Chapter 27
The Meta Soil Model: An Integrative Multi-model Framework for Soil Security

Sabine Grunwald, Katsutoshi Mizuta, Marcos B. Ceddia, Érika F.M. Pinheiro, R. Kay Kastner Wilcox, Carla P. Gavilan, C. Wade Ross, and Christopher M. Clingensmith

Abstract The profound human-centric dominance in the Anthropocene has created changes in land use, biomes, climate, food networks, economies, and social communities, which in turn have impacted global resources, such as food, energy, and water, as well as the soils, that humanity and other terrestrial life-forms depend on for survival. We posit that a new *integrative science* is needed to support *global soil security* that facilitates improved soil synthesis of data, knowledge, understanding, experiences, beliefs, values, and actions related to soils considering multiple perspective dimensions, such as soil-environment, soil-politics, and soil-human. *Integrative soil security* – a new term we coin in this paper – is based on (i) integration of individual and collective human needs, uses, values, beliefs, and perceptions of soils coalesced with (ii) quantitative knowledge of soils derived through empirical observation and quantitative analysis as well as (iii) systems that soils are embedded in (e.g., economic, political, social, and legal systems). We propose a Meta Soil Model (MSM) that is rooted in integral theory and integral ecology as the foundation for a new *integral soil security* with cognizance as the key integrator. We define an MSM as an integrative, multi-model framework to assess soil security within the context of regional and global human-environmental interactions. The MSM fosters enactment for securing soils rooted in inter-, trans-, and post-(integral) disciplinary thinking and allows to diagnose integration gaps, such as the values and beliefs people hold about soils and scientist's observations, data, maps, and models of soils, ultimately constraining global soil security.

Keywords Meta Soil Model • Soil security • Integration • Integral theory • Integral ecology • Multi-model

S. Grunwald (✉) • K. Mizuta • R.K.K. Wilcox • C.P. Gavilan • C.W. Ross • C.M. Clingensmith
Soil and Water Sciences Department, University of Florida, Gainesville, FL, USA
e-mail: sabgru@ufl.edu

M.B. Ceddia • É.F.M. Pinheiro
Soil Department, Institute of Agronomy, Universidade Federal Rural do Rio de Janeiro (UFRRJ), Seropédica, RJ, Brazil

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27.1 Significance and Rationale

The terrestrial biosphere has made the transition from being primarily driven by natural biophysical processes to an anthropogenic biosphere shaped primarily by human systems in the latter half of the twentieth century (Ellis 2011). This profound human-centric dominance in the Anthropocene has created changes in land use, biomes, climate, food networks, economies, and social communities, which in turn have impacted global resources, such as food, energy, and water, as well as the soils, that humanity and other terrestrial life-forms depend on for survival (Amundson et al. 2015) (Fig. 27.1). As such, human security depends on the health/state of these resources. Generally, security denotes the state of being free from danger or threat (King and Murray 2001). Hence, securing soils can be defined as the freedom from risks of losing (i) a specific or a group of soil functions, (ii) goods and services that soils provide to benefit humans and – in its broadest sense – (iii) sustainability of life on Earth. Unfortunately, there is no absolute threshold or method that can classify a soil as "secure" or "insecure." Here we advocate a relative view along a spectrum of soil security-insecurity with the tendency, likelihood, or possibility to be in a present state of "more" or "less" secure.

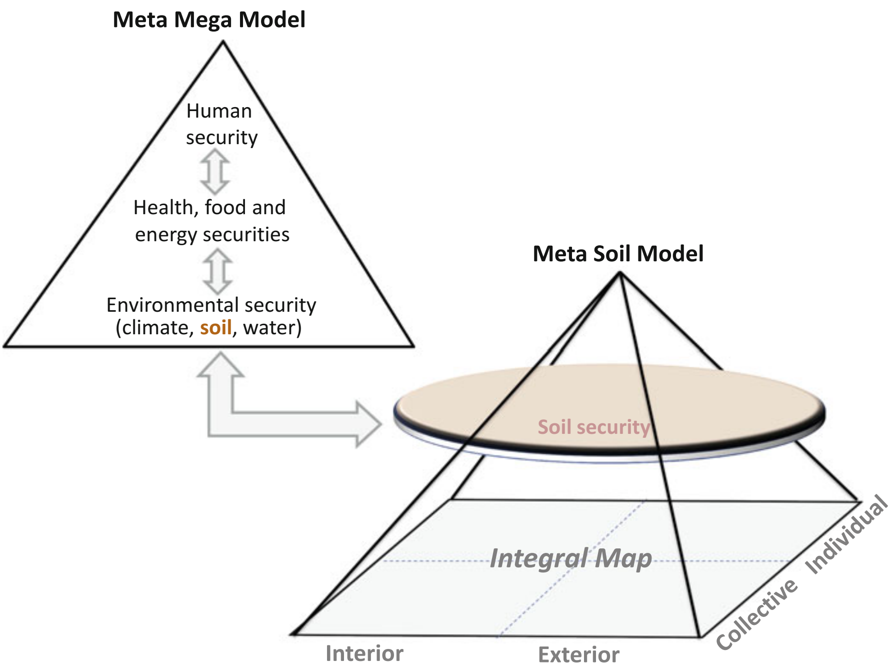

Fig. 27.1 Nested hierarchical structure of different securities with soil security placed within environmental security. Soil security serves to support other securities, such as health, food, and energy security, which are encompassed holonically by human security

The risk of losing soil security is tied to the fact that soil resources are finite (Schmidtz and Willott 2012; Oliver and Gregory 2015). The competition among uses is amplified as the specific needs (e.g., food and fiber production, bioenergy, biodiversity, recreation, preservation of natural beauty) increase, often at the expense of soil degradation. We assert that to achieve soil security depends on the vulnerability and resilience of soil and soil-ecosystems. Adger (2006) described vulnerability as "the state of susceptibility to harm from exposure to stresses associated with environmental and societal change and from the absence of capacity to adapt." Resilience has emphasized the elasticity and capacity of an ecosystem to recover from threat, stress, or continued sustained use (Folke 2006). Noteworthy, processes and response feedbacks to soil-ecosystems have accelerated in the Anthropocene jeopardizing both the resilience and sustainability of soil-ecosystems at local, regional, and global scales (Grunwald et al. 2011).

Given the complexity underlying soil security – namely, risk, vulnerability, resilience, and sustainability of soil and soil-ecosystems – an integrative framework is needed that allows us to harmonize human, soil, and ecosystem dimensions. Such an integrative framework goes beyond individualized and compartmentalized research assessing specific soil properties (e.g., soil organic carbon), soil processes (e.g., decomposition), soil functions (e.g., storage of nutrients), soil quality (e.g., aggregation of multiple soil properties), soil maps (e.g., assessment of the spatial distributions of soil properties), or soil models (e.g., assessment of soil change). These individual components of soil security are all critically important, yet individually they fall short to assess soils in a holistic manner. There are silos of studies of soils that have focused in depth on assessing separately the condition, capability, capital, codification, and connectivity – identified as the core dimensions of soil security (McBratney et al. 2014). These five dimensions of soil security have been described conceptually but at this point in time lack explicit quantification and integration. We posit that a new integrative science is needed to support global soil security that facilitates improved soil synthesis of data, maps, knowledge, understanding, interpretations, beliefs, values, and actions considering multiple perspectives, such as soil-environment, soil-politics, and soil-human. In ecology, synthesis has been recognized as a key integrative concept, and it occurs when disparate data, concepts, or theories are combined in ways that yield new knowledge, values, insights, understanding, or explanations (Pickett et al. 2007; Peters 2010). Science integration is the process by which insights are incorporated or assimilated into an individual's and society's worldviews, e.g., to improve soil quality (Grunwald et al. 2015). Therefore, *integrative soil security* – a new term we coin in this paper – is based on (i) integration of individual and collective human needs, uses, values, beliefs, and perceptions of soils coalesced with (ii) quantitative knowledge of soils derived through empirical observation and quantitative analysis as well as (iii) systems that soils are embedded in (e.g., economic, political, social, and legal systems). In short, *integrative soil security* is based on the human domain + assessment/quantification of soils and soil-ecosystems. Integration linking soil models across temporal and spatial scales is still in its infancy (Grunwald et al. 2011). Yet, they are urgently needed to connect pedon and global soil-ecosystems and assess their

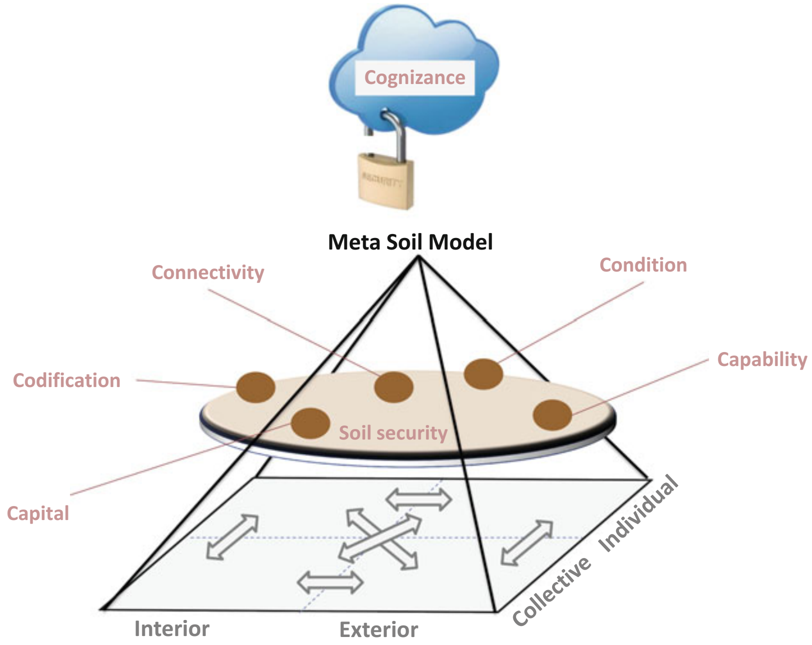

Fig. 27.2 Conceptual relationships between the integral soil security model that provides the foundation for the Meta Soil Model (MSM), the five dimensions of soil security as defined by McBratney et al. (2014) and cognizance (i.e., the sixth dimension of soil security). Note that the four quadrants of the integral model (shown in *gray*) are clearly discernible perspective dimensions that interact with each other and are revealed through cognizance arising within and across quadrants. It formalizes the MSM structure and can be applied to diverse soil security problems. The five dimensions of soil security (shown in *brown*) are not placeable in a specific quadrant because they are ambiguous dependent on their implementation

change and evolution through time. In this chapter, we adopt integral theory (Wilber 2000a, b) and integral ecology (Esbjörn-Hargens and Zimmerman 2009) as the foundation for a new *integrative soil security*. We propose a Meta Soil Model (MSM) that is rooted in integral theory with cognizance as the key integrator (Fig. 27.2). Cognizance describes the knowledge, awareness, and perceptions held by individuals and people (communities) interacting with soil-eco and other systems that pertain to secure soils. Hence, without cognizance there is no tight integration among the five Cs (condition, capability, capital, codification, and connection) proposed earlier by McBratney et al. (2014). Cognizance brings forth clarity and insight to wisely act, decide, and manage a soilscape due to intrinsic motivation to secure soils and derive other benefits and services that depend on them (e.g., food production, filtration of endocrine disruptors, carbon storage, preservation of biodiversity, and human livelihood). This point is often overlooked because simple awareness that a soil is degraded or limited in some way or another to provide a specific function or benefit (e.g., maximize crop yield) will not invoke people to act and improve and secure soils. We argue that a deep understanding or cognizance of soils and their inherent value in providing water, food, human, and other securities evokes *action*. Importantly, it is the awareness of the integrated nature of resources that motivates people to secure our common future. These ethical underpinnings of soil security are at the forefront in the Anthropocene that calls forth integration and synthesis. The MSM framework facilitates soil-ecosystem, soil-human, soil-education, soil-technology, and other syntheses. It explicitly uses integration trajectories connecting the different perspective dimensions of soil security to create the MSM structure. Our objectives are to:

1. Formalize the MSM as the underlying integrative multi-model framework for soil security.
2. Demonstrate the value of integral theory and integral ecology to create MSMs that assess soil security.

27.2 Approach

27.2.1 What Is the Meta Soil Model

At its core, the MSM can be defined as the process of synthesis in which disparate data, concepts, or theories are integrated in ways that yield new knowledge, insights, or understanding. The term meta ("after," "beyond," "self") is used to indicate a concept that is an abstraction from another concept (Grunwald 2014). Meta models are typically nested holonically. The MSM consists of coupled data of data and models of models describing soils of soilscapes embedded within systems of systems. Wilber (2000b) posited that reality as a whole is composed of holons. A holon is something that is simultaneously a whole and a part. For example, a molecule is part of an aggregate, and soil aggregates are part of a pedon, and pedons make up soil-landscapes, and so on. Yet, from another perspective molecules are a whole with their own agency and purpose. In essence, multi-models are composed of holons that are spatially nested, coupled, and interconnected in hierarchical fashion that change through time.

Meta models are prominent in computer science where coupled frameworks enable complex data analysis, knowledge integration, and big data processing (Beckman et al. 1998; Ford et al. 2006) and ecology (Larson et al. 2005). Meta modeling is not limited to quantitative applications but has also been extensively used in conceptual, descriptive, and qualitative ways. For example, Edwards (2008) presented an overview of integral meta-studies and emphasized that meta-theorizing is essential to move from single disciplinary to multi-, cross-, inter-, trans-, and post-disciplinary projects. Since soil security is not isolated from other securities (food, energy, human, etc.) a meta model structure is essential to take the leap from a classical soil-centered view (Koch et al. 2013; McBratney et al. 2014) to a more open view that embraces partnerships with other disciplines. Meta modeling has been applied in a large number of ecology-oriented studies synthesizing across domains and disciplinary boundaries. For example, Ostrom (2009) analyzed the sustainability of complex social-ecological systems adopting a multilevel, nested framework. Therefore, we define an MSM as an integrative, multi-model framework to assess soil security within the context of field, regional, and global human-environmental interactions and various systems. Importantly, the MSM includes (i) human (individual and collective perspectives of land use managers, stewards of soils, and beneficiaries of goods and services derived from soils) and (ii) environmental analytical perspectives (i.e., individual and collective views of soil particles, pedons, soilscapes, and their interactions with other biophysical, biochemical, social, economic, and other system domains). Grunwald et al. (2015) presented a MSM fusing soil, soil spectral, and remote sensing data to model soil properties for the purpose of soil quality and soil change assessment. They provided an overview of different integration pathways that fuse, synthesize, and integrate various soil-environmental data and methods/models into something bigger than single soil properties. Similarly, other MSMs can foster the integration of data, methods/models, and systems to support *integrative soil security*. In summary, this integral theory-inspired MSM framework facilitates soil, soil-ecosystem, and soil-human system syntheses based on formalized integration trajectories.

27.2.2 From Integrative to Integral Soil Security: Integral Ecology

The MSM enacts soil security through inter- and transdisciplinary (*integrative soil security*) and post-disciplinary (*integral soil security*) studies. The integration process of *integral soil security* is anchored in integral theory (Wilber 2000a, b) that interlinks four quadrants (Fig. 27.3): (i) *individual-interior* comprising subjective experiences of the soil-environment through our sense perceptions, (ii) *collective-interior* (i.e., culturally flavored communication that impact soil security, values, and beliefs of groups of people about soils and nature), (iii) *individual-exterior* (i.e., soil attributes, soil management, soil use, soil processes, etc.), and (iv) *collective-exterior* comprising political, social, environmental, legal, economic, eco-, and other systems (e.g., global and national governance structures, soil-related policies, financial resources provided to secure soils, etc.). These four quadrants are referred to as “I,” which represents first person perspective (upper left quadrant (UL)); “We,” the second-person perspective (lower left quadrant (LL)); “It” (upper right quadrant (UR)); and “Its” (lower right quadrant (LR)). The latter two represent third person perspective in the integral model and are often referred to as AQAL (all quadrants, all levels and lines) by Esbjörn-Hargens (2005). These four quadrants represent *perspective dimension* that interact with each other dynamically and evolve to higher and more complex levels along developmental lines. According to Esbjörn-Hargens (2010) the four *perspectives* of integral theory (i.e., subjective, UL; inter-subjective, LL; objective, UR; and interobjective, LR perspectives, Fig. 27.3) are

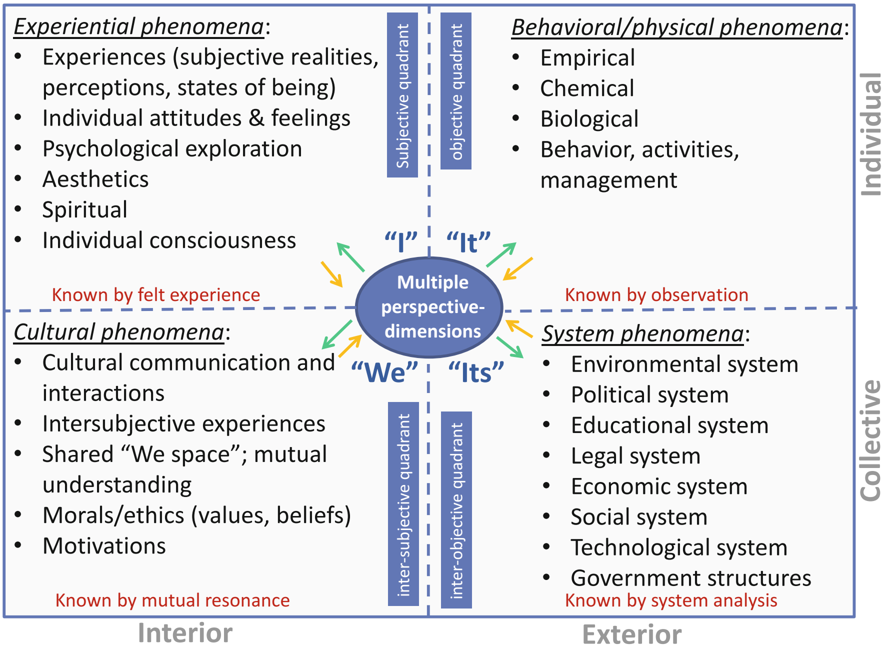

Fig. 27.3 Overview of the integral model consisting of four quadrants (perspective dimensions): individual-interior ("I"), collective-interior ("We"), individual-exterior ("It"), and collective-exterior ("Its") (After Wilber 2000a, b; Esbjörn-Hargens and Zimmerman 2009). The *green arrows* pointing out represent an individual placed in the center of the integral map (quadratic approach) viewing, perceiving, and understanding the dimensions of each quadrant. The *orange arrows* pointing to the center depict an issue/problem placed in the center of the integral map (quadrivia approach) using different methodologies to disclose the perspectives of each quadrant

irreducible and must be consulted when attempting to fully understand any issue or aspect of reality. This suggests that soil security cannot be fully understood through a one-dimensional approach that assesses only the conditions of soils or the capability of soils. For example, even if a given soil map or soil capability assessment is highly accurate and precise, it would not necessarily secure soils. The limitation of such a reductionist approach is that it does not necessarily consider the perspectives and values from all stakeholders or groups, such as land stewards, knowledge brokers, politicians, urban dwellers, and the general public (see left-hand quadrants, UL, and LL in Fig. 27.4). Examples of different perspectives and quadrants applied to soil security are presented in Fig. 27.4.

Wilber (2000b) adamantly advocates avoiding the reduction of one of the perspective dimensions into the other – what he calls "flatland." For instance, the attempt to reduce interiors to their exterior correlates (i.e., collapsing subjective and intersubjective realities into their objective aspects) leads to incomplete attempts to address an issue as complex as soil security. However, this is prevalent in soil science studies that map, quantify, model, and simulate soils ignoring people's felt

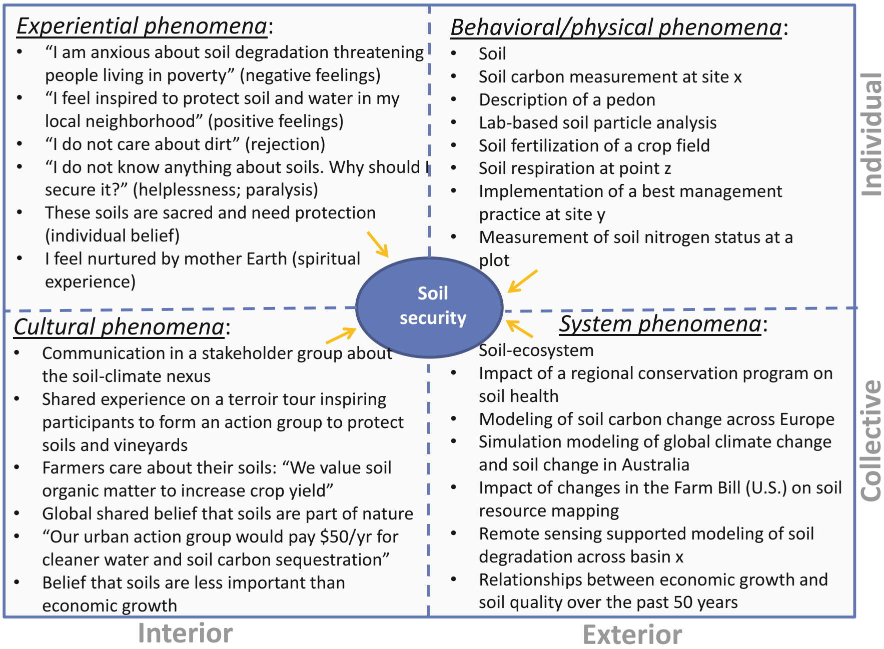

Fig. 27.4 A quadrivia of soil security with examples of different perspectives (individual-interior, collective-interior, individual-exterior, and collective-exterior) for each of the quadrants in the integral model. The quadrants interact with each other as visualized by the *dashed lines*. Different methodologies are used in each of the quadrants to understand soil security through different perspectives ("vantage points")

sense of first- and second-person experiences which has led to ignorance, nonaction, paralysis, delusion, or helplessness toward securing soils. The integral map reveals gaps and disconnects between quadrants that cause soil security problems. Participatory approaches that link right and left quadrants are most valuable to create MSMs. For example, Chaikaew (2014) built a meta model using Bayesian belief networks to integrate multiple perspective dimensions to assess three different ecosystem services and benefits in a multifunctional region with diverse soil conditions. Bouma et al. (2012) pointed out that sharing experiences of experts with citizen groups creates more awareness and links soil information and policies that foster soil security which in essence integrates across quadrants of the integral map.

Integral theory allows viewing of the integral map based on two contrasting approaches. The "quadratic approach" depicts an individual situated in the center of the quadrants where he/she perceives reality (nature) as a result of his/her own embodied awareness. Here the individual is placed in the center of the integral map and has direct access to experiential, behavioral, cultural, and social/systemic aspects of reality because these are actual *dimensions* of his/her own existence (Esbjörn-Hargens 2010). This empowers him/her to cognize the world more intimately which subsequently evokes him/her to care and thus act in ways that are insightful. For example, an individual that cognizes the beauty and value of soils as a common global good to sustain soil security and human security is likely to deeply care about soils and is willing to contribute to secure them. In the "quadrivia approach," the different *perspectives* associated with each quadrant are directed at a particular issue (e.g., soil security) that is put in the center of the integral map (Fig. 27.4). Here different methodologies are utilized to learn, understand, and address a complex problem such as soil security. For example, individual experiences (UL) can be disclosed through phenomenology, mutual shared space of groups/communities talking and interacting with each other (LL) can be revealed through hermeneutics or structural analysis (e.g., surveys, questionnaires), the actual conditions of a pedon (UR) can be deducted from empirical observations (e.g., laboratory soil analytics, remote sensing), and the soil-ecosystem interacting with other systems (LR) can be discerned through system theory or simulation modeling (Wilber 2000a; Esbjörn-Hargens 2010).

27.2.3 How to Create a Meta Soil Model?

Grunwald (2014) first proposed the MSM concept. Here we extend the concept to create a MSM using five key questions:

- *Why* is soil security important? (to identify the value and beliefs that people hold about soils)
- *For whom* to secure soils? (to identify the motivations, needs, and purpose of securing soils)
- *What* soil? (to identify what soil characteristics to measure, describe, and experience)
- *Who* participates in the process to secure soils? (to identify key players to use, protect, benefit, and provide knowledge about soils)
- *How* to assess soil security? (to identify how to assess soil security using different methodologies)

To answer these questions, we adopt the integral map to assess soil security using *perspective dimensions* (i.e., the quadrant and the quadrivia approach of integral theory) (Fig. 27.5). First, values, motivations, and beliefs that are underlying the purpose to secure soils are identified from different individuals and groups that represent different *dimensions* of the integral map (Fig. 27.5). Ethics and moral beliefs play a major role in the values attached to soils. This step is often overlooked or ignored by soil scientists but factually the most important one in the process of meta soil modeling. Second, soil and ancillary environmental, social, cultural, and other data and knowledge are assembled to capture different *perspectives* of soil security using the integral map (Fig. 27.5). The data are integrated to create new insight and understanding of the specific soil security problem through synthesis of data of data (e.g., pooling of data and integration of databases). Third, data and methods/models are integrated (e.g., through ensemble modeling, meta-analysis, or meta-theorizing) to create multiple soil realizations derived from different paradigms, where each paradigm presents a different quadrant (e.g., soil data are collected (UR) and digital soil mapping used to assess soil security (LR), the benefits of soils are assessed using a questionnaire among residents (LL), and individual experiences and perceptions related to soils and nature are identified (UL) (Fig. 27.5)). Grunwald et al. (2015) provided a comprehensive overview of integration pathways that fuse/synthesize different data and methods applied to soil-ecosystems that are at play in this meta modeling process. Forth, the MSM creates output that is interpreted and shared with people (Fig. 27.5). Importantly, output of

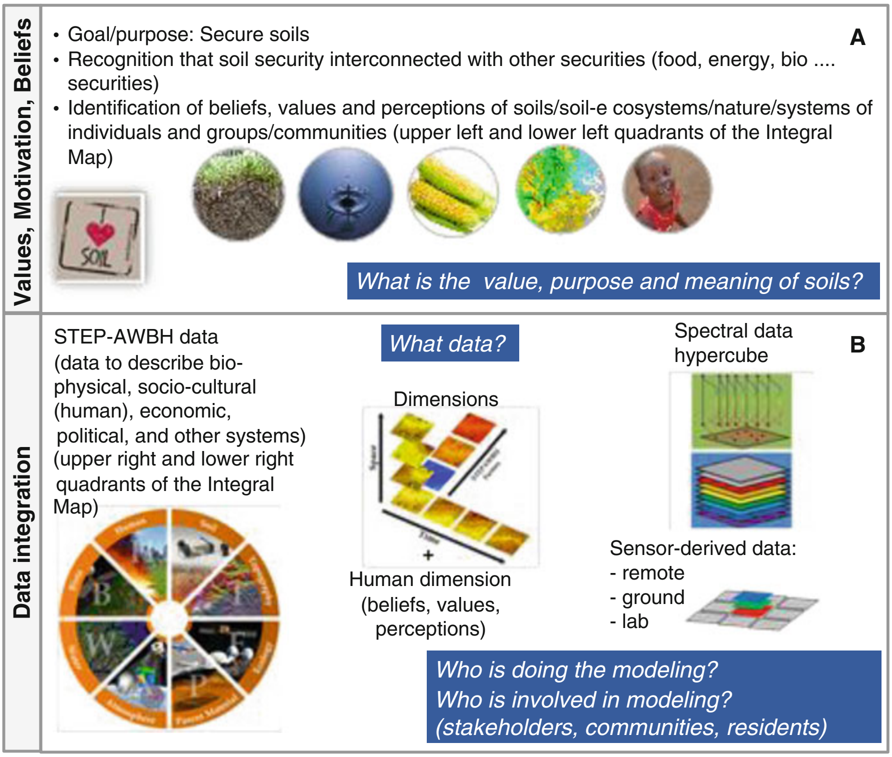

Fig. 27.5 Workflow to create a Meta Soil Model. *Panel A*: The values, underlying motivations, and beliefs of individuals and groups/communities in relationship to soil security. These are situated in the individual-interior and collective-interior quadrants of the integral model. *Panel B*: Data integration from all four quadrants of the integral model. Cognizance plays a pivotal role in the identification of data aiming to achieve soil security and becoming aware of humans beliefs, values, and perceptions.

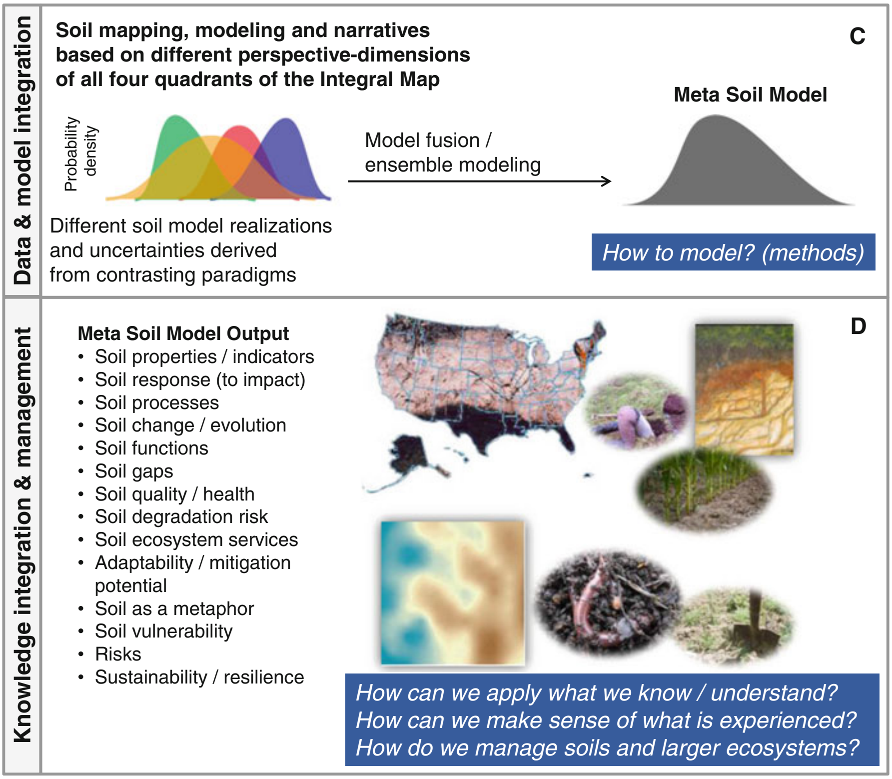

Fig. 27.5 (continued) *Panel C*: Data and model/method integration to build a Meta Soil Model. *Panel D*: The output/response from a specific Meta Soil Model. The output of a Meta Soil Model entails base properties, responses, and processes up to highly integrated metrics such as vulnerability, risks, sustainability, and resilience. The latter outputs derived through the meta modeling process depend on the former more simple metrics

the MSM is not limited to soil functions but includes a whole suite of outputs, such as soil properties, processes, gaps, vulnerability, and narratives customized to a specific soil security application. This is a co-creative process among those who are intricately involved in the development of the MSM and those who inform/provide inputs into the integral MSM that is then used for informed decision-making to secure soils.

27.3 Final Remarks

We believe that integration facilitated through cognizance within and across the integral map is pivotal for securing soils across local, regional, and global scales. Integral ecology and theory, which are both meta-theories, provide a foundation to guide the integration process to secure soils. The paradox is that as we move toward the tip of the MSM revealing risk, vulnerability, resilience, and sustainability of soil and soil-ecosystems, through pluralistic integration of multiple perspective dimensions, we gain clarity through simplicity. We are able to see gaps and disconnects with more clarity (e.g., between soil science models and people's views) that empower us to make wise decisions on how to live and connect with soils rather than to use and exploit soils. Paradoxically securing soils does not depend on understanding the full complexity of soils and "the world" by generating more soil data, finer and more accurate soil maps, and complex process-based space-time simulation models (UR and LR). Rather, global soil security depends on cognizing the values, beliefs, felt experience, and perceptions that all stakeholders have in regard to soil and nature and by harmonizing the cognizance dimension with traditional soils knowledge. *Integral soil security* provides guidance along this path into the future.

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