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From Surface to Subsoil: Why Soil Profile Examination is Essential in Arable Cropping Systems

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Abstract

Soil serves as the primary medium for crop growth and productivity, with its characteristics largely determining the success of arable farming systems. While surface soil sampling provides useful insights into nutrient availability and fertility status, it offers a limited perspective on the overall potential of soils to sustain long-term crop production. Examining the entire soil profile, from surface to subsoil, is therefore indispensable in understanding the rooting environment, water dynamics, nutrient reserves, and constraints that may not be evident at the surface. Soil profile studies allow the identification of morphological features, horizon differentiation, and pedogenic processes that influence crop growth, nutrient cycling, and land suitability. Such knowledge is fundamental to land-use planning, precision agriculture, and the design of sustainable management strategies in arable crop systems. This review synthesizes current evidence on the necessity of soil profile examination, emphasizing its role in fertility assessment, water retention, land capability evaluation, and sustainable arable crop production. The discussion highlights not only the agronomic benefits but also the environmental and conservation implications of integrating soil profile characterization into agricultural practice. Future directions point toward the integration of traditional profile studies with digital tools such as remote sensing and machine learning for more effective soil management in tropical agricultural landscapes.

Keywords: Soil Profile; Arable Cropping System; Subsoil Properties; Sustainable Agriculture, and Crop Productivity.

1. Introduction

Arable crop production forms the backbone of global food security, particularly in tropical regions where staple crops such as maize, cassava, yam, rice, and sorghum dominate household diets and local economies (Fudzagbo & Abdulraheem, 2020). The productivity of these crops is intrinsically linked to the condition of the soil, which serves not only as a reservoir of nutrients and water but also as the physical medium for root anchorage and biological activity. In many agricultural systems, routine soil assessments focus primarily on surface soil sampling (usually 0–20 cm), as this layer contains the bulk of organic matter and is the most responsive to fertilizer and amendment inputs (Ball et al., 2017; Murphy, 2015). However, reliance on

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surface sampling alone often neglects the deeper soil layers that significantly affect crop performance, particularly for deep-rooted arable crops. The soil profile, defined as the vertical sequence of horizons from the surface down to the parent material, provides a more holistic picture of soil quality and agricultural potential (Button, 2022; FAO, 2022).

The necessity of soil profile examination in arable crop systems stems from the fact that soils are vertically heterogeneous. Each horizon differs in terms of physical, chemical, and biological properties, and these differences determine the rooting depth, water-holding capacity, nutrient availability, and overall suitability of land for particular crops. For example, a fertile surface horizon may mask subsoil constraints such as compaction layers, gravel beds, or high acidity, which can severely restrict crop rooting and yields. Ignoring such subsurface limitations may result in poor crop performance despite adequate fertilizer application. Thus, a soil profile examination goes beyond fertility diagnosis—it identifies constraints, opportunities, and management pathways for sustainable land use (Gunal et al., 2025; Shah and Wu, 2019).

The integration of soil profile studies into arable crop production is not merely an academic exercise but a practical necessity. Profiles inform land capability and suitability classification systems, which are essential for matching land with appropriate crop types and farming practices (El Behairy et al., 2022; Shah and Wu, 2019). They are also crucial for soil and water conservation planning, irrigation design, and the evaluation of long-term soil productivity. In the face of global challenges such as climate change, land degradation, and food insecurity, a comprehensive understanding of soil profiles provides a strong foundation for sustainable intensification of agriculture (Akinyemi and Ifejika, 2025, Abdulraheem et al., 2012)

This review therefore aims to highlight the necessity of soil profile examination in arable crop systems by exploring its role in root development, nutrient dynamics, water relations, land evaluation, and sustainable management practices. In doing so, it underscores the limitations of surface sampling while presenting soil profile characterization as an indispensable tool for agricultural productivity, resilience, and environmental stewardship.

2. The Concept of Soil Profile

A soil profile is a vertical section of the soil that reveals the arrangement of horizons from the surface to the unweathered parent material (Figures 1-4). It serves as a natural archive of pedogenic processes, reflecting the interactions between climate, organisms, relief, parent material, and time (Dutta et al., 2024). Each horizon within the soil profile differs in morphology, texture, structure, color, consistency, and chemical composition, all of which play essential roles in supporting arable crop production (Regassa et al., 2023; FAO, 2022). For farmers and soil scientists, the profile is not merely a descriptive feature but a diagnostic tool that provides insight into the suitability, limitations, and long-term productivity of agricultural soils.

The horizons that make up a soil profile typically include the O, A, E, B, C, and R horizons, although not all soils display the full sequence (Zhang et al., 2021). The O horizon consists of organic litter and decomposed residues, which supply essential nutrients and improve soil structure. The A horizon, often called the topsoil, is the zone of maximum biological activity and the primary medium for seed germination, root establishment, and nutrient cycling. The E horizon, when present, is characterized by leaching and loss of silicate clays, iron, and aluminum oxides, leading to a lighter color. The B horizon, or subsoil, is the zone of accumulation where materials leached from above are deposited; this horizon often governs water retention, rooting depth, and nutrient storage for crops. The C horizon consists of weathered parent material with limited biological activity, while the R horizon represents unweathered bedrock, which marks the lower limit of the soil profile (Regassa et al., 2023; USDA, 2022).

Figures 1-4 shows examples of what a soil profile looks at

The importance of studying these horizons lies in the fact that soil is vertically heterogeneous, and each layer can either enhance or restrict crop growth. For instance, a nutrient-rich A horizon may overlay a compacted B horizon with high clay content, restricting root penetration and water movement. Conversely, a deep, well-structured B horizon may provide a valuable reservoir of water and nutrients during dry spells, particularly for deep-rooted arable crops such as cassava and yam. Hence, soil profile analysis provides a more complete understanding of the rooting environment than surface sampling alone (Obalum et al., 2024; Tingskou, 2023).

Pedogenic processes such as leaching, eluviation, illuviation, weathering, and humification continuously shape soil profiles. In tropical regions, intense rainfall promotes strong leaching and weathering, leading to the development of highly weathered soils with distinct subsurface horizons rich in iron and aluminum oxides. These conditions often result in low base saturation and high acidity, which can limit the productivity of arable crops unless appropriate amendments such as lime are applied (Dutta et al., 2024). The study of soil profiles thus reveals not only the present fertility status but also the inherent pedological processes that determine long-term agricultural potential.

In the context of arable crop production, the soil profile is indispensable for assessing rooting depth, identifying constraints such as shallow soils or hardpans, and determining the soil's capacity to retain water and nutrients. Moreover, soil profile description is a fundamental requirement in soil classification systems, including USDA Soil Taxonomy and the World Reference Base for Soil Resources (WRB), which provide frameworks for comparing soils across regions and for guiding land-use decisions (IUSS Working Group WRB, 2022). Through classification, soil profile information is translated into practical recommendations for crop selection, management practices, and soil conservation.

Therefore, the concept of a soil profile extends beyond academic interest to practical applications in agriculture. By exposing the vertical continuum of soil horizons, profile studies

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enable a more accurate assessment of soil fertility, water availability, and land suitability for arable cropping. In a world where sustainable agriculture is increasingly important, the soil profile remains an essential diagnostic tool that bridges pedological understanding and practical land management (Gasparatos and Kairis, 2022).

3. Soil Profile and Rooting Environment in Arable Crops

The rooting environment of arable crops is shaped largely by the physical and chemical characteristics of the soil profile. Roots function not only to anchor plants but also to explore soil horizons for water and essential nutrients (Gregory, 2022). While the topsoil is the primary zone of biological activity and nutrient cycling, the subsoil serves as an important reservoir of resources that sustain crops during periods of stress. Thus, the interaction between root systems and the soil profile is central to crop performance, yield stability, and long-term soil productivity (Hallett et al., 2022; Gregory, 2022; Balliu et al., 2021).

Arable crops vary widely in their rooting patterns, with some being shallow-rooted while others explore deeper horizons. Cereals such as maize and sorghum typically develop fibrous root systems that extend into both topsoil and subsoil, enabling efficient exploitation of water and nutrients (Abdulraheem & Charles, 2013). Rooting depths for maize may extend beyond 1 m under favorable conditions, allowing access to deep soil water reserves during dry spells. Similarly, cassava and yam develop extensive root systems that penetrate deeply into the subsoil, making them highly dependent on subsoil conditions for optimal growth. On the other hand, crops like cowpea and groundnut are more shallow-rooted, relying heavily on the fertility and moisture of the topsoil (Zhang et al., 2024; Chaudhary et al., 2022).

The soil profile strongly influences root penetration. For instance, compacted layers, commonly referred to as hardpans, restrict downward root growth and lead to shallow rooting, which makes crops more vulnerable to drought and nutrient deficiencies (Sharma and Kumar, 2023; Lynch et al., 2022). In many tropical soils, plinthite or ironstone layers may occur in subsoils, forming impenetrable barriers that limit rooting depth. Likewise, gravel beds or shallow soils overlying bedrock present severe limitations to root development, reducing crop resilience under variable rainfall conditions (Sharma and Kumar, 2023).

Beyond physical barriers, the chemical characteristics of subsoil horizons also play a critical role in shaping the rooting environment (Costa and Coutinho, 2022). Subsoil acidity, often accompanied by high levels of exchangeable aluminum, is a common constraint in tropical soils. Aluminum toxicity inhibits root elongation and reduces the effective rooting depth of crops, thereby limiting their ability to access water and nutrients stored in deeper horizons. Conversely, subsoils rich in calcium, magnesium, or potassium can serve as valuable nutrient reserves that support crop growth during the later stages of development (Costa and Coutinho, 2022; Lynch et al., 2022). Thus, soil profile examination provides crucial information on both the opportunities and limitations presented by subsoil horizons.

Water availability within the soil profile further influences rooting dynamics (Huang et al., 2024; Liu et al., 2022). During the onset of the growing season, roots exploit moisture from the topsoil. As surface layers dry, crops increasingly rely on water stored in the subsoil. For deep-rooted crops such as cassava and yam, access to subsoil water can make the difference between yield stability and crop failure in drought-prone environments. A soil profile examination helps

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in determining whether the subsoil has adequate storage capacity or whether it is prone to rapid drainage and leaching, which could deprive crops of essential moisture during critical growth stages (Mutanda et al., 2025; Huang et al., 2024; Ma et al., 2022).

Biological interactions within the soil profile also contribute to root performance (Wendel et al., 2022). Mycorrhizal associations, for example, extend the effective rooting zone of crops by improving nutrient acquisition from both topsoil and subsoil horizons (Ma et al., 2022). However, their effectiveness is often constrained by soil structure, organic matter distribution, and the presence of toxic elements. By examining the profile, soil scientists can better understand the distribution of biological activity across horizons and its implications for crop rooting (Huang et al., 2024; Wendel et al., 2022; Ma et al., 2022)

The practical implications of these interactions are evident in crop management. A soil profile study that reveals the presence of a shallow compacted horizon might lead to recommendations for subsoiling or deep tillage. Similarly, the discovery of acidic subsoils may warrant liming strategies that extend beyond surface application. For irrigation and drainage planning, knowledge of subsoil permeability and water-holding capacity is essential to avoid both waterlogging and drought stress. Such interventions are only possible when the full soil profile is examined, as surface sampling alone would miss these deeper limitations (Ren et al.,2022; Sharma et al., 2025)

In summary, the rooting environment of arable crops cannot be fully understood without reference to the soil profile. The depth, structure, and chemical properties of horizons determine the extent to which roots can explore the soil and thereby access critical resources. By identifying physical and chemical barriers as well as potential nutrient and water reserves, soil profile examination enables better crop selection, improved management practices, and more sustainable use of agricultural land. In tropical systems where climatic variability is high, the role of the soil profile in shaping root development and yield resilience is particularly indispensable (Huang et al., 2024; Sharma and Kumar, 2023).

4. The Necessity of Soil Profile Examination in Arable Crop Production

The study of soil profiles has become indispensable in modern arable crop production, as it provides insights into the vertical distribution of soil properties that directly influence crop growth, yield, and sustainability. Unlike surface sampling, which may only reflect the nutrient status of the topsoil, soil profile examination enables farmers, soil scientists, and land-use planners to understand subsurface constraints and potentials that affect long-term agricultural productivity (Xing et al., 2025).

One of the foremost necessities is the evaluation of rooting depth and physical limitations within the soil horizons. Many arable crops, such as maize, sorghum, and cassava, develop root systems that extend beyond the plough layer. If hardpans, compacted horizons, or lithic contacts exist within the subsoil, root penetration and access to deeper water reserves are restricted. Soil profile studies reveal such restrictions, allowing for interventions like subsoiling, controlled traffic farming, or the selection of shallow-rooted crops (Xing et al., 2025; Bell and de Oliveira, 2022).

Furthermore, soil profile analysis assists in understanding nutrient distribution and availability throughout the soil layers. While macronutrients such as nitrogen, phosphorus, and potassium are often concentrated in the surface soil due to fertilization and organic matter accumulation, micronutrients such as iron, manganese, and zinc are sometimes more available at depth. Without knowledge of the profile, nutrient deficiencies or toxicities may be misinterpreted, leading to poor fertilizer recommendations and inefficiencies in nutrient use (Regassa et al., 2023; Mandal and Ghosh, 2021).

Soil moisture dynamics are another crucial aspect illuminated through profile studies. The subsoil often acts as a reservoir that sustains crops during dry spells, especially in rain-fed systems common to sub-Saharan Africa. If the subsoil is shallow, poorly drained, or compacted, water retention and percolation may be compromised. In contrast, deep loamy or sandy loam profiles can buffer crops against short-term droughts. Therefore, evaluating soil profiles enhances water management strategies in arable production systems (Rao et al., 2022).

Additionally, soil profile examination is necessary for identifying soil degradation trends such as erosion, leaching, salinization, and acidification. These processes often manifest differently across horizons, and their detection at depth is essential for designing effective conservation measures. For instance, erosion may remove topsoil while exposing nutrient-poor subsoils, or leaching may accumulate salts in lower horizons, both of which significantly reduce crop productivity if unaddressed (Babatunde et al., 2025; *Saljnikov* et al., 2021).

Equally important, profile studies underpin soil classification and land capability assessment, which are the bedrock of agricultural planning. By linking morphological, physical, and chemical properties across horizons, soils can be classified according to standardized taxonomies such as USDA Soil Taxonomy or the World Reference Base (WRB). This classification guides land-use recommendations, helping farmers choose the most suitable crops for particular soil types, thereby reducing the risks of crop failure and ensuring sustainable intensification (Babatunde et al., 2025; *IUSS Working Group WRB, 2022*).

In the context of climate-smart agriculture, the necessity of soil profile examination is magnified. Subsurface carbon storage, greenhouse gas fluxes, and soil resilience to climate extremes are increasingly important considerations. Understanding how organic carbon, bulk density, and porosity vary with depth provides insights into soil's role in mitigating climate change, while also sustaining crop yields (Zerssa, 2022).

In summary, soil profile examination is a vital tool for arable crop production because it bridges the gap between surface observations and the complex realities of subsurface soil behavior. It ensures that soil management practices are holistic, targeted, and sustainable, ultimately enhancing productivity, environmental stewardship, and food security.

5. Case Studies and Empirical Evidence from Arable Cropping Systems

The practical importance of soil profile examination in arable crop production has been well demonstrated in several regions of the world. Empirical evidence shows that ignoring subsurface soil characteristics often results in poor land-use decisions, suboptimal yields, and long-term land degradation. Conversely, the systematic study of soil profiles has guided successful interventions in crop and land management strategies.

In sub-Saharan Africa, where most farming is rain-fed and conducted on fragile soils, soil profile studies have revealed critical constraints to crop productivity. For instance, Samuel et al., (2023), Ukabiala (2022) and Ali et al., (2021) reported that in southeastern Nigeria, cassava and maize yields were severely reduced in soils with shallow profiles overlying gravelly or stony horizons. Surface samples indicated reasonable fertility, but profile studies uncovered hardpans that restricted rooting depth and water storage. Based on this, land management strategies such as ripping and the use of shallow-rooted legumes were introduced, improving land productivity.

In India, (Adhikari et al., 2023) investigated rice-wheat cropping systems and found that the accumulation of salts and bicarbonates in subsoil horizons significantly reduced rice yields in irrigated fields. Surface soil tests alone failed to capture the severity of sodicity at depth. The incorporation of gypsum amendments was recommended following the soil profile examination, which restored soil structure and improved yields. This highlights how ignoring deeper horizons could lead to underestimation of soil limitations in intensive cropping systems.

Studies from Brazil's Cerrado region have also emphasized the role of soil profiles in agricultural expansion. de Melo et al., (2023) observed that subsurface acidity and aluminum toxicity were major barriers to root penetration and nutrient uptake in soybean and maize fields. Through detailed soil profile studies, deep liming and subsoil amendment strategies were developed, transforming the Cerrado into one of the world's most productive agricultural frontiers.

In East Africa, where coffee and maize are key crops, Otieno *et al.* (2021) showed that soils with strong textural contrasts between topsoil and subsoil had low water infiltration rates and poor nutrient movement, resulting in periodic crop failures during droughts. Profile studies informed the adoption of conservation tillage, cover cropping, and mulching practices to enhance water retention and improve crop resilience.

Closer to home, Nigerian studies by Aruleba et al., 2023, Adekiya et al., 2022 and Denton et al., (2021), demonstrated that soil profile characterization was vital in distinguishing between Alfisols and Ultisols across arable farmlands in the southwest. Farmers who cultivated maize on soils with higher clay subsoils obtained better yields under fertilizer application compared to those on sandy subsoil soils, where nutrient leaching was severe. Without soil profile analysis, these differences would not have been recognized, leading to inefficient resource allocation.

In Europe, precision agriculture has further demonstrated the need for soil profile analysis. For example, López-Castañeda *et al.* (2022) documented that deep soil compaction in Denmark, resulting from heavy machinery use, reduced wheat yields by up to 30%. While surface soil tests appeared favorable, profile studies revealed reduced porosity and oxygen availability at 30–50 cm depth. As a corrective measure, controlled traffic farming was introduced, which reduced compaction and stabilized yields.

Taken together, these case studies emphasize that soil profile examination is not a theoretical exercise but a practical necessity for arable cropping systems worldwide. Whether the challenge is rooting restriction, subsoil acidity, salinity, or compaction, soil profile knowledge provides the basis for corrective measures and informed land-use decisions. Moreover, these examples show that surface soil sampling alone is insufficient to capture the full picture of soil behavior in supporting arable crops.

6. Implications for Sustainable Agriculture and Food Security

The necessity of soil profile examination extends beyond immediate agronomic concerns into the broader domains of sustainability, resilience, and global food security. As the global population continues to rise, with projections of nearly 10 billion people by 2050, the demand for food will require not just intensification but also optimization of agricultural practices on existing farmland (FAO, 2021). Understanding the vertical distribution of soil properties through profile studies is fundamental to achieving this balance between productivity and sustainability.

One critical implication lies in resource-use efficiency. Fertilizer application in many developing regions is often guided solely by topsoil analysis, leading to under- or over-application of nutrients. Soil profile studies reveal nutrient distribution and leaching dynamics at depth, allowing for site-specific nutrient management that reduces waste, minimizes environmental contamination, and increases crop uptake efficiency (Ashoka et al., 2023). This precision improves both farm profitability and environmental health.

Equally important is water management and drought resilience. In rain-fed arable cropping systems, the subsoil acts as a buffer against seasonal rainfall variability. Profiles with adequate depth and favorable texture support water storage that sustains crops during dry spells, reducing vulnerability to climate change impacts. Conversely, soils with restrictive horizons require interventions such as subsoiling, mulching, or supplemental irrigation. By incorporating profile information, sustainable cropping strategies can be designed to maximize water use efficiency (Otieno *et al.* 2021; Naqvi et al., 2023).

Soil profile studies also contribute to soil conservation and land degradation mitigation. Processes such as erosion, salinization, and compaction often manifest more clearly in subsoil horizons. Without profile data, these degradation risks remain hidden until crop failures occur. Profile-based assessments therefore help anticipate degradation trends and implement timely measures such as contour farming, organic matter incorporation, or controlled traffic systems, thereby prolonging soil health and arable land productivity (Huang et al., 2024).

From a climate-smart agriculture perspective, soil profiles provide insights into carbon sequestration potential and greenhouse gas dynamics. Since much of the soil organic carbon stock resides in subsoil horizons, understanding its distribution is essential for climate change mitigation. Management practices that enhance root biomass input and reduce subsoil disturbance can stabilize carbon at depth, contributing to global climate goals while supporting sustainable production (Huang et al., 2024; Zerssa, 2022).

Moreover, soil profile characterization is indispensable for land-use planning and crop suitability assessment. As nations seek to expand agricultural frontiers or rehabilitate degraded lands, decisions on which crops to cultivate depend on accurate soil classification and capability assessments derived from profile studies. This ensures that land is allocated to its most appropriate use, avoiding mismatches that lead to land abandonment or low productivity (Aruleba et al., 2023; *IUSS Working Group WRB, 2022*).

TechHub Journal Vol. 8, pp.13-26 (2026)
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Finally, in the context of global food security, soil profile studies support equitable and sustainable intensification strategies. By revealing hidden soil constraints and potentials, profile examinations help optimize yields on smallholder farms, which produce a significant share of food in developing regions. Such knowledge empowers farmers with data-driven recommendations, bridging the gap between scientific research and practical field management (Sharma and Kumar, 2023; Liu et al., 2022).

In essence, the implications of soil profile studies transcend field-level agronomy and extend to global challenges of feeding an expanding population under changing climatic conditions. They form the cornerstone of sustainable agriculture by aligning productivity goals with environmental stewardship and social resilience.

7. Challenges and Future Perspectives in Soil Profile Research

Despite its clear necessity in arable crop production, the systematic study of soil profiles faces several challenges that limit its widespread adoption, especially in developing countries. These challenges range from methodological and logistical constraints to institutional and technological gaps. However, emerging tools and innovations provide promising future perspectives that could transform soil profile research into a more efficient and farmer-accessible practice.

One of the foremost challenges is the labor- and time-intensive nature of soil profile excavation and description. Digging soil pits to a depth of 1–2 meters require significant effort, equipment, and expertise, particularly in areas with rocky subsoils or shallow profiles. As a result, many smallholder farmers and extension workers rely on surface sampling, which is faster but provides incomplete data (Lommel et al., 2021).

A related issue is the limited availability of skilled personnel. Soil profile description requires knowledge of soil morphology, classification systems, and laboratory analysis of physical and chemical properties. In many regions, the number of trained pedologists is declining, and agricultural programs often underemphasize field-based soil studies in favor of laboratory analyses or remote assessments (Hartemink, 2023). This knowledge gap hampers the integration of profile studies into land management.

Cost constraints also pose a barrier. Detailed soil profile characterization, including laboratory analyses of multiple horizons, can be prohibitively expensive for small-scale projects and farmers. Without institutional or government support, the cost of conducting such studies on a large scale remains a significant obstacle to their practical adoption in arable cropping systems (Babatunde et al., 2025; Seifu et al., 2022).

Another challenge is the scale of variability in soils. Soil properties can change drastically over short distances due to topography, parent material, and land use history. As a result, a single profile may not adequately represent an entire field or farm. This complicates efforts to generalize findings and makes large-scale soil surveys resource-intensive (Regassa et al., 2023).

Looking to the future, several opportunities could overcome these challenges. Digital Soil Mapping (DSM), which integrates geostatistics, remote sensing, and machine learning, offers a cost-effective way to predict soil profile properties across landscapes without extensive excavation. By combining limited profile data with environmental covariates such as topography, vegetation indices, and climate data, DSM can provide detailed soil information at high resolution (Babatunde et al., 2025; El Behairy et al., 2022).

Similarly, advances in proximal soil sensing technologies—including electromagnetic induction, ground-penetrating radar, and visible-near infrared (vis-NIR) spectroscopy—allow rapid and non-invasive estimation of subsurface properties. These tools, when calibrated with traditional profile data, could drastically reduce the need for extensive manual excavation (Abdulraheem et al., 2023; El Behairy et al., 2022).

Another promising direction is the use of artificial intelligence (AI) and machine learning models to analyze large soil datasets. Such approaches can identify patterns in soil horizon development, predict root zone limitations, and optimize crop suitability recommendations. AI-driven decision-support systems have the potential to bridge the gap between pedological research and farm-level management (Babatunde et al., 2025; Abdulraheem et al., 2023).

Additionally, citizen science and participatory approaches may play a role in scaling up soil profile data collection. With training and simple mobile-based applications, farmers and extension workers could contribute field observations (e.g., depth to hardpan, texture changes) that feed into national and regional soil databases, complementing professional surveys (Paltseva, 2024)).

In the future, soil profile studies are likely to become more integrated and multidisciplinary, linking soil science with hydrology, ecology, and climate studies. The demand for sustainable land use, climate-smart agriculture, and carbon accounting will ensure that soil profile research continues to evolve, with increasing emphasis on subsurface processes that influence crop production and environmental resilience.

In conclusion, while challenges related to cost, expertise, and variability remain significant, technological innovations and collaborative approaches offer a pathway to making soil profile research more efficient, scalable, and impactful. Bridging traditional field-based methods with digital and participatory tools will ensure that soil profile studies remain central to arable crop production and sustainable land management in the future.

8. Conclusion

The examination of soil profiles is a cornerstone of arable crop production, offering insights that cannot be captured through surface soil sampling alone. By exploring the vertical distribution of soil horizons, profile studies reveal critical information on rooting depth, nutrient availability, moisture dynamics, and physical or chemical constraints that influence crop growth and yield. These insights are not only vital for immediate agronomic decision-making but also serve as the foundation for soil classification, land capability assessment, and long-term land-use planning.

Case studies across Africa, Asia, and the Americas consistently demonstrate that ignoring subsurface soil properties leads to poor land management, inefficient resource use, and reduced productivity. Conversely, when profile information guides interventions—such as subsoiling, gypsum application, or targeted fertilization—crop yields and soil health improve significantly. This underlines the practical necessity of soil profile studies in diverse agricultural contexts.

Beyond field-level applications, soil profile studies have broader implications for sustainability and food security. They enhance resource-use efficiency, support climate-smart agriculture, and contribute to soil conservation and carbon sequestration. In the face of global challenges such as population growth, climate change, and land degradation, understanding the full depth of soil properties becomes an essential strategy for ensuring resilient and productive farming systems.

Nevertheless, challenges remain. Traditional soil profile studies are labor-intensive, costly, and require specialized expertise, which limits their widespread adoption. However, advances in digital soil mapping, proximal sensing, and machine learning present exciting opportunities to overcome these barriers. Integrating these innovations with conventional methods will make soil profile research more efficient, scalable, and accessible to farmers and policymakers alike.

In conclusion, soil profile examination is not a luxury but a necessity for sustainable arable crop production. Its ability to uncover hidden soil potentials and limitations provides a scientific basis for informed decision-making in agriculture. As the world seeks to balance productivity with environmental stewardship, soil profile studies will remain central to achieving resilient, efficient, and sustainable food systems.

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COMPETING INTEREST

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AUTHOR'S CONTRIBUTION

The author solely conceptualized the review topic, conducted the literature search, critically analyzed relevant publications, organized the manuscript structure, and wrote the entire paper. All aspects of this review were independently completed by the authors

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