et al., 2011), being one example, is calling on the sustainable use of soils while minimizing detrimental impacts of soil management to the environment and a better understanding of human–soil relations. However, as shown in the examples of archaeopedology, ethnopedology, and the application of the ES framework to soil scientific questions, despite the many benefits, these collaborations also face challenges. This includes the matter of communication, as different disciplines have different views on the material soil and use different theoretical frameworks within their research. Some of the introduced subdisciplines do not rely on a specific interdisciplinary methodological approach, others use a model such as the Cosmos–Corpus–Practice complex from ethnoecology, which is also used in ethnopedology. There, it is applied to the research of rural regions in Africa, Asia, and Latin America, but rarely to the Global North and the human–soil relations there. The focus of the Cosmos–Corpus–Practice model is on cognitive knowledge and practical land-use strategies, which are integrated into a specific religious-magical world vision. This might explain the missing Cosmos–Corpus–Practice model in the ethnopedological studies from the Global North, as scientists working on land use in the countries of the Global North usually are from that part of the world and might not be able to identify the Cosmos component of the model. However, professionals from the humanities, like cultural anthropologists, might want to focus on these cultural phenomena and on the specific world visions of social groups that have different traditions. Hardenberg (2018), for example, is concerned with the study of cereals in Odisha (eastern India), which is known among archaeobotanists as a region where evidence of very early forms of rice cultivation has been found (Fuller, 2006, 2011). In present-day Odisha, large areas of rice cultivation exist in coastal areas, as well as on plateaus and in some cases in mountainous regions. Rice is considered the most important staple food in Odisha compared with other grains, and the cultivation and consumption of rice are embedded in Hindu cosmology and rituals (Skoda, 2013). With the Green Revolution, rice cultivation has intensified greatly throughout India. The term Green Revolution refers to a period from the 1960s to the 1980s where investment in crop research was high, and infrastructure, policies as well as markets were developed to enhance crop productivity, leading to higher yields per hectare (Pingali, 2012). However, the Green Revolution affected agricultural and social practices and led to a perception of soils as inert substrate, while plants are no longer considered to be an organic unit (Molina-Zapata, 2021). In India, the Green Revolution increased rice cultivation, mainly through the introduction of new fertilizers, pesticides, machinery, and high-yielding hybrid varieties, leading to the increasing dependence of farmers on multinational companies (Kloppenburg, 2014). Other disadvantages quickly became apparent: soil degradation, increasing water shortages, unbalanced diets, and social inequalities (Gupta, 1998). As a result, new environmental movements emerged in India, campaigning for the preservation of biodiversity and against habitat destruction (Linkenbach, 2007, 2008). One consequence of the protests has been stately as well as civil society actions to conserve different rice varieties, in situ and ex situ, and to promote seed banks (Patnaik et al., 2017). Another consequence of the criticism of modern cereal policies has been the search for alternatives to intensive rice cultivation, whose sustainability is in question in the context of increasing water scarcity and soil degradation. This has led to various millet varieties coming back into the focus of government support in recent years. Since the Green Revolution, production of millets had declined significantly not only in Odisha but throughout India, while cultivation of rice, wheat, maize, and barley intensified (Finnis, 2008). Millet was long considered a low-status food, the food of the poor and the "socially backward" (Hardenberg, 2018). Nowadays, millets (including sorghum) have been promoted as "forgotten foods for the future." Under this slogan, the Smart Food Initiative at the International Crop Research Institute for Semi-Arid Tropics (ICRISAT) has begun to develop new programs to make various millets attractive to people in Africa and India (ICRISAT, 2018). Key business and policy stakeholders have recognized that millets can play an important role in achieving the SDGs due to their drought resilience and health benefits (*UNDP: SDGS*). In India, these findings are being implemented by a variety of government institutions and nongovernmental organizations. In 2017, the Prime Minister of India decided to include millets (including sorghum) in the Public Distribution System, a system to provide food to the poor, and declared the year 2018 to be the "National Year of Millets" (PIB India, 2018). The hope is that more millets will be produced and consumed by the urban population and the biodiversity of millets will be preserved. As a result, communities whose millet consumption was previously considered backward are now becoming the focus of promotional activities as "custodians of millet," such as through the Odisha Millets Mission (*milletsodisha*). Millets are no longer said to be poor people's food but are promoted as "nutri cereals" and even "super food" and are becoming part of the Indian mainstream (Bergamini et al., 2013). This example shows how cultural anthropologists can contribute to understanding the processes that emerge through the interplay of food research, agroeconomy and local political actors.

Interdisciplinary collaboration in the field of ethnopedology is very much based on individual scientists and their willingness to cooperate, which requires a mutual understanding and willingness to step out of the respective comfort zone. Further, even when the more functional ES approach of MEA with its distinct categories is applied to soil scientific research, often market value is assigned to soils, while the cultural ES related to soils are not considered or merely mentioned. Thus, aspects central to cultural anthropology are not addressed in these studies.

This illustrates that scientists from different disciplines might not understand, why the respective research topic is important and what is gained by the collaboration. As each scientist is educated according to a certain set of rules and ideas present in the respective discipline, they need an approach that enables their collaboration. Further, each scientific discipline can be seen as "an epistemic unit consisting of a set of closely related cognitive resources such as, for example, concepts, models and theories, and as a social unit consisting of highly similar experts who were employing and at the same time developing their shared cognitive resources." (Andersen, 2016). This means that within a given discipline scientists generally agree on research questions and how to approach them (Andersen, 2016). This leads to fruitful communication and successful collaboration within any scientific community but can result in misunderstandings and disagreement if scientists belong to different disciplines and do not address their different scientific rules and languages (Kuhn, 2012). Further, Andersen (2016) highlights that scientists from different disciplines, who want to collaborate interdisciplinary, need to "combine cognitive resources that are distributed among them and which they do not all possess individually." Thus, further expertise is required to achieve any collaboration, which goes beyond the disciplinary based expertise of the involved scientists (Andersen, 2016). This can become a decidedly big challenge, for example, if a soil scientist is forced to understand assemblage theory (Deleuze & Guattari, 1987) and a sociologist is urged to understand the soil's microbiome.

Approaches to include expertise from different disciplines into a holistic study are the social-ecological systems and the complex adaptive systems frameworks. Berkes and Folke (1998) showed that both the social and the ecological system need to be investigated in the context of resource management. However, they observed that depending on the discipline, resource management either focusses on social systems or on ecological systems, but rarely on both at the same time. Ostrom (2009) thus proposed a framework consisting of resource systems, resource units, governance systems and users, with each consisting of several variables as well, and interactions between them, leading to a multilevel nested framework. However, this social-ecological system approach divides the system in the categories "natural" and "social." Another interdisciplinary framework for the study of social and natural systems are the complex adaptive systems, which are part of the complexity sciences displayed by Castellani (2018). Any complex adaptive system consists of different components such as for example humans, animals, plants, soils, and others that interact across multiple scales in space and time. These systems display characteristics such as emergent properties, domination of nonequilibrium states, feedback relationships, and regime shifts (Holland, 1992; Lansing, 2003). However, as Hertz et al. (2020) point out, both social-ecological systems as well as complex adaptive systems often follow a substance ontology, where entities are the research interest. They argue that a shift to a process ontology might offer new perspectives to understand social-ecological as well as complex adaptive systems (Hertz et al., 2020).

4 | A RESOURCE PERSPECTIVE TOWARD INTERDISCIPLINARY COLLABORATION IN SOIL SCIENCE

Here, we introduce an analytical tool that still consists of entities, but where the interactions between these entities are considered and social and cultural dimensions are emphasized. If soil scientists want to collaborate with scientists from other disciplines, especially from the humanities, this tool, which uses resources as an analytical category, might enable fruitful discussions and a successful interdisciplinary collaboration. It enables scientists of different disciplines to contribute their perspective to the respective challenge or research question while simultaneously acknowledging the other perspectives. Through this, collaboration can start and eventually might raise new truly inter- and maybe even transdisciplinary research questions.

In public discourse, the term "resource" is often used synonymously with "raw materials," or more generally, with things that can be monetized. However, from a social perspective, something becomes a resource when people ascribe a culturally shaped interest to it, that is, attach a value to it and use it as part of a socially and culturally shaped practice. A main argument of the interdisciplinary collaborative research center SFB 1070 is that today's understanding of resources is often an expression of the socio-cultural conditions of modern industrial societies, while other societies have developed other ways of looking at and dealing with resources according to their culturally shaped orders. In other words, societies have their own resources, which they use for their own purposes, and these cultural attributions and forms of use are at the center of the SFB 1070's research (Bartelheim et al., 2015; Hardenberg, 2016; Hardenberg et al., 2017; compare analogously Richardson & Weszkalnys 2014).

The German Research Foundation explicitly funds so called SFB's as collaborative research centers to strengthen interdisciplinary research within a certain university and engage in a mutually beneficial exchange of ideas. The SFB 1070 ResourceCultures is such an interdisciplinary research center where archaeologists, social and cultural anthropologists, historians but also geoscientists, linguists, and several other disciplines focus on how resources develop, how they affect migration and movement, and how values and practices are affected by resources. In order to facilitate the communication between the different disciplines, the analytical tool of the ResourceComplex was introduced early on to understand relations between different entities. Whenever one wants to understand one specific resource, one needs to identify every aspect that affects the resource. In order to understand soils as a resource we need to identify everything that affects this resource, ranging from the geology, the plants and the time to cultural aspects such as political programs, knowledge of soil scientists, other soil professionals such as farmers and gardeners as well as of the general society.

The different cultural attributions societies assign to resources become particularly clear when attention is paid to the concrete form of a resource and not only to its function. Thus, it can be argued that there are universal resources that play a central role not only in certain societies, but in principle in all human populations completely independent of culture, such as soil for agriculture, air for breathing, food for eating, or water for drinking. This line of reasoning places the function of a resource at the center of inquiry. However, when the concrete form that a resource takes for a community is considered at a particular time and place, the specific cultural attributions and manners that have historically emerged become apparent. Even for the essential elements of life there can be significant cultural differences: water and food are valued very differently by different societies, depending on climatic conditions, ecological availability, and cultural rules (Bartelheim et al., 2021).

The "value" of a resource such as soil can be defined in various ways (see Gregory, 2015). In economic terms, it can mean the use-value of soil, that is, its usefulness for concrete practices. It may also refer to the exchange-value, for example of ore-bearing soils when they are traded in a particular ratio. The value of certain types of soil may also be expressed in terms of an individual's desire, such as what a person is willing to give up in order to own or use a rare type of soil. Or, the value of soil is assumed to be derived from the amount of labor invested in its extraction or processing. The resource valuation argument put forward in this paper is more in line with the concept of "values" (plural!) as used in linguistics and anthropology. In these subjects, values are best translated as "meanings" or significant cultural "differences" (see Graeber, 2001). In this sense, resources, such as soil for example, refer to certain values of a society, such as fertility, wealth, or power, which are often hierarchically ordered. In situations of gift exchange, the values of a resource may also depend on the status of the person or community with whom it is in an "inalienable" relationship. Resources are then, often controversial, bearers of meanings ("values") ascribed to them in the context of specific socio-cultural systems. An extension of this concept has been proposed by David Graeber, who following Nancy Munn argues that "value emerges in action" (Graeber, 2001). Applied to resources such as soils, his argument is that they serve to make clear to people the value of their own actions. Thus, if people invest a great deal of time and energy in preserving and cultivating their soils, then these soils are merely the medium through which people visualize the realization of their own potentials.

Thus, people all over the world have had—and continue to have—different ideas of what soil is, distinguish between different types of soil, and develop their own ways of dealing with soil depending on their cultural orientation. These cultural variations in form and usage make it understandable how resources help to shape, maintain, and change different social identities and relationships. Thus, while material things exist, they only become a resource when used by humans due to valuation processes. Iron, for example, existed on Earth prior to the Iron Age, but was not used. After it was made accessible and after its valuation, it became an important material that was used over a long time, so that archaeologists named one epoch from the human past—the Iron Age—after this material (Schweizer, 2018). Similarly, soils existed, and have had significance, for example in the context of Mesolithic uses in burials in special sediments and at certain places or in the extraction of ochre. During the Neolithic transition, soils gained even more importance after their properties had been judged as useful for human life. Farmers developed tools like digging sticks, spades and later ards and plows to work with the soil (Lal et al., 2007), domesticated cereals (Bakels, 2014; Dreslerová et al., 2013; Rösch, 1998), and animals (Larson et al., 2007), and simultaneously gained knowledge about soil and plant cultivation as well as about livestock upbringing. This resulted in specific practices like plowing or breeding specific animals deemed useful for the respective society. These farmers, thus, used a combination of plants, soils, tools, knowledge, and practices to provide food to themselves and their social groups. The knowledge for using soils consists of individual experiences as well as the collective memory; it can be, for example, personal or institutionalized, tacit or explicit, scientific or traditional. It is preserved and handed down either codified in written texts, embedded in oral traditions, or through material culture. Related to different knowledge orders even different identities and conceptions related to the use of soils might have arisen through time and in space. While soils have been the research focus of the natural sciences—especially in soil science—the humanities and social sciences tended to take soils for granted focusing on other aspects such as territorialities (Krzywoszynska & Marchesi, 2020). Thus, soil scientists might have to raise awareness for soils in these disciplines prior to starting interdisciplinary collaborations. While the tools for and practices of farming changed through the centuries (Teuber et al., 2017), soils are still important for food production today. However, in urbanized areas around the globe most people do not regularly work with soils and might refer to the soils they see in the urban landscape as "dirt." Urban citizens usually do not work in agriculture or horticulture but instead in the service sector, in industry or the IT sector. Soils, thus, are not necessarily present in public perception. However, certain groups of humanity—farmers, (urban) gardeners, soil scientists—still work with soils using knowledge, practices, tools for soil cultivation, or soil analysis, and more. Working with soils also means that someone has the opportunity, authority, and power to possess, to use, and to valorize them. Thus, these elements need to be identified and analyzed separately, to understand how soil is perceived by humans from different walks of life. Within the interdisciplinary Collaborative Research Center 1070 RESOURCECULTURES, the heuristic of the ResourceComplex allows to identify and analyze such elements needed for the valuation and use of any resource, in our case soils, not only in an economic way of thinking. With this analytical tool, one can identify all elements and connections that affect the use of a specific resource and also visualize the feedbacks between these elements. Such an approach can for example disentangle human–land interactions and cultural concepts during the Holocene (James et al., 2021). Like the theories and concepts of Gudeman (2001), Latour (1999, 2011), Ingold (2016) and Hodder (2012) explain, networks, meshworks, or entanglements exist between resources and other elements that enable the use of the resource itself. Once these elements are identified, they can be analyzed by scientists from different disciplines, while enabling the discussion of the results via the heuristic of the ResourceComplex, which focusses on functional and intentional interactions between the different elements that entangle a resource. The analytical tool of the ResourceComplex can be used in soil science to understand the social and cultural dimensions related to soil and how this might turn soil into a valued resource for society apart from monetization. In eastern India, for example, indigenous communities worship the earth as a life-giving goddess, who demands the blood of a victim in order to make the soil firm and ready for cultivation. For this reason, local communities annually perform buffalo sacrifices before the beginning of the agricultural cycle and offer some of the animal's blood to the stones representing the earth goddess. This sacrifice is part of a ResourceComplex in which cultivation is intimately connected to knowledge about different types of soil, plants, and animals, to a particular form of clan organization, and to people's religious ideas and practices (Hardenberg, 2017).

5 | THE EXAMPLE OF CEREAL CULTIVATION

If one considers soil as a socially constructed resource, soils and their cultivation became the means for identity creation and the formation of social relations and units, because the social group of farmers came into being during the Neolithic transition. Thus, people began to identify as a farmer, developed certain practices and worldviews, and distinguished themselves from the hunter-and-gatherer populations. While there are no written records for the time from the Neolithic to Antiquity, archaeologists like Salisbury (2012) argue "that people are impacted by and draw inspiration from interactions with the materiality of soil." While western scientists look upon soil in a mainly technological, generalized and standardized way, they do not consider the cultural framework of soil knowledge (Barrera-Bassols et al., 2006). Contrary to this western view, local soil knowledge circles around a complex spiritual and cultural concept of soil fertility, where religion and ritual together with practical aspects regulate the use of soil (Toledo, 2000; WinklerPrins & Barrera-Bassols, 2004). Even today, soil cultivation creates not only favorable conditions for planting and high yield but also social identities, as farmers distinguish themselves from other professions. They also have social relations with other farmers, shaped by agricultural activities, such as harvesting. Thus, using the heuristic of the ResourceComplex as a heterogeneous network of phenomena of different materiality can provide insights into the sociocultural dimensions of soil cultivation at a specific location. This holds true as well for networks, for example national and international unions of soil scientists like the German Soil Science Society or the International Union of Soil Science, where soils are valued, and their values are made accessible to a community. From this perspective, soils provide different functions (Blum & Eswaran, 2004; Vogel et al., 2019) and several ES (Daily et al., 1997) to society.

For the following application of a ResourceComplex, the focus will be on cereal cultivation since this has been a central activity of humans in their handling of soils since the sedentism of human groups. In a first step of the analysis, it is necessary to identify all elements needed for cereal production. This includes above all soils, in the context of land use strategies and climate variables, and the availability of domesticated plants, but also tools and technology for soil cultivation, planting and harvesting. Further, knowledge and values as well as political programs and economy affect how soils are used and which kind of cereals are produced by whom and in which way (Figure 1).

The analytical tool ResourceComplex shifts the perspective from the purely functional analysis of soil properties and soil plant interaction including organisms, water and other climatic control variables to the interactions happening between the different entities. Two important entities regarding the role of interdisciplinary collaboration are knowledge and values.

Early concepts of soil were based on ideas of German agronomer Albrecht D. Thaer (1752–1828), German chemist Justus von Liebig (1803–1873), English naturalist and biologist Charles Darwin (1809–1882), American scientist Eugene W. Hilgard (1833–1916), Russian scientist Vasily Dokuchaev (1846–1903), and Swiss-born American soil scientist Hans Jenny (1899–1992). Justus von Liebig, for example, publicized the law of the minimum developed by Carl Sprengel (1840) based on agricultural findings from laboratory, greenhouses, and field experiments (Sinclair, 1994). Liebig's law describes plant growth being constraint not by total resources available, but by the most limiting resource. This idea of one single limiting factor has also been applied to biological populations and ecosystem models for factors such as sunlight or specific nutrients. The scientific basis of soil science was established by the classical works of Vasily V. Dokuchaev (cited in Glinka [1927] and Rusakova et al. [2022]), who considered soil not as just a substrate from which plants derive nutrients but as a complex natural body with its own genesis and history of formation. Such scientific knowledge of soil scientists about soils as a natural body and the interactions with the other components of the environment (climate, organisms, relief, parent material, and time) has been gathered in agrarian schools and universities for decades, for example, by Jenny (1941), Glinka (1927), or Hilgard (1921) to name some of the early big minds in soil science. This knowledge also leads to new technological advancements, today for example the application of machine learning in precision agriculture (e.g., Qin et al., 2011; Schmidt et al., 2008).

In turn, technological development affects our knowledge of cultivation and of soil–plant–environment interactions. Such knowledge about certain interactions might affect our values. For example, if we know about soil erosion and consider it as a constrain for cereal cultivation, conservation tillage or no-tillage approaches might be valued differently than before since these cultivation techniques can reduce soil erosion (Seitz et al., 2019). This knowledge might eventually lead to new political programs, which in turn affect the different components of the ResourceComplex (Figure 1). Prominent examples are the use of farming terraces by the Incas or the Grain for Green program in China in 1999 that was designed to mitigate and prevent flooding and soil erosion (Schönbrodt-Stitt et al., 2013) and paid farmers for changing farmland into forest.

Also, today's knowledge can be used for the interpretation of colluvial deposits and archaeological finds and applied to observations of land use in earlier societies and other cultures (James et al., 2021; Pietsch & Kühn, 2017; Scherer, Höpfer et al., 2021; Teuber et al., 2017). In a larger context, such ResourceComplexes can then be understood as ResourceCultures (see Hardenberg et al. [2017] for a theoretical discourse about this concept and James et al. [2021] for a comparison of ResourceCultures with other concepts applied to human–land interactions during the Holocene). However, this might be misleading from a soil science perspective alone, when not considering recent advances in sociology or anthropology concerning knowledge orders, such as those also present in the perspective of the SFB 1070 RESOURCECULTURES and which become apparent in human practices and in material culture. Knowledge orders are also embedded, for example, in "foodways" or "food systems," which may not only include knowledge about availability and use of specific cereals or soils, but also knowledge about practices and infrastructures, equipment, and technologies for cultivation, processing, storage, distribution, and consumption of food (e.g., cereals). By analyzing, for example, archaeobotanical remains, ceramic vessels, agricultural tools as well as land use strategies still visible and built structures from the past, archaeologists try to identify these "foodways" and "foodsystems" (e.g., Reed, 2021) as well as related identity formations—or even values attributed to certain foods. Further, sociocosmic connotations can play an important role. For example, in today's India, rice is associated with various goddesses (e.g., Annapurna, Ponniyamman), but is particularly seen as a representation of the goddess of wealth and happiness, Lakshmi. In numerous Indian temples, goddess Lakshmi is worshipped in an anthropomorphic form,

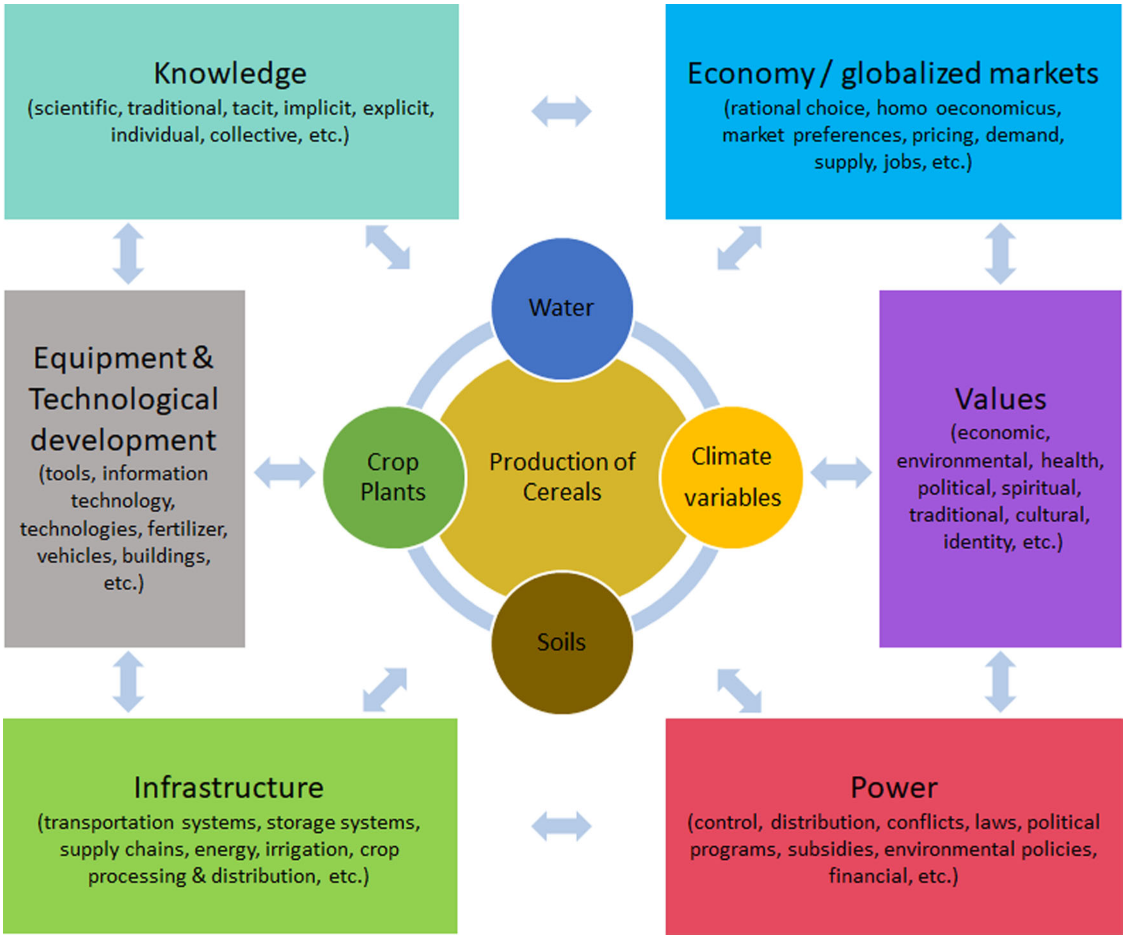

FIGURE 1 The ResourceComplex: A schematic representation of possible relationships, connections, and interactions using the example of cereal cultivation.

but in rural areas she is often represented only by a bundle of rice straw or a rice basket (Hardenberg, 2018). In eastern India, the rice plant, as well as rice sowing, is symbolically associated with pregnancy and motherhood (Tokita-Tanabe, 2014), and in individual communities like the Gadaba, bringing in the rice harvest is celebrated like "fetching the bride" at a wedding (Berger, 2015). Women recite extensive oral traditions in which Lakshmi's wedding is recounted, but also her disappearance and the famine it ushered (Gregory & Vaishnav, 2003). Both, knowledge and values are important parts of the ResourceComplex, so that social and cultural anthropologists, economists and others can contribute their insights into social processes, which influence soil management because of the diverse feedbacks that exist within the ResourceComplex.

Further, ethnopedological studies show that the perception of erosion in traditional, mainly subsistence-orientated, nonmechanized, small-scale farming agricultural societies strongly differs from western scientific views and western perceptions of soil, soil fertility, and erosion (Barrera-Bassols & Zinck, 2003b; Ericksen & Ardon, 2003; Niemeijer & Mazzucato, 2003; Warren et al., 2003). The cosmovision of these societies pictures soil as a living being that, just as any other living organism, changes throughout times but has an immortal character as well and belongs to the spiritual sphere of supernatural beings. Erosion of topsoil is seen as part of a landscape's natural process of change, and the natural phenomena that trigger erosion (like rainfall and storms) are visioned as supernatural powers as well (Bocco, 1991; Lindskog & Tengberg, 1994; van Dissel & de Graaff, 1998). Even though traditional farmers often have a very detailed understanding of the underlying mechanisms of erosion (soil degradation, role of water, organic material, plant cover, surface-relief, etc.), they believe that the process itself can only be partly controlled by human as weather, soil-type, and topography are beyond their influence. For this reason, farmers strongly tend to tolerate and view erosion as inevitable. In fact, as their economies strongly rely on a large variety of different landscapes and different agricultural strategies and resources, erosion is valued as a process that increases landscape diversity and also provides fertile soil sediments that can be trapped and used for agriculture (Critchley et al., 1994; Kiome & Stocking, 1995; Warren et al., 2003). Farmers worldwide trap fertile soil sediments, for instance, with terraces and mechanical barriers like stone-walls, fences and vegetation barriers or the digging of ditches (Barrera-Bassols & Zinck, 2003b; Bocco, 1991; Critchley et al., 1994; Sillitoe, 1993). Besides, many farming strategies commonly used to maintain soil fertility prevent erosion as well, for instance mulching (Barrera-Bassols & Zinck, 2003b; Showers, 2006a; Warren et al., 2003), fallow or field and crop rotations (Scott & Walter, 1993; Showers, 2006b). Even occasional events of massive erosion can be balanced by the diversity of the ecosystem and usage strategies. However, anthropological studies also show that when major changes (e.g., climate changes, migration of people, increase in population, political changes, technological changes) occur, the firmly rooted agricultural traditions and values of farmers do only slowly react to new needs and situations (Beach et al., 2006; Bork, 2006).

Not only soil threats and land management but also preferences for specific cereals in a ResourceComplex can be understood only in a cultural context. In India, for example, different cereal varieties are preferred in different regions of the country (Kingwell-Banham & Fuller, 2012). This is partly a response to ecological conditions, but also an expression of certain cultural ideas and practices, particularly religious ones, that have shaped these regions over long periods of time. For example, in the rather arid north and northwest of the country, wheat is the preferred staple food, while in the very water-rich east and northeast of the country, rice is particularly widely grown and consumed. In the mountainous and plateau regions of central and southern India, on the other hand, various types of millet are cultivated and make up the daily diet. In each of these regions, there is a certain hierarchy and competition between grains, for example in eastern India, where rice is the highest form of cereal, offered as sacred food even to the gods, while wheat products are seen as "foreign" and millet as "poor man's foodf." Particularly in India, whose society is highly differentiated and where grain as food or drink serves to publicly express these multiple identities, grain hierarchies are always linked to claims of social status. As briefly mentioned above, such hierarchies can also change, for example, when millets are suddenly valorized at the local level by an urban elite because of international policies oriented toward the SDGs.

6 | SYNTHESIS AND CONCLUSION

By analyzing soils in the context of food production and using the ResourceComplex approach, scientists from different disciplines contribute their insights to the process of cereal cultivation from different points of view. This leads to interdisciplinary collaboration as displayed in the example.

Therefore, the resource perspective offers a new way to show the importance of soils to a wider society. If sociologists and anthropologists are included in the assessment of soil related problems, soil scientists might be able to communicate different values of soils to a wider audience, including politics, industry, and the public.

Our examples show that the interpretation of soils as part of a ResourceComplex leads to a better understanding of human developments, for example regarding the location of settlements, which might be based on valorization processes, and which has associated interactions of natural and cultural factors and processes. This, ultimately, leads to a holistic understanding of soils as a dynamic-adaptive system. Currently, in addition to the classical soil functions (Blum & Eswaran, 2004), aspects of soil health, soil biodiversity, and soil resilience are increasingly being added (Lehmann et al., 2020). This certainly broadens the spectrum of the significance of soils for humans, but their appreciation by a wide range of the world's population is still low (e.g., Lal et al. 2007) and the valuation of soils is still primarily linked to technical aspects. Holistic approaches like the ResourceComplex approach can help to overcome not only old cultural concepts of favor and disfavor for analyzing human–land interactions (James et al., 2021), but also to understand why certain actions are not effective or are not applied. For example, from a soil scientific point of view sensible countermeasures, for instance to conserve soil health or prevent loss of biodiversity, are often not applied, even though they would prevent loss of soil health.

We can conclude that there is still a great need for interdisciplinarity between the sciences and humanities, here explained and discussed for the case of soil science in an agricultural context. However, there is also a need to distinguish between fundamental interdisciplinary research and application of findings in a socio-economic context. Benefits of an interdisciplinary understanding of soils in a socio-economic context go beyond a better understanding of environmental processes and dynamics within soils which are typically done through fundamental interdisciplinary research, but toward countering environmental changes. One prominent example is the international student movement of Fridays for Future. They understand environmental changes as a loss of opportunities and demand a sustainable planet Earth that can be used for the needs of the young generation. For soil science, this could mean that a stronger focus on research on values and related appreciations and their economic as well as social importance by means of dynamic-complex approaches such as ResourceComplexes is necessary and can help to meet current societal challenges.

ACKNOWLEDGMENTS

Funds to support this research were provided by the *German Research Foundation* (*DFG*), collaborative research center *SFB 1070 ResourceCulture* (*project number 215859406).*

Open access funding enabled and organized by Projekt DEAL.

DATA AVAILABILITY STATEMENT

Data sharing not applicable to this article as no datasets were generated for the article.

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How to cite this article: Teuber, S., Bartelheim, M., Hardenberg, R., Knopf, M., Knopf, T., Kühn, P., Schade, T., Schmidt, K., & Scholten, T. (2022). Why do we need interdisciplinary cooperation with anthropologists and archaeologists in soil science? *Journal of Plant Nutrition and Soil Science*, *185*, 752–765. https://doi.org/10.1002/jpln.202200120